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Enhancing the Relationships between Society, Economy and Ecology – The Sino-German Co-operative Projects on Sustainable Land Use in a Nutshell

加强社会、经济和生态之间的联系 ——中德土地可持续利用合作项目

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Abstract

Societies and their economies as well as their environment are intrinsically tied to each other. The German Federal Ministry of Education and Research (BMBF) together with the Chinese Ministry of Science and Technology (MOST), therefore, financially support nine co-operative projects on Sustainable Land Use in order to develop and examine methods and protocols towards a reconciliation of these major pillars of human existence. Research focuses on the assessment and forecast of changes in the structure, function, and dynamics of natural and man-made ecosystems, embracing the relationships between society, economy and ecology.

Six of the nine Sino-German co-operative projects started in 2007, while the other two began in 2008. Basically all of them are interdisciplinary, and in many cases they are transdisciplinary. General management of the joint projects lies in the hands of the Division Sustainable and Environmental Research of the German Project Management Jülich (PTJ) (Projektträger Jülich) in Berlin. The projects combine the expertise of 53 partners (28 from Germany and 25 from China) from various disciplines such as agriculture, biology, ecology, economy, environmental engineering, forestry, geography, sociology, soil science, water and material flow management. Additionally the projects encompass 44 small or medium sized enterprises (SME) as partners.

The current project phases are running until 2010 and 2011, respectively. After approximately one and a half years of co-operative research, the projects have achieved a high degree of integration and cross-fertilisation amongst the different representatives of the research communities in China and in Germany. Initial scientific results have already emerged and are in part published. As the joint projects continually evolve, the opportunity exists not only to adjust but also to create new developments - for the benefit of society, economy and ecology.

摘要

社会和经济以及他们赖以生存的环境彼此间有着内在联系。德国联邦教育与研究部（BMBF）与中国科学技术部（MoST）联合给予 9 个可持续土地利用的项目财政支持，旨在开发和检验

有利于人类生存的这三个主要支柱之间和谐发展的方法和议案。研究的重点是评估和预测自然和人为的生态系统在结构、功能和动态方面的变化，包括社会，经济和生态之间的关系，。9 项中德合作项目中的 6 项于 2007 年开始实施，其他两个项目于 2008 年开始。基本上，它们都是跨学科的综合研究。联合项目的综合管理由位于柏林的德国项目管理中心(PTJ)可持续和环境研究处负责，该项目有 53 个不同学科的合作者（ 28 名来自德国， 25 名来自中国），包括农业，生物学，生态学，经济，环境工程，林业，地理，社会学，土壤科学，水和物质流管理。此外，该项目还包括 44 个中小型企业作为合作伙伴。

目前在研项目将分别于 2010 年和 2011 年结束。经过约一年半的合作研究，该项目在中德合作研究团体代表之间已经实现了高效的结合，同时有了初步的科学研究成果，部分已出版。随着合作项目的不断发展，不仅存在项目调整的机会，而且还能创造新的发展以造福社会，经济和生态。

1 General Objectives of the Collaborative Research Activities

The general objectives are:

- To improve interactions between man and his environment by the development of technical and conceptual solutions towards sustainability.
- To assess potentials and risks of environmental changes in terrestrial and freshwater ecosystems due to land management practices.
- To develop a research network that is consistently interacting and investigating across different environmental issues and across different spatial and temporal scales of ecosystem changes.
- To provide a contribution to objective based politics, to help integrating policy and to derive outcome-oriented policy measures in the field of land management by contributing to the integrated assessment of socio-economic drivers affecting land-use.

2 The Sino-German Research Collaborations—A General Outline

In order to achieve the objectives mentioned above, MOST (Ministry of Science and Technology) and BMBF (Federal Ministry of Education and Research) have agreed on financing and handling co-operative projects to be conducted in China. Several project proposals went through a review process and finally nine proposals were selected by a steering committee. The chosen projects deal with sustainable land management in the broadest sense – reforestation, rehabilitation of watersheds, biological control and nitrogen management in agriculture, renewable products, recycling of organic residues, generation of value added products, landscape planning and coal fire research as well as elimination of odour emissions from food processing. They combine the expertise of partners from 36 institutions including 11 Non Governmental Organisations (NGO) and small or medium sized enterprises (SME) from China, and 28 research institutions and 39 SME from Germany (Tab. 1 & 2).

Table 1 List of participating Chinese and German institutions (in alphabetical order)

Scientific Partners from China	Scientific Partners from Germany

Beijing Normal University (BNU)	Alfred-Wegener-Institute Bremerhaven
Beijing University of Technology (BJUT), Beijing	Bergische University Wuppertal (BUW)
Center for Chinese Agricultural Policy / Chinese Academy of Sciences (CCAP/CAS), Beijing	Dresden University of Technology
Chengdu Biogas Science Research Institute, Chengdu, Sichuan	Federal Institute for Geosciences and Natural Resources (BGR)
China Agricultural University (CAU), Beijing	Federal Institute for Materials Research and Testing (BAM)
China National Bamboo Research Center	Georg-August-University Göttingen
Chinese Academy of Agricultural Sciences (CAAS), Beijing	German Aerospace Center (DLR)
Chinese Academy of Forestry	GKSS Research Centre Geesthacht
Chinese Academy of Sciences / Institute for Remote Sensing Applications (CAS/IRSA)	Humboldt University, Berlin
Hunan Normal University (HNU)	Johann Heinrich von Thünen-Institute (vTI), Federal Institute for Rural Areas, Forestry and Fisheries, Braunschweig
Nanjing Institute of Soil Science / Chinese Academy of Sciences (ISS/CAS), Nanjing	Justus-Liebig-University, Giessen
Nanjing Agricultural University, Nanjing	Laboratory of the Federal State of Hesse (LHL), Subsidiary Kassel
National Agro-Technical Extension and Service Centre (NATESC), Ministry of Agriculture (MOA), Beijing	Leibniz Centre for Agricultural Landscape Research (ZALF), Müncheberg
Northwest Agricultural and Forestry University, Yangling, Shaanxi	Leibniz Institute for Applied Geophysics (LIAG)
River Scientific Research Institute, Wuhan, Hubei	Leibniz University, Hannover
Sichuan Agricultural University, Ya'an	Research Centre Borstel, Borstel
Tianjin Academy of Agricultural Sciences (TAAS), Tianjin	Technical University Braunschweig
Tianjin Agricultural Technology Information Network, Tianjin	Technical University Freiberg (TU BAF)
Tianjin University, Tianjin	Technical University Hamburg-Harburg
University of Shanghai for Science and Technology, Shanghai	Technische Universität München, Center of Life and Food Sciences Weihenstephan
Xishuangbanna Tropical Botanical Garden/ The Chinese Academy of Sciences, (XTBG/CAS) Menglun, Mengla	Trier University of Applied Sciences, Environmental Campus Birkenfeld
Yunnan Academy of Social Sciences (YASS) Huanchengxilu, Kunming	University of Bonn
Yunnan Agricultural University, Heilongtan, Kunming	University of Freiburg
Yunnan University	University of Hamburg
Zhejiang University, Hanghzhou	University of Hohenheim, Stuttgart
	University of Kassel (Witzenhausen)
	University of Kiel
	University of Passau

Table 2 List of participating Chinese and German SME* and NGOs*

China	Germany
Beijing Dao Institute for Environment and Development (Dao IED), Beijing	ABiTEP GmbH, Berlin
Center for Biodiversity and Indigenous Knowledge (CBIK), Kunming	Agraferm Technologies AG, Pfaffenhofen
China Huadian Group New Energy Development Company, Beijing	Airsense Analytics GmbH, Schwerin
China Shenhua Energy Company Ltd. (CSEC)	AMD Intectra GmbH, Harpstedt
Circular Economy Research Institute of Shaanxi Province	Areal Company, Hengstbacherhof
Feng He Co. Ltd. Kunming	Backhus Kompost-Technologie GmbH, Edewecht
Friends of the Earth (Hongkong)	Bellassana, München
Qingdao Environmental Protection Bureau	Biokraft Albersdorf GmbH & Co.KG., Heide
Shenhua Remote Sensing & Geo-Engineering Company Ltd. (BRSC), Bejing	Cargill, Hamburg
Tian Zi Biodiversity Research & Development Centre, Jinghong	Creaso, Gilching
Yangling Agriculture High-Tech Industry Zone, Yangling	Deutsches Institut für tropische und subtropische Landwirtschaft, DITSL GmbH, Kassel
	Dr. Otto GmbH, Wittenberge
	Environmental Electronic Company, Geislingen
	Gerstel GmbH & Co.KG, Mülheim/Ruhr
	gewitra GmbH, Hannover
	HarbourDom GmbH
	INFOTERRA GmbH, Potsdam
	IP Syscon, Hannover
	JatroSolutions GmbH, Stuttgart
	Kaffeehaus Willy Hagen, Heilbronn
	Kaffee-Veredelungs-Werk GmbH & Co.KG, Hamburg
	Kleeberg Umweltanalytik GmbH, Hamburg
	L.E.E. s.a.r.l., Junglinster, Luxemburg
	LINDENBERG Anlagen GmbH, Rösrath
	Lufttechnik Bayreuth, Goldkronach
	Merck KGaA, Darmstadt
	Noske-Kaeser, Hamburg
	Ölmühle, Hamburg
	Pfeffer Agri Consult Limited, Gingen
	Phyto-Energy Ltd, Scharnebeck
	Rubotherm, Bochum
	Silver & Baryte Minerals, Marl
	SKW Stickstoffwerke Piesteritz GmbH, Lutherstadt Wittenberg
	Studentenwerk Hamburg
	tec5 AG, Oberursel
	Troki Manufaktur, Witzenhausen
	Umwelt-Elektronik GmbH, Geislingen
	Wehrwissenschaftliches Institut Münster, Münster
	WESSEL Umwelttechnik GmbH, Hamburg
	Wilhelm Schwabe GmbH, Karlsruhe
	X-TERN International, Altenbamberg
	YARA, Dülmen

*SME = Small or Medium sized Enterprises
*NGO = Non Governmental Organisation

All the co-operative projects are funded by BMBF and MOST, the latter is supporting the Chinese research consortia while BMBF is financing the German research teams. General management of the German research teams is the task of the Project Management Jülich in Berlin (PtJ). Figure 1 shows the structure-activity relationships of the co-operative projects.

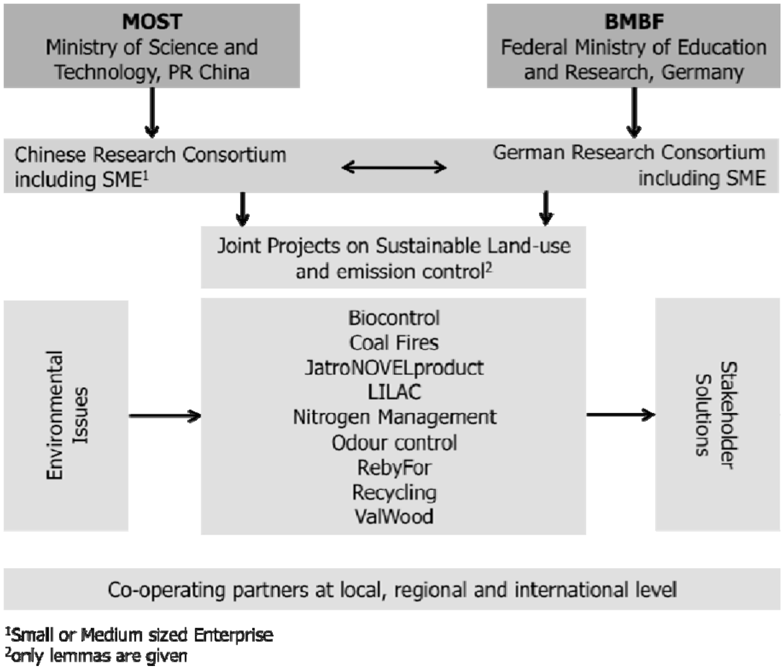

Figure 1 General structure and integration of the Sino-German co-operative projects.

3 Geographical Range of the Research Collaborations

The geographical map (Fig. 2) depicts some of the regions in China where research takes place. The Sino-German co-operation is addressing environmental issues throughout the country. The study area extends from the tropics to the temperate zone, covering remote and biologically diverse regions as well as densely populated and environmentally degraded areas.

Figure 2 Geographical map of the Sino-German co-operative projects.

4 Research Approaches and Scientific Contents

The issue of land use is simultaneously influenced by economics, society and the natural environment. Economic development, along with improvement in infrastructure, can open new opportunities for a region to market its products. However, such development can also lead to the loss of natural resources and cultural heritage. The danger of this is particularly prevalent where economic development occurs very rapidly due to increased concentration of only a few forms of land use. It is therefore the task of land use planners to offer an economic perspective, as well as to ensure the preservation of natural and socio-cultural values. In addition, it is necessary to assess the consequences of possible land use changes for the economy, society and environment, along with their reciprocal effects.

The matrix indicated in Table 3 was constructed to develop synergy and facilitate the co-operation between the different projects.

Table 3 Matrix of cooperativeness

Lemma	RebyFor	LILAC	ValWood	RECYC LING	JatroNOVEL product	Biocontrol	NITROGEN	Odour Control
RebyFor	1, 2, 3, 4, 5, 6, 8, 9, 10, 11							
LILAC	1, 2, 3, 4, 5, 6, 8, 9, 10, 11	1, 2, 3, 4, 5, 6, 8, 9, 10, 11						
ValWood	1, 2, 8, 9, 10, 11	1, 2, 3, 9, 10, 11	1, 2, 3, 4, 8, 9, 10, 11					
RECYCLING	3, 4, 5, 9	3	3, 4, 9	3, 4, 7, 8, 9, 10, 11, 12				
JatroNOVEL product	-	1, 2, 3, 5, 9, 11	3, 8, 9	-	1, 2, 3, 5, 8, 9, 11			
Biocontrol	1	1, 9, 11	1, 9	-	-	1, 9, 11		
NITROGEN	2, 3, 4, 8, 9, 11	-	-	3, 8, 9, 10, 11, 12	-	-	6, 8, 9, 10, 11, 12	
Odour Control	-	-	-	-	-	-	12	12

Legend (Key activities): **1** Agro-Forestry, **2** Poverty Reduction, **3** Biomass & Renewable Energy, **4** CO_2 Potential & Sequestration, **5** Erosion, **6** GIS-Application, **7** Recycling Management, **8** Land Use Planning, **9** Economy, **10** Sociology, **11** Soil Analysis, **12** Emission Control

4.1 LILAC(Living Landscapes China)*"Rural development by land use diversification-actor-based strategies and integrative technologies for agricultural landscapes in mountainous Southwest China"*

The Chinese province of Yunnan harbors a unique landscape, as well as great biological and cultural diversity. Over the past few years, the southern part of Yunnan, the Dai Autonomous Prefecture of Xishuangbanna, as well as the whole Mekong regions have witnessed a rapid growth of both infrastructure facilities and economy; keeping a balance between such changes and the maintenance of the natural and cultural heritage is currently the greatest challenge faced in developing the region sustainably.

The market entry into national and international markets has progressed very fast, resulting in a dramatic effect on land-use management. The production of natural rubber (*Hevea brasiliensis*) plays a prominent role in the region's economy. China is a major consumer of this natural resource. Due to its tropical origin of the plant China's land suited for cultivation of the rubber tree is restricted to the very southern parts of the country. Therefore, despite efforts to extend rubber cultivation by developing adapted clones, China is still strongly dependent on imports and further promotes its cultivation and extension.

There has been a dramatic increase in the area dedicated to monoculture rubber plantations – to the detriment of floral and faunal diversity, as well as to the traditional land use and culture. At the same time, however, due to the largely improved infrastructure, there are new opportunities for the marketing of specific regional products, such as medicinal plants, spices, or ornamentals. This opens alternative avenues for income diversification and improvement in the quality of life of rural populations.

The goal of the collaborative project Living Landscapes China (LILAC) is to develop a

GIS-based computer model that can produce precise, spatially-specific prognoses of the effects of land use changes on the economy, society and environment, and evaluate such projections, in order to achieve a stakeholder and knowledge-based procedure for land use planning. For development of the model, data are being collected in the Nabanhe catchment area near Xishuangbanna's prefecture capital Jinghong, in the three major fields of research: economy, sociology and ecology. In each of the three fields of activities submodels will be generated that will be integrated in the overall model. Additional aims of this project are to: i) develop and demonstrate the expertise of German researchers and businesses in land use and environmental planning under tropical conditions, and ii) strengthen their position in the environmental sector, which is becoming more and more important for development in China. Regular updates on the project are being provided through the project website www.lilac.uni-hohenheim.de/en

4.2 Jatro NOVEL product *"Fuel and Feed for the Future from Jatropha"*

Jatropha curcas, a multipurpose plant, has high water use efficiency, is not grazed by animals and is drought and disease resistant in the wild. Other major attributes which make *Jatropha* an exciting future crop for energy generation is its capability to grow in degraded, poor and marginal lands, with no competition for food or feed.

Environmental degradation and depleting oil reserves are matters of great concern around the world. Developing countries like China depend heavily on oil imports. *Jatropha* based biodiesel is receiving increasing attention in China because its use is benign to the environment and enhances energy security by making it less dependent on fossil fuel imports. Our financial analysis has shown that with the present production level of *Jatropha* seeds and hence of oil for conversion to biodiesel, planting *Jatropha* for biodiesel production alone is not economical. Therefore, it is imperative to generate high-valued co-products and make the oil extraction process more efficient; and the joint BMBF-MOST project on 'Fuel and Feed for the Future from *Jatropha*' aims to achieve this.

So far, we have detoxified the kernel meal (60% protein) and it has been demonstrated to be an excellent substitute for soybean meal in the diets of fish and farm animals. From the screw-pressed *Jatropha* cake high-valued protein concentrate (90% protein) having good amino acid levels has been generated. The use of by-products obtained during the process of biodiesel production from oil as a constituent of livestock feed has been investigated. Other innovations include: i) enhancement of the efficiency of screw-press based oil extraction from *Jatropha* seeds by over 30% compared, and ii) development of a low cost furnace which uses *Jatropha* seed shells as a source of energy, and of small and large scale *Jatropha* oil cleaning processes so that the oil could be used in cooking stoves.

The production of value-added coproducts would motivate the farmers and the industry for extensive planting of *Jatropha* for reclamation of marginal and degraded lands by enhancing economy of the biofuel production and decreasing investment risk.

4.3 Odour Control *"Separation of odorous compounds by adsorption and absorption"*

Odorous emissions, especially exhaust air from restaurants, cause increasingly inconveniences and disapproval in highly populated areas. A major aim is to provide technologies to meet these large demands of the population and of the legal regulations. Modern technological methods, based on adsorption and absorption techniques deliver potentials to reduce these emissions significantly. Industrial partners delivering compounds for waste gas treatment plants see promising perspectives to market their products, such as adsorbents, and catalysts, respectively, process engineering and plants, inclusively process analyses and control, preferably in these regional market segments of Europe and China. The project is organized in the following three subprojects:

Odour Management and Analytics: In this group the industrial on-site management of diverse odour emissions as well as the process analyses on the basis of sensor arrays applied in 'electronic noses' are on focus. Chemical analyses are to be developed for the evaluation of the different industrial purification methods as well as for the identification of substances causing odorous effects.

Application of Adsorption and Absorption Technologies: Adsorption techniques employing different adsorbents, and also catalytically procedures will be evaluated to separate and convert the waste substances simultaneously. A new highly potential separation processing within a fluidized bed is also planned to be investigated. Further concentration is put on absorption processes to purify the (off-)gases of a fermentation plant converting "bio-waste" to energy.

Simulation and Process Automation: For the industrial application the developed technologies have to be integrated into whole automated processes. For the engineering the simulation tools ranging from the basic thermo-physical data to the whole process simulation become more and more important, which will contribute into the project. Additionally, the energy optimization will be calculated by the process integration.

The project homepage is accessible via: www.odour.de

4.4 Biocontrol *"Sustainable agriculture by use of bacterial formulations which supports plant growth and suppress plant diseases caused by phytopathogenic microorganisms"*

In order to secure the supply of safe and wholesome food, there is clearly a need to develop new agricultural practices that supplement and, ultimately, may even replace existing plant disease control strategies. This is also true in Chinese agriculture, where in past the massive use of agrochemicals has damaged the environment in a manner which is not further tolerated by the government. Therefore, a strategy with the potential to supplement or to reduce the use of chemical pesticides has to be implemented now. A promising alternative is the use of formulations of selected natural soil bacteria as plant growth promoting (biofertilizer) and/or biocontrol agents. Some root colonizing bacteria (rhizobacteria) are considered as efficient microbial competitors in the root area where they are exerting their beneficial effects on plant growth and development.

In frame of the Sino-German collaboration program a highly efficient plant growth promoting bioproduct based on spore-forming natural soil bacterium *Bacillus amyloliquefaciens* FZB42® (proprietary name of Abitep GmbH Berlin, Germany) was successfully applied as microbial biofertilizer in different Chinese crops (http://www2.hu-berlin.de/chinapgp/). After positive experience during application in 2007 and 2008, the companies FengHe Co. Ltd., Kunming, P.R. China and ABiTEP GmbH, Berlin, Germany, which are partners in the Sino-German collaboration project, agreed to establish a joint venture enterprise named JV enterprise Defeng Co. Ltd. JV is aimed to apply microbial products, especially biofertilizers and plant strengthening agents, in Chinese agriculture and horticulture. The first office of the company has already been started its work at the territory of the Chinese cofounder company FengHe Co., Kunming, Yunnan province. Further offices in Nanjing and Beijing are planned, which will greatly improve efficiency of the JV.

During the first stage, the JV will concentrate on applying biofertilizer in different Chinese regions and crops in order to improve conditions of their application. In addition, a network of distributers and experts for their application will be established. Also comparison of the biofertilizer with native Chinese products including several promising bacterial strains, provided by the partners of the Sino-German collaboration program, will be performed. After a successful trial period the second stage of the JV is planned to be introduced in 2010. In this stage, a production line will be established. It is necessary to ensure, that during the process of product manufacture in a Chinese fermentation plant, all the quality parameters of ABiTEP products are rigorously fulfilled. Then, it will be possible to produce a biofertilizer according to the international standard with a price competitive for Chinese farmers. A successful introduction of such a product to a Chinese market will greatly facilitate further improvement of Chinese agriculture especially in respect of a better environment, saving of chemical fertilizers and pesticides. Scientific work performed in frame of the “Biocontrol” project will pave the way for a successful development in applying environmental friendly bio-agents in Chinese agriculture.

4.5 ValWood *"Innovative sustainable land use"*

The aims of the project are the development and the introduction of an innovative sustainable land use concept that is adapted to the specific conditions of China and Germany. The developed concept should provide an alternative to the current afforestation, reforestation and landscape restoration of formerly agricultural land as well as secondary and degraded forest land.

The new system combines the production of valuable timber and the production of biomass together on the same site. Biomass can be cultivated as fast-growing tree species as well as rattan or bamboo. The combination of long-rotation cycles and short-rotation cycles leads to a multilayered stand structure and a continuous supply of resources. This generates various ecological and economical benefits. Continuous cover of land and soil with valuable crop trees offers protection against erosion caused by water and wind. The trees also have a beneficial influence on the micro-climate by reducing extreme fluctuations in weather conditions. The stand structure will in many cases improve fauna habitats. As a result of the long-term growth and the processing of valuable timber into products of high quality and long durability substantial amounts of carbon will be stored over considerably long time. If the biomass is used for energy generation fossil carbon emission can be reduced.

In addition, economic benefits are generated during the differing production periods. Cultivating plants with a short rotation leads to yields in a short time while cultivating valuable timber with a long rotation brings yields in a long time. Because of aiming for different production targets on one hand the site productivity can be increased and on the other hand the income of the land owner can be diversified and increased. For more detailed information about the ValWood project please have a look at the project homepage: www.valwood.de

4.6 NITROGEN *"Innovative nitrogen management technologies to improve agricultural production and environmental protection in intensive Chinese agriculture"*

In this joint transfer project new technologies and innovative agricultural practices together with a guidance of policy and decision makers will optimize the agricultural production and protect the environment in intensive Chinese agriculture. The project will strongly contribute to extending technology in China by formulating and implementing agro-tech extension programs, by introducing, testing and demonstrating new techniques, products, and innovative management practices in representative cropping systems and for different farm sizes. The aim is to reduce the excessive mineral nitrogen use in order to support sustainable and resource-saving agricultural production. Improvements in nitrogen and water management will be able to optimize China's agriculture in terms of productivity, cost efficiency, resilience and self-sufficiency, and to protect the environment from nitrogen pollution.

In the TUM-coordinated research group experimentation within on-farm field trials has been started with the goal to sense increasing levels of nitrogen fertilizer applications and to develop algorithms for optimized nitrogen management. Training of Chinese scientists in proximal sensing technologies as well as on-farm quick testing has been commenced at TUM. A large survey of soil nitrate sampling has been conducted in various provinces in China with the goal to test the applicability of soil nitrate quick testing.

In the TU Braunschweig-coordinated research group, five pilot counties have been chosen from N to SE China. Studies on farmers' fields for demonstration purposes have been initiated. Exact field experiments (irrigated rice, maize) for the testing of slow-release fertilizers with nitrification inhibitors are currently in progress. For more information please refer to the project homepage: www.nitrogen-management.de

4.7 RECYCLING *"Recycling of organic residues from agricultural and munici-pal origin in China"*

The project takes advantage of different research groups and the involvement of German small and medium-sized enterprises to develop integrated strategies and solutions for the recycling of organic residues in China. It aims at reducing pollution, abating greenhouse gas emissions, improving nutrient cycling, generating renewable energy and increasing regional added value in the Chinese countryside.

In one approach, five research sites in Shaanxi, Shandong, Jiangxi and Beijing have been selected to develop economically viable and ecologically sound recycling projects through regional material flow management, stakeholders' involvement, innovative financial schemes and technology transfer. A parallel approach takes into account planning, technical improvement regarding animal production techniques, feed optimization, manure storage and treatment for minimizing emissions, as well as sanitation, designation of organic fertilizers for specific usage, carrying capacity of cropland, economic factors, administrative issues and environmental regulations. Starting from the technical situation of a selected pilot pig raising farm near Beijing, an improvement of the regional situation, as well as intensive animal husbandry in peri-urban areas of other large Chinese cities is envisaged.

On-site visits in Lingtong and Yangling (Shaanxi Province), as well as Xunwu County (Jiangxi Province) were carried out in October 2008. Representatives of four company partners joined the visits. Based on the information and data collected, the Institute for Applied Material Flow Management (IfaS) has developed the material flow analysis for

Yangling and Lingtong research sites together with the German company partners. In April 2009, data were collected in the Changping district of Beijing. Furthermore, the Trier research group was able to conclude that German biogas technologies have advantages and market potentials for type III biogas projects in China: Market potentials oriented projects with companies as independent investors.

The Bonn-Braunschweig research group started their sampling campaign in Shunyi District of Beijing following a workshop in Beijing in March 2009. A variety of different field plots with different crop rotations and fertilizer use were selected and soil was sampled to be analyzed for C, N, P, K, heavy metals and antibiotics. In questionnaires, farmers described their fertilizing practice. The nutrient fluxes on the farm are currently being investigated by balancing the nutrient and water inputs, and the outputs in form of pigs, excrement, waste water and gaseous emissions. Parallel the existing treatment technologies of the excrement such as composting and biogas production are assessed in terms of hygiene, treatment efficiency and nutrient loss. A socioeconomic survey will describe the economic, hygienic and agronomic situation of the farmers in Beilangzhong Farm and village. The data are the base to optimize the nutrient fluxes on the farm. German SMEs started their activities in the field of composting and gaseous emissions from biogas plants.

The results will improve nutrient fluxes and reduce the resource input into animal husbandry. (i). Different new organic and mineral fertilizers will be produced to create an added value to organic waste. (ii). The potential risk by excessive use of organic and mineral fertilizers will be reduced. (iii). The project is presented in details on the homepage: www.organicresidues. com

4.8 RebyFor *"Rehabilitation of degraded land ecosystems by forestation in mountainous areas in Southern Shaanxi Province, China"*

Multiple attempts have been made by the Chinese Government to improve the environmental situation and protect water resources in the south of the Shaanxi Province, as land ecosystems have been degraded due to inappropriate land use and deforestation. Rehabilitation of degraded lands is an option which offers potential commercial value as well as important ecological benefits. Therefore, the Sino-German project was initiated with the overall objective to develop and demonstrate a "land use planning system" for a sustained land use. Information to support the development of the planning system is largely gained from three field experiments on erosion, rehabilitation measures, and assessment of forest resources in addition to a study on socio-economy in the study area. The conception of the project is based on the assessment of the prevailing situation (erosion of various vegetative covers, forest resources, and socioeconomic conditions), evaluation of rehabilitation measures employed to improve the situation, and the development of the planning system. The land use planning system will provide a range of prospective possibilities to improve the soil conservation in the region. Taking into account the particular economic and social considerations, a priority list of areas, where urgent actions must be taken, can be compiled. In addition, recommendations for appropriate land use can be formulated. www.wzw. tum.de/china

4.9 Coal Fires *"Coal Fire Research"*

China is the biggest producer of coal in the world and mines with about approx. 2000 Mt of raw coal per year. Approximately 70% of Chinas energy consumption is covered by coal. According to the 10th five-year-plan for the coal industry of the State Economic and Trade Commission[1], coal will continue to be the major source of energy for China's industries in the next years. Taking into account economic growth rates of 7-8% in the coming years it is obvious that coal is going to play an even more important role in China's economic development. At the same time it is estimated that about 10-20 Mt of coal are being burnt in uncontrolled coal fires each year, which corresponds roughly about the yearly production of coal in Germany (approx. 26 Mt in 2006). Estimation exists that significantly more coal is lost in China each year, since the fires hinder the accessibility for mining operations in the vicinity of previous fires.

The rapid expansion of uncontrolled small-scale coal mining activities in remote areas during the last 30 – 40 years is expected to have led to an increase of human-induced coal fires. Especially the arid and semi-arid belt in North China - stretching from Xinjiang the west to Heilongjiang in the east - is affected by numerous of coal fires of various dimensions. This northern coal fire belt in China extends over a huge area of 5000 km east-west and 750 km north-south. Beyond the huge economic losses of natural resources resulting from uncontrolled combustion of high quality coal deposits, another problem is the enormous environmental consequences of derelict land that results from coal fires.

Extinguishing uncontrolled coal seam fires is an extremely difficult, time-consuming, and costly enterprise. Even large-scale efforts often fail since they lack a thorough scientific understanding of the ignition processes. Based on different applied geophysical, geochemical and remote sensing related approaches, extinguishing methods are evaluated and improvements are currently under development. In addition measures derived from in-situ and laboratory experiments serve as input parameters for numerical modelling strategies to simulate and accompany the extinction activities. The aim is to maximise the extinction success and to minimise the inherent risks.

[1] In march 2003, the responsibilities of the State Economic and Trade Commission (SETC) were taken over by the National Development and Reform Commission (NDRC), SETC no longer exists as a Commission

The project will also contribute to the current ambitions to accredit coal fire extinction activities within the framework of the Kyoto Protocol and beyond. Mainly CDM-related activities will give credit and mutual benefit for reducing the greenhouse gas (GHG) emissions from coal fires in future.

5 Synthesis

China is currently at a crossroads of its agricultural and environmental development. The increas ing industrialization, with a growing urban population and an unprecedented rise in the country's economy, is leading to changes in human consumption and agricultural production patterns. At the same time, new forms of pollution from animal livestock raising, organic residues from intensive agricultural production, and over-fertilization, besides depletion of water resources and soil erosion, are increasingly common. For China, this situation is especially dramatic, as nutrient cycles which were largely closed until about 25 years ago when agriculture was mainly carried out on a farmers' household scale, are being disrupted with grave consequences. The situation is particularly serious at the rural-urban interfaces. The recent harmful developments can be grouped as environmental pollution, greenhouse gas emissions, sanitary risks and soil degradation aspects, among others, and are risking to undermine the very basis of China's recent successful economic modernization drive.

The Chinese government is aware of the current threats to its sustainable development. On the other hand, Germany is a leading nation in environmental technology and environmental management. Therefore, as has frequently been pointed out by our Chinese partners, the present time is very suitable for carrying out joint Sino-German co-operative research aimed at transferring innovative technologies and management strategies into Chinese agriculture and environmental sciences as well as to establish market links.

We are therefore convinced that this group of nine projects on sustainable land-use which have been jointly agreed upon in the Sino-German Science and Technology (S&T) Consultations between the Chinese MOST and the German BMBF in March 2007 may add a further impetus and momentum to our two countries' cooperation in the field of the environment and beyond.

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Land Use History and Recent Development in the Naban Watershed: the Case of Rubber

纳版河流域的土地利用历史和现状——橡胶生产案例研究

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Abstract

In Yunnan province, rapid rural development is coupled with a dramatic decline of biodiversity. Within the framework of the "LILAC: living landscapes China" project consortium the authors are looking for relevant options for the introduction, adaptation and diffusion of innovations which may help to conserve the status-quo of biodiversity in the NabanHe National Nature Reserve (NNNR). The project aims at organisational development, i.e., ways to influence local institutions and structures as well as processes of generation, dissemination and use of knowledge including extension and education activities.

Systemic interventions of this kind require profound insights into the historical as well as the present land use situation. Based on a typification and analysis of more recent innovations, the factors and framework conditions for the adoption and dissemination within the local and the formal knowledge system are being assessed in order to make predictions on future scenarios.

The paper is focusing on changes in land usage which were, and still are being, implemented by introducing a new variety: rubber. It is presenting basic findings of an in-depth analysis of economic, ecologic and societal potential and problems for the case of two villages and from a users perspective: The farming system, land relations, household economy and social life are in transition, environmental balance and biodiversity are meeting tremendous challenges.

摘要

云南省农村的快速发展伴随着生物多样性的急剧下降。在“生命·景观·中国”项目框架内，作者试图寻找相关的途径来引进、改造和推广帮助在纳版河国家级自然保护区内保持生物多样性现状的创新方法。该项目旨在通过影响当地制度和结构以及知识的产生、传播和使用的各个环节，优化当地各相关机构的组织结构和功能。这种体系的干预需要深刻了解过去以及当前的土地使用情况。基于对典型化特点和最近创新性的分析，来研究当地所采用的知识体系内所传播的各种因素和条件，从而预测未来情景。

本文重点讨论土地使用的变化，这种变化是由一种新品种——橡胶的引进而造成的，并且橡胶的引进仍在持续进行中。本文从使用者的角度，以两个村子为例，深入分析了其经济、生态和社会的潜力以及存在的问题，介绍了研究的基本发现：耕作制度、土地关系、家庭经济和社会生活都处于一个过渡期，生态平衡与生物多样性面临着巨大挑战。

1 Introduction

NabanHe National Natural Reserve (NNNR), located in Jinghong county, Xishuangbanna Autonomous Prefecture of Yunnan Province, covers about 2600 ha of land. NNNR is multi-ethnic, inhabited by LaHu, Han, Dai, HaNi, Yi and BuLang. The main source of income is agricultural production. Since 1980, the household contract responsibility system has been adopted in NNNR. With the promotion of hybrid rice and development of forestry the economic wealth of the region improved considerably. The introduction of rubber in the 1980s was regarded as a key innovation on land usage. Rubber has become the main source of income for many farming households. Because of its high economic profit, the size of rubber plantations grew rapidly and by 2004, the total planting area covered nearly one quarter of the landscape. This rapid rural development is coupled with a dramatic decline of biodiversity (Li et al. 2007, Langenberger et al. 2008).

Within the framework of the “LILAC: living landscapes China” project consortium the authors are looking for relevant options for the introduction, adaptation and diffusion of innovations which may help to conserve the status-quo of biodiversity. The subproject on “Land use related innovations and knowledge flows” aims at organisational development for a relevant knowledge system of the Naban He National Nature Reserve. Organisational development hereby is seen as influencing institutions, structures and processes of generation, dissemination and use of knowledge. Based on an analysis of former and present land-use problems, the factors and framework conditions for the adoption and dissemination of innovations within the local and the formal knowledge system will be assessed. This will give important orientations for the implementation of the LILAC-scenarios, and for further development.

Land use has a history. The present and future of land use, and its influences on the users and on the biodiversity, are based on this history. Through understanding of the history of land use in the Naban He National Nature Reserve and in Yunnan Province, we get important orientations on the likelihood of the introduction, adoption and diffusion of innovations. Changes of land use interact with changes in ecology, society and economy. A precondition for behaviour change of land users is information that emerges from interactions in the relevant knowledge system. The local and the formal knowledge system and their development provide the information base for individual acquisition of knowledge and the decisions about land use. These issues are to be assessed and reconstructed for the research site. Consequences for extension and education activities will be shown.

Systemic interventions of this kind require profound insights into the historical as well as the present land use situation. Based on a typification and analysis of more recent innovations, the factors and framework conditions for the adoption and dissemination within the local and the formal knowledge system are being assessed in order to make predictions on future scenarios.

The introduction of rubber has brought fundamental changes in land usage. This paper is presenting the basic findings of a potential/problem analysis of the impact of rubber on local economy, ecology and society from a user's perspective. Starting in January 2007, an in-depth situational analysis has been conducted in order to elaborate the subjective view of local officials and farmers combining (amongst other PRA tools) narrative expert interviews and extensive observations with a stratified, semi-standardized household survey. Two villages (one Dai, one HaNi) have been selected as case studies for "innovation histories". To understand the introduction and dissemination of innovations, framework conditions within the NNNR are being elaborated, particularly the changes in land tenure.

2 Overview on the Two Village Case Studies

Village A is located near the gate of NNNR in an altitude of 670m above sea level (asl). It consists of 56 households with 287 inhabitants and about 170 working population. Three simple restaurants and more than ten new concrete townhouses indicate a quite good living condition, compared with other villages.

The village has some paddy land so the main food source is rice. Two to three households are growing a small amount of maize as a cash and alcohol crop. The main source of income is rubber. The state-owned Rubber Plantation Farm is located nearby, having strong linkages with village A.

Table 1 Description of study villages

	Village A	**Village B**
Altitude	670 masl	770 masl
Households	56	40
Population	270	150
Land size	2457 mu	1049 mu
Farm land		
Irrigated land	205 mu	97 mu
Dry land	53 mu	120 mu
Rotation land	284 mu	144 mu
Rubber plantations	1761 mu	749 mu
Source: NNNR administrative officer		

Village B is on higher altitude than village A. It is less densely populated with less than half of (farm) land. The village does not origin in the location. It was resettled in 1971 from another county. Until recently, the population in village B increased from 18 to 40 households and about 151 persons. Population increase is coupled with deforestation. After resettlement, villagers were organized to reclaim paddy land and rotation forest land in the natural forests. In 1982, village B owned 86 mu Paddy land and 1590 mu rotation forest land. In 1997, they constructed 92 mu terrace land. In 2002 all of the terrace land was reforested with subsidies from the central government, mainly with rubber. Village B has only a few irrigated paddy fields. Farmers therefore must grow hybrid rice.

3 Land Tenure History

Introduction and diffusion of rubber is clearly dependent on the development of land tenure in the NNNR (table 2). Therefore we will give a short introduction:

Table 2 History of land tenure in NabanHe National Nature Reserve

Time	Background	The tenure of land in NNNR
- 1956	Dai Autonomous Prefecture of Xishuangbanna	Landlords
1956-1958	Land Reform	Landlords dispossessed; land distributed to households from local government
1958-1982	People Commune Movement (Renmin Gongshe)	Community: co-operation of villagers, profit distribution by work quota.
1982-1999	First land contract	Villages distributed forest land, rotation land and paddy land to the households; contracts of 15 years
1999 -	Second Land contract	Land contracts adjusted to the population and land resource change; contracts extended to 30 years.
Source: key informant		

Dai Autonomous Prefecture of Xishuangbanna was founded in 1953. Most of the land belonged to landlords.

After 1958, the villages in NNNR like all over China began a collective agricultural production within the People Commune Movement. The core of the movement was that all the land belonged to the government, and the agricultural production was organized in community level. Profits of agricultural production were distributed by Work Quota.

In 1978, China Central Government decided to implement the so-called Rural Economy System Reform. The key step was a land reform towards a Household Contracted Land System: the ownership right of land still belonged to the community and usufruct rights contract with the households. Agricultural production in village A and village B was mainly dry farming in rotation land and irrigated farming in paddy field. Farmers grew local rice species with low productivity. Due to limited size of paddy fields, the production could hardly meet the grain ration of the households themselves. Therefore, also dry rice was grown on rotation land, supplemented by local old species maize, peanut and bean, etc., which were adapted to dry land conditions but showed relative low yield.

Table 3 Agricultural production structure before the 1980s

Land type	Crop name	Species	Yield (kg/mu)	Main Function
Rotation land	Maize for dry land	Local	100	Main food
	Peanut	Local	40	Cooking oil
	Bean	Local	40	Cash crop
	Dry rice	Local	25	Main food
	Broomcorn	Local	20	Forage
Paddy field	Rice	Local	100	Main food
Forest land	Natural forest	Local	No information	Firewood
Source: key informant				

NNNR began the land reform in 1982. The core philosophy of the Household Contracted Land System is that each resident of a village has the same chance to get land use rights. An average size of different types of land was rented to each resident without consideration of gender and age. In both villages, inhabitants agreed to categorise land into rotation land, paddy land and forest land according to the altitude and location. The per capita amount of land differs between the two villages because of differences in population and total amount of land (table 4).

Table 4 Land distribution in 1982

Land type	Description	Village A	Village B
Rotation land	Foot area of the mountain / dry rice and maize in history	10 mu/person	14 mu/person
Paddy Land	Valley and plain area / irrigated rice	1.25 mu/person	0.15 mu/person
Forest land	Mid of the mountain / forest	14 mu/person	Not distributed
Source: key informant			

This system of land tenure is a main reason for intensification of agricultural production in the villages, reduction of varieties, and the introduction of rubber (table 5). Land distribution was adjusted in 1999 to the changes in population structure and contracts were prolonged for 30 years according to the New Land Law in China.

Table 5 Agricultural production structure in 2007

Land type	Crop	Yield (kg/mu)	Main Function
Paddy field	Maize	200	Alcohol crop and cash crop
	Rice	400	Food crop
Rotation land	Rubber	-	Cash income
Forest land	Rubber / natural forest	-	-
Source: key informant			

4 The Introduction and Diffusion of Rubber

4.1 General history of the introduction

The introduction of rubber trees to Xishuangbanna was not before 1940, when a Chinese settler who came back from Thailand planted the first trees in trials. After 1949, rubber has been seen as an important strategic resource by the Government. In 1953, the state started to prove the feasibility of rubber in the area, and in 1955, the first rubber state farm has been founded. This farm was staffed by people from the inland province of Hunan, mostly by retired soldiers and Han Chinese farmers, who had volunteered to "settle the frontiers". Later on in 1960s and early 1970s, it was reinforced by the migration of the "educated youth" to rural areas. As a result, state-owned rubber plantations have been rapidly established in southern China, especially in Xishuangbanna and on Hainan Island (Xu 2006).

Back in that time, rubber was considered as a perfect way to modernize the savage shifting cultivation practices of local minorities. The first rubber planted by local farmers dates back to the year 1963, and starting from this time up to now, rubber has spread quickly in most of the mountainous areas of Xishuangbanna (Xu 2006).

In the late 1980s, the Government incentives led to an increase of smallholder private rubber production, since the state-owned farms faced difficulties with their own production. Rubber plantations have been promoted by the Government. As a result, mostly young people started with rubber plantations as they provided more cash income and were less labor-intensive, which has been desired to purchase modern consumer goods and live a modern lifestyle (Xu 2006).

4.2 Current situation of the introduction

Currently, Xishuangbanna represents the second largest producer of rubber in China next to Hainan Island. In 2007, China's largest natural rubber processing plant was founded in JingHong city with an annual production capacity of about 40,000 tons. Its focus will be on high quality natural rubber for the steel tyre industry (Xishuangbanna Sinochem 2008). At the moment, rubber tree plantations cover around 400,000 hectares of Xishuangbannas landscape and thereby occupy approximately 20% of the prefectures area.

Rubber is a cash crop, its development clearly driven by market prices. Introduction of rubber was strongly supported by the state. JingHong Farm provides technical assistance and young plants. During the interviews, many villagers revealed their deep affection towards Jinghong Farm. Four stages in rubber development in the NNNR can be identified (figure 1 and table 6):

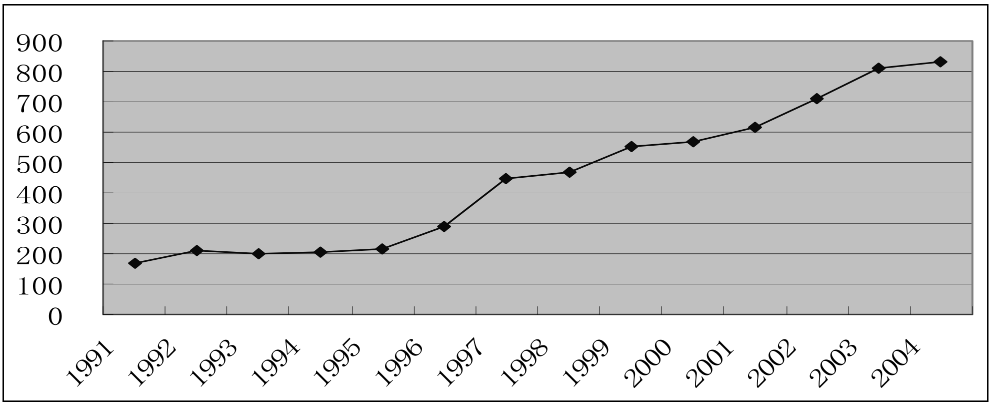

Figure 1 Rubber plantation in NNNR (ha) (Source: NNNR administrative officer)

1. At the beginning, only a few community elites tried to plant rubber although this was strongly supported by government policy. Reasons were a lack of knowledge and experience and risk: rubber was an external and new variety for the villagers, the rubber in JingHong farm was still in the process of growing and did not show yields, and profits could not yet be realised. Usually, it takes eight years to have any economic return.
2. The situation changed after rubber trees in JingHong farm could be tapped and market income was realised. village A and village B both are neighbouring JingHong farm, the villagers were easily convinced to invest in rubber plants.
3. With falling prices for caoutchouk in 1991 also the interest of farmers declined.
4. From 1996 the price of rubber juice rose, farmers realised great profits and enlarged plantation size. At the same time the central government started the Natural Forest Protection Project (NFPP) with the aim on environmental protection. Since the launch of the National Program of Natural Forest Resource Protection, forests covered by nature reserves are prohibited from logging. It was forbidden to transfer forest land into agricultural land and the natural forest areas were strongly protected. Local farmers wanted to "catch up the last bus" for rubber plantation which led to a rubber boost, and further deforestation.

4.2.1 The introduction of rubber in village A

"In 1984, 48 mu of rubber were planted for trial on collectively owned land, 8 rubber trees per farming household. At that time, nobody in the village planted rubber trees but some neighbouring state-run farms had already started to practice. The township government selected one person from each of its villages to learn techniques of rubber planting in Gadong Town Office of Tropical Crops. Y.-X. was chosen as the representative. In order to share risks, rubber trees were firstly planted on collectively-owned forest land. Every farmer was asked to plant 8 trees and be responsible for management. In other words, farming households provided labor, and the collective

village provided land. If the planting failed, farmers would not have any direct economic losses.

In 1985, five farming households, among others Y.-X. planted another thirty five mu of rubber trees on their own land. In 1986, Y.-X. planted another 7 mu of his own land. In 1987, the village government promoted rubber planting and the township institute of tropical crops helped to dig tree planting holes and distributed young rubber plants free of charge. Farmers were only responsible for field management. They were asked to plant at least 2 mu of land and 70 young plants were provided to each farmer. At this time, most farmers in the village began their rubber planting practice. However, the total acreage was still not large and most people took a wait-and-see attitude.

In 1989, Jinghong Farm began rubber tapping and the price was pretty high that year. Dry rubber was 18 yuan per kg and staff members made money out of rubber sales. As a result, farmers of Village A started to plant rubber trees at a large scale after 1989 and they planted all their fallow land with rubber trees. From 1991 to 1994, rubber price fell down and the lowest price of dry rubber was only 5 yuan per kg; therefore, farmers stopped the expansion of rubber planting. But rubber price began to climb up in 1995 and dry rubber was 20 yuan per kg that year; accordingly, farmers began to plant rubber trees in their contracted mountains in 1996.

The Government of China launched the National Program of Natural Forest Resource Protection in 1998 and carried out the logging quota management system in 1999. Many farmers had somehow learned this information beforehand and they knew that forest in their mountains could not be logged arbitrarily after 1997. Therefore, they fell all the trees in their contracted mountains and replanted rubber trees. Some villages in the Nature Reserve planted all their collectively-owned forest land with rubber trees due to the policy." (quoted from various interviews).

4.2.2 The introduction of rubber in village B

"Rubber planting was a bit later than that in village A. The former head recalled that both villages are part of the same administrative village. Y.-X., the technical instructor of village A, came for rubber planting promotion. In 1986, three farming households played the lead in rubber planting, namely the father of persons in charge at that time, who had many friends from the state-owned farm. In 1987, with the promotion activity of the township government and the leading role played by the three households, many other farmers in the village began to plant rubber trees. Village B didn't contract mountains to any farmers when the land contract responsibility system was implemented. Only fallow land was allocated to farmers and by 2003, all fallow land in the village has been planted with rubber trees." (quoted from various interviews).

5 Changes Implemented by Rubber

Extensive rubber plantation in NNNR has positive and negative impacts on local development, namely in the field of farming systems, household economy, livelihood, environment and biodiversity, but also on the land tenure.

5.1 Farming system

Before rubber introduction to NNNR, the traditional agricultural production system could be described as a four-field crop rotation (table 6). The arable land was cultivated for two or three years, followed by a fallow of four to twelve years to recover land capacity naturally.

Table 6 Four-field crop rotation in village B

Year (c.)	Land piece 1	Land piece 2	Land piece 3	Land piece 4
1965-1968	Dry paddy	Fallow	Fallow	Fallow
1968-1971	Dry Maize	Dry paddy	Fallow	Fallow
1971-1974	Fallow	Dry Maize	Dry paddy	Fallow
1974-1977	Fallow	Fallow	Dry Maize	Dry paddy
1977-1980	Dry paddy	Fallow	Fallow	Dry Maize
Source: key informant				

With rubber increase, local residents aimed at transferring all the rotation land, particularly the fallows, into rubber plantation. This was made possible by the cultivation of hybrid paddy rice with its considerable higher yields. Food production area could be reduced to a minimum. Recently, almost all slopes in both villages are covered with rubber.

Table 7 Fertilizer application in rubber plantations

Age of tree	Kinds	Amount	Fertilizing time	Source	Price yuan/kg
1-3 year	Urea	60 kg/ha	April and November	Market	2
3-8 year	Compound fertilizer	215 kg/ha	November	Market	3
8 year ff	Compound fertilizer	600 Kg/ha	April and November	Market	3
	Urea	450 kg/ha		Market	2
	Manure	7500 kg/ha		Farm	-
Source: key informant					

Different kinds and amount of fertilizers are being applicated in the growing phases: after plantation twice a year urea, later once a year compound fertilizer to stimulate growth. When the trees are harvested, compound fertilizer, urea and also manure are being used. Detailed information is given in table 7.

To control white powder sickness (Baifenbing) and scale insects, the farmers are spraying pesticides (table 8). According to local statistics, in village B, 190,000kg fertilizer and 2,700kg pesticide are used each year.

Table 8 Pesticide application in rubber plantations

Pest / Disease	Phenomenon	Pesticide	Amount	Spaying time
White powder sickness	White dots on leaves	Sulfur Powder or Triadimefon	37.5kg/ha	Regularly: End of February / Beginning of March
Scale insects	Leaves turn black	Rogor	"Some"	Immediately
Source: key informant				

5.2 Household economy

Economic returns from rubber are by far more than that from other crops or trees such as teak, longan or litchi (table 9). Rubber can be gathered in the 8th year of planting. After a village expert, farmers earn about 2,000 yuan from every mu of rubber trees in the first 5 years after the first tapping, and 5,000 yuan from 5th year to 12th year. If farmers are good at field management, they can get 3,000 yuan from each mu of rubber trees from 13th to 40th year of rubber tapping (prices: 2008).

JingHong Farm is just nearby and the rubber liquid gathered in the day can be delivered and sold to the farm in the same day. Farmers get cash income which is the second reason for the rapid development of rubber planting. The production of tropical fruits such as longan and litchi faces much more marketing risks.

China initiated a logging quota management system in 1999. Farmers must get an approval by the local forest authority and pay a certain amount of money for afforestation, even if they cut trees from their own timber forest. In 2003, China abolished the tax on special forest products which includes rubber. It means that farmers now can gather rubber freely without paying any kinds of taxes or fees. Therefore, farmers are more enthusiastic to plant rubber trees than before.

Considering the above factors, a simple agricultural production mode was formed in villages of low altitude in the natural reserve: *"getting grain from hybrid rice, earning money from rubber, and having other goods traded with money"* (farmer).

Table 9 Comparison of rubber and other tree crops

Name	Average profit (yuan/mu*year)	Know-how	Market	Marketing risk	Tax/fee
Rubber	2,000-5,000	Established industry	Nearby	Lower	None
Timber forest	Not available	Not-established industry	Long distance	Higher	Afforestation Fund
Fruit trees	Not available	Not-established industry	Long distance	Higher	none
Source: key informant					

In recent years, rubber became the main source of income for the local households. One important risk is the dependency of prices on the international market. In 2007, local farmers expected increased prices in the near future. According to them, it was time to renew rubber trees in South-East Asian area. This would reduce the supply of dry rubber in the international market. So they thought they would not suffer the market risk these years. However, this situation changed in the end of 2008 due to global financial crisis. From the end of 2008 the price of dry rubber declined rapidly to one-third (figure 2).

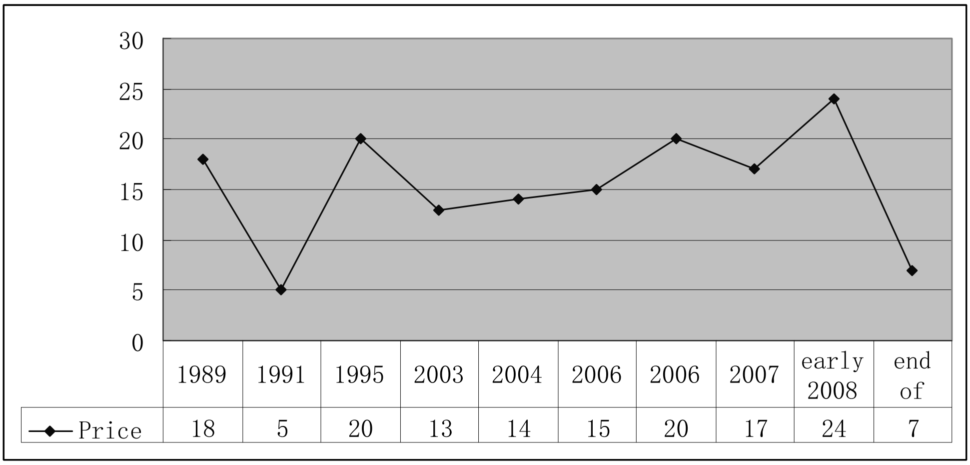

Figure 2 Dry rubber prices in NNNR (in yuan/kg)
(Source: key informant)

5.3 Environment and biodiversity

Rubber is a non-native plant to Xishuangbanna. Its natural habitat is the Amazonian rainforests. If compared to the humid tropics and alluvial plains in the Amazon basin and Southeast-Asia, Xishuangbanna's rubber plantations are mostly located in subtropical mountainous regions with a relatively low temperature and prevalent poor soil fertility. If rubber is grown in such a marginal biophysical environment, higher labor input is needed, e.g. for weeding, for terracing of the soil erosion control and for soil fertility management (Xu 2006).

Yunnan Province is estimated as the northern latitude limit for rubber cultivation. The decision to introduce the plant species to this marginal climatic zone back in the 1950s was based on the Government's interest to achieve self-sufficiency in latex production (Xu 2006).

The increase of rubber planting in NNNR induced negative impacts on the environment. Most of the rotation land was transferred. This is recognised by the farmers: some talk about landslides during the raining season which takes place much more frequently than in the past. Water in the rivers become less and less; some water source was polluted. In village B they got water from the river near the village. Now they must construct a pipe-water system to attract water from the peak of the mountains.

Next to the landslides, the most dramatic change in the recent years reported by the farmers is the change in the water household of the area. A drop of the groundwater level is perceived as well as the missing of winter mist or fog. An explanation for this incident can be found in QIU 2009: during the winter time, this dense fog of evaporated water was trapped beneath the rainforest canopy. Since the rubber trees have been taken over more and more of the area, the winter fog is becoming less. Rubber trees are known as huge water consumers, even considered by the locals as so-called *"water pumps: the trees suck up the water"*.

Erosion is another problem: compared to the rain forest, more water seems to be lost from the spaces in between since there are no plants which can hold the water back or store it, causing more surface water run-off during the rainy season. As a result, the water content of the soil will be reduced and in consequence, less water can evaporate. And further, a drop down of the stream flows and dwells and rivers are likely to dry out (Qiu 2009). Another environmental consequence of the shift from rainforest to rubber plantations is the negative influence on carbon dynamics and climatic changes in the area (QIU 2009). However, these issues have never been mentioned in our interviews with local farmers. But according to data of meteorological stations in Xishuangbanna it seems that the region received less rainfalls, has been getting warmer and experienced more severe droughts since the 1960s (QIU 2009).

5.4 Livelihood

Livelihood within a household also changed (see table 10). According to interviews with local villagers, rubber plantation and management is labour intensive. They have to do some tending work such as fertilizing, branches cutting and weeding and so on. After the rubber tree can be tapped they have to tap the rubber juice every early morning from April to October. Households which planted on large scale had to hire waged workers to help them to tend the rubbers.

Table 10 Livelihood changes

	Before rubber plantation	**After rubber plantation**
Agricultural products	various	Rice and maize
Labour need	self-hired labour	Labour intensive (night!), waged labour
Main income source	Agricultural products Off-farm work	Rubber latex
House	Traditional wooden houses built by locals	New style, concrete, built by external craftsmen
Consumables	Few	TV set, washing machine, fridge, motorcycle etc.
Plough power	Buffalo	Tractor
Livelihood character	Subsidence	Market oriented

Due to the fact that rubber farmers have more purchasing power, traders from JingHong and MengHai are attracted and they might occur frequently in the villages to sell vegetables, meat, clothes etc. This is also a major reason why most farmers in rubber planting villages gave up pig farming; it is just much easier for them to buy meat from such traders. Moreover, farmers are able to buy tractors to cultivate their fields and as a result, buffaloes lose their importance to the villagers. This tendency will become more prevalent when rubber plantations have either displaced the former grazing land for buffaloes and cattle or the area for corn planting, which is needed to feed the animals. Also local households could improve daily live and buy commodities such as TV, washing machine, fridge, motorcycle. Instead of the traditional style houses with wood and grass, new concrete ones could be built, often by external craftsmen. This shows a transition from subsistence to a market oriented agriculture.

5.5 A new phenomenon: Land renting

Renting land for rubber plantation became very popular in both villages, especially in village2 with its large-area slopes. Different forms of contracts have been concluded regarding to the period and the ways of sharing the profits (table 11). About 19 households contracted their land to others and get renting income. The renters come from different neighbour villages, other provinces or counties.

Table 11 Different forms of land renting in village 2 (examples)

Renter from	**Size (mu)**	**Benefit sharing**	**Contract period**	**Starting time**
Other county	20	Lessee invests in rubber planting for 6 years; later land will be shared	26 years after first tapping	2003
Village A	47.7	17000 yuan	25	2004
Jinghong county	17	25000	25	2004
NNNR administrative bureau	20	15000	30	2003
Food and Oil Company	15	32580	26	2003
JingHong farm	8	4000	40	2003
Source: key informant				

6 Concluding Remarks

Rubber introduction was strongly supported by the government. However, the adoption took several years of trial and comparison. Farmers considered a range of factors: driving forces such as the regular income and as a result the immense higher personal welfare; but also the higher risk due to monoculture and changing prices. Villagers are aware of the environmental conditions including changes in soil fertility, the tremendous change of the landscapes, and also ecologic problems. Insofar development of the land use structure was in both surveyed villages a quite complex process. Decisions were rational and clearly towards rubber.

Meanwhile, rubber is the main source of cash income. It has not only influenced agricultural activities and the seasonal calendar of the farms; but also everyday lives and behaviour of the people with a complete change of their daily routines.

Rubber has become the main driver of economic development in the NNNR. Future scenarios for innovations which may help to conserve the status-quo of biodiversity have to consider this. Alternatives might not be found, at least not easily or without massive compensation. The question might not be “rubber or not?” but “how to improve the rubber production system towards a conservation of biodiversity?”

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Ecosystem Services Valuation as a Basis for Promoting Policies Conducive to PES and Climate Change Mitigation in Xishuangbanna, Southern Yunnan, China

中国云南南部西双版纳地区以生态系统服务价值评估为基础推广生态系统服务补偿及减缓气候变化的政策

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Abstract

Ecosystem services are increasingly receiving attention across the world (Wulan et al. 2007, Frost and Bond 2006), particularly, when it comes to payment for maintaining such services. One of the fundamental arguments promoting payment for ecosystem services (PES) is the need to sustain downstream services, such as provision of water in quantity and quality from upstream sources. Although payment for ecosystem services has been advocated by multilateral development institutions for some time now, governments in the Greater Mekong Subregion have been slow in promulgating policies conducive to PES, particularly for forest ecosystems. One of the few exceptions in the Greater Mekong Subregion is the Decision of the Prime Minister on "the Pilot Policy for Payment for Forest Environmental Services" April 2008, applicable to Lam Dong and Son La provinces Viet Nam; a similar example is from China, Yunnan "Provincial Government's Position on Enhanced Biodiversity Conservation in Northwest Yunnan" (No.43, 26 February 2008), which explicitly mentions implementation of PES.

Governments have been concerned about the issues, such as how much, by whom, to whom, and how. Hence, valuation of ecosystem services (VES) gains importance in order to: a) why and what services are important to whom; and b) provide some calculation framework on "how much" needs to be provided to whom if we are to avoid damage cost to the ecosystem (e.g. forest or watershed). Increasingly, anticipated impacts of climate change on the ecosystem and its services will require mitigation and adaptation measures and valuation exercises highlight the importance of livelihoods of local people as well as their dependence on forest ecosystems.

Ecosystem services can be defined as goods and services provided by a natural unit of living things (animals, plants and micro-organisms) and their physical environment that benefit

human beings (Defra, 2007). While some of the forest ecosystem services (e.g. water, clean air, pollination etc.) are difficult to quantify or put a value in money terms, certain other goods such as timber and non-timber forest products (e.g. forest food, rattan, latex, resins, etc.) are tradable in the market. However, the price mechanism often fails to reflect the real value of those ecosystem service products because their valuation is based on the cost of extraction (labor, equipment, and transport) and raw material only. It does not take into consideration the ecosystem service value, such as watershed protection, soil fertility, carbon sequestration, and biodiversity conservation. As markets and economic development planning rarely reflect the full social costs or benefits of environmental goods or services, valuation of ecosystem services is essential in the correction of market failures and in supporting economic policy making by planners and decision-makers.

摘要

生态系统服务正在世界范围内受到与日俱增的关注，有关维持生态服务的付费问题更是备受关注。支持生态付费的最主要的论点之一是保持生态系统下游服务的必要性。尽管生态系统付费机制已被国际发展组织倡导多年，然而，大湄公河次区域的各国在促进这方面的政策却相当滞后，特别是森林生态服务付费。大湄公河次区域成员国中在这方面屈指可数的成功典范是《森林生态系统付费试行政策的总理决议》，该决议在越南的林同和山萝两省试行。另外一个成功的典范则是中国云南的《云南省人民政府关于加强滇西北生物多样性保护的若干意见》，该《意见》中明确提出了执行生态服务付费的有关规定。

政府们已经考虑了生态服务付费中诸如补偿额度、补偿主体、补偿对象以及补偿手段等问题。因此，对生态系统服务的价值评估对解决以下问题有着突出意义：1）什么样的生态系统服务重要、重要的原因、适用的对象；2）旨在避免对生态系统破坏而进行补偿的计算标准，以及补偿对象(例如，森林和分水岭)；3) 伴随着气候变化对生态系统及生态系统服务影响的预测不断增加，对有关减缓和适应气候变化带来的影响的各项措施和价值评估的需求也会相应地增加。这将凸显当地居民生计及他们对森林生态系统依赖的重要性。

生态系统服务的定义是指有生命的实体（如动物、植物和微生物）向人类所提供的物品和服务，以及有利于人类生存的自然环境。大部分森林生态系统服务的价值很难用金钱的数量来体现。尽管一些如木材及其他林产品（橡胶、林产食品、藤制品、树脂）可以在市场上交易，但是市场价格往往不能体现这些产品的真实价值。因为这些产品的价格往往是以一些外在的因素如劳动力的价值、设备成本和运费等为基础的，而不仅仅是原材料的价值。而且，这些价格往往不包括生态系统服务费用例如分水岭的保护、土壤施肥、碳封存等。由于市场和经济发展规划几乎不反映生态产品的全部社会成本和效益，所以生态系统服务的价值评估对纠正市场的不足发挥着举足轻重的作用，对市场规划者和政策制定者制定政策有着积极的支持作用。

1 Importance of Xishuangbanna in the Greater Mekong Subregion

1.1 Gneral introduction of the Greater Mekong Subregion

The Greater Mekong Subregion (GMS) is one of the fastest growing regions in the world, which involves significant economic and social changes transforming economies, countries and natural landscapes in the subregion inevitably affecting the environment. Recognizing this development challenge, in 2004, the GMS Working Group on Environment (WGE), facilitated by the Asian Development Bank (ADB), initiated a review of the GMS economic program from an environmental sustainability and management point of view. Both the Environment Ministers Meeting in Shanghai (May 2005) and the 2nd GMS Summit of Leaders and Heads of State held in Kunming (July 2005) endorsed the Core Environment Program and its flagship component, the Biodiversity Conservation Corridors Initiative (BCI), for implementation.

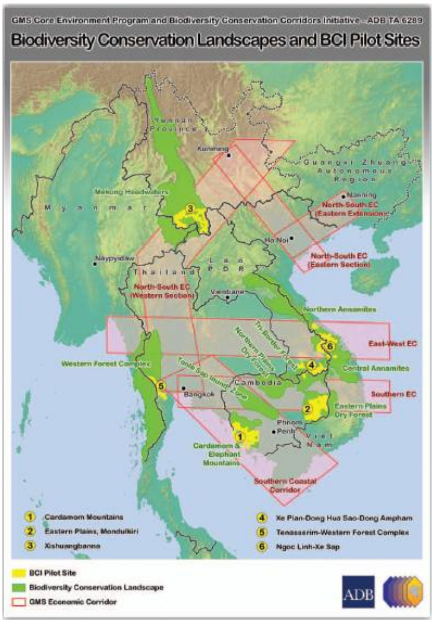

Figure 1 Biodiversity Conservation Landscapes and BCI PilotSites in the Greater Mekong Subregion (ADB RETA 6289)

The GMS BCI identified nine key biodiversity conservation landscapes (BCL) representing ecological networks, with natural and/or semi-natural landscape elements of high biodiversity value in which six pilot sites were selected for launching the BCI implementation between 2006-2009. The long term vision of BCI is that by 2015, GMS countries will have established priority biodiversity conservation landscapes and corridors for maintaining the quality of ecosystems, ensuring sustainable use of shared natural resources, and improving the livelihoods of people. The BCI has five sub-components: i) Poverty alleviation through sustainable use of natural resources and development of livelihoods; ii) Clear definition of optimal land uses and harmonized land management regimes; iii) Restoration and maintenance of ecosystem connectivity; iv) Capacity building in local communities and government staff; and v) Sustainable financing mechanisms and structures integrated with government planning and budgeting procedures.

1.2 Significant role of Xishuangbanna

The tropical forests of Xishuangbanna in southwest China (Yunnan) are unique because of the transitional geographic location and climatic features crossing the tropics and subtropics, which harbor some of the richest fauna and flora and provide habitats for various animal species. While the initial BCI focal area identification takes a long term approach towards establishing linkages in the fragmented ecosystem, identifying eight potential corridors, BCI implementers in phase I (2006 – 2009) gave priority to establishing connectivity between: (i) Nabanhe to Mangao; and (ii) Mengla to Shangyong (wild elephant sanctuary), which is also a transboundary nature reserve bordering Lao PDR. (See map 2 below).

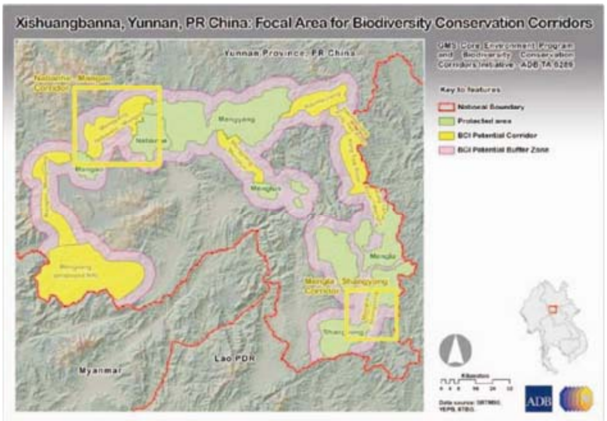

Figure 2 Bidiversity Corridors selction in Xishuangbanna

Nabanhe—Mangao Biodiversity Corridor Segment (for detailed information on the corridor segments mentioned herein, see ADB, 2008)**:** The proposed corridor area between Nabanhe Nature Reserve and Mangao Subreserve is estimated at 15,446.74 ha with an outer perimeter and an inner core having a linear forest connectivity stretching to roughly 25 km. This corridor covers 40 natural villages in three administrative villages of Menghai and Mengsong townships in Menghai County. Within the corridor, a linear forested "core" strip has been identified that is dissected in the north and the south by two roads. This area also has the weakest link in the forest cover and requires stabilization and restoration measures. However, if we add the area of both Nabanhe and Mangao Nature Reserves, the total area amounts to 51,718 ha. The corridor belongs to the south subtropical area and the natural vegetation is seasonal evergreen broadleaf forest dominated by Castanopsis sp, Schima wallichii etc. Wild boar is common while Bos gaurus roam occasionally in this area. Animals like tiger, bear, and Red Deer disappeared from the corridor because of habitat destruction and impact of increasing human activity. On the other hand, population of Bos gaurus and wild boar increased because of in-migration and propagation after the hunting ban.

Mengla to Shangyong Biodiversity Corridor Segment: The biodiversity corridor strip between Mengla-Shangyong Subreserves covers a total area of 2,471.43 ha. It is a narrow strip of forest connectivity that still remains between Mengla and Shangyong.

However, if we add the area of both Mengla and Shangyong Nature Reserves, the total area amounts to 152,076 ha. Wild animals such as tiger (in Shang Longyin village), monkey, bear, boar, and wild elephant used to be in the corridor area but cannot be found anymore because of denudation of forests and replacement with large areas of rubber plantation. Since the construction of the Xiao Mo expressway started in 2003, there has been no elephant sighting in this area except near the corridor border areas such as Dalongha, Manfen, Chachang and Huilang villages. Currently, besides rubber plantations all around the villages, there are few remaining species such as teak, Anthocephalus chinensis, Cassia siamea and some fruit trees.

While the importance of Xishuangbanna, as one of the last remaining tropical rainforests of the GMS, is well known, it also has tremendous pressure on land, and fast changing land use, with a high rate of conversion of forests to rubber plantations. The decline in rainforest area and degradation of watersheds are bound to affect ecosystem services in Xishuangbanna as well as the water flow downstream for the Lower Mekong countries of the GMS. While the real or true value of the ecosystem (e.g. source of water supply, pollination, medicinal herbs, essences, oils, and cosmetic ingredients, food and food supplements through non-timber forest products) for local people need to be considered as an opportunity cost vis-à-vis those (e.g. rubber plantations of high economic value due to market demand - high price/return) gained from human induced, and irreversible changes in the Xishuangbanna tropical forests ecosystem, anticipated negative impacts of climate change will also likely take their toll unless mitigation and adaptation measures are put in place. Amidst the large scale land use change that replaces forest ecosystems with commercial agricultural crops like rubber, the state may have to regulate more vigorously to protect watersheds in order to guarantee essential ecosystem services, such as a sustainable supply of water or soil conservation. These impacts are not captured in decision-making because some of the ecosystem goods and services affected are not sold in markets or attached with an economic value for society at large.

2 Valuation of Ecosystem Services: Some Methodological Caveats

Methodologically, starting as early as 1958 with the Proposed Practices for Economic Analysis of River Basin Projects by the Committee on Water Resources (Bingham and Costanza, 1995), valuation of ecosystems was given its basic framework and was further developed by Daily (1997) and Costanza et al (1997) estimating, more than a decade ago and at that time, a staggering value of $33 trillion for ecosystem services across the globe. By 2007, a study of only two protected areas in Cambodia in the Greater Mekong Subregion (Phnom Aural and Phnom Samkos Wildlife Sanctuaries) by IIED (2007) showed a net present value of over $1.89 billion covering only an area of 585,787 ha taking into consideration only sustainable timber harvesting, agriculture, non-timber forest products, and carbon storage. Also in 2007, a study on in Menglun County, Xishuangbanna Prefecture in Southwest China (Hu et al. 2007) using Constanza's coefficients shows a value of $29.8 million covering an area of 33,488 ha in one county alone. In Vietnam, the Da Nhim watershed (ARBCP 2008), water regulation and value of reducing sedimentation downstream has been estimated at $69 per ha per annum covering an area of 63,000 ha. This only underlines the fact that valuation methodologies vary widely and may not be comparable across all countries or sites. Nevertheless, it is important to note that valuation exercises are increasingly being conducted and can become the basis for policy decisions on securing sustainable financing, providing a conducive incentive framework for PES, conservation and sustainable use, or for climate change mitigation and adaptation considerations.

Valuation methods of ecosystem services can be classified into two broad economic categories based on demand and supply: 1) Stated preference method by asking people for their willingness to pay for a certain ecosystem service; 2) Revealed preference method by using a relation with a market good or service to estimate the willingness-to-pay for the service. The latter has been used in the study in Xishuangbanna BCI pilot site.

Specific methods for estimating particular ecosystem services according to the nature of goods or services and proxy function availability usually list contingent valuation method (CVM), hedonic prices, direct estimation of opportunity costs, replacement costs, cost savings, threshold values etc. (Thampapillai, 2002). In 2003, Xie Gaodi et. al. developed A List of Unit Ecosystem Services Value of Different Ecosystem Types in China, based on a questionnaire survey of 200 ecological experts and previous studies on ecological information system (EIS) developed by Chinese Academy of Sciences (Chen and Zhang , 2000). However, almost all methods contain varying degrees of constraints and not all may be applicable in each case study. The choice of appropriate methodology usually depends on the selection of ecosystem service to be valued.

Therefore, in consultation with local implementing partners - experts from the Xishuangbanna Environmental Protection Bureau (XEBPB), Xishuangbanna National Nature Reserves Management Bureau (XNNRMB) and Xishuangbanna Tropical Botanical Garden (XTBG) of the China Academy of Sciences -of the BCI pilot site in Xishuangbanna, a broad spectrum of ecosystem services were identified as a first step, as documented in table 1 below, which were used as a first cut to further refine and narrow down the selected menu of ecosystem services to be assessed:

Table 1 Types of ecosystem services in Xishuangbanna BCI pilot sites

Direct use values	Indirect use values	Non-use value
-Non-Timber Forest Product (NTFP) (i.e. Food, medicine plants, fuel wood, materials, etc.) -Recreation and tourism -Plant genetics -Agro-biodiversity	• Climate Regulation (Carbon Sequestration, Oxygen Generation) • Water Regulation (Watershed Protection, Storage, Water Quality regulation) • Soil erosion protection • Nutrient cycling • Micro climate functions (temperature / humidity control • Air purification • Pollination • Biodiversity	-Existence value -Culture/spiritual value

Based on data availability and time constraints, only major ecosystem services were selected for inclusion in the valuation study of the corridor segments in the Xishuangbanna BCI Pilot Site. The selected ecosystem services are presented in the table below:

Table 2 Selected ecosystem services, valuation methods and requirements

Ecosystem services	Valuation Method	Data requirements	Data collection
NTFP	Market Analysis	Biophysical data Cost inputs Prices of outputs	Local survey and studies
Climate Regulation -Carbon Sequestration -Oxygen Generation	Cost saving	International carbon sequestration or industrial oxygen production cost; areas of the ecosystems; carbon sequestration or industrial oxygen production capacity of ecosystems	Local studies Benefit transfer
-Water Regulation -Watershed Protection (Storage) -Water Quality regulation	Cost saving	Reservoir construction cost; annual precipitation of area in research; annual evaporation in forest of all climate types; area of coniferous and broadleaf forest of all climate types	Local studies Benefit transfer
Soil erosion protection	Damage cost	Erosion module difference of ecosystems and non-forest land; Area of ecosystems; cost of 1 ton sediment removal；Ratio of sand entering river or reservoir to total sand loss；	Local studies Benefit transfer
Nutrient cycle	Cost saving	Area of ecosystems ； Erosion module difference of ecosystems and non-forest land; N,P,K contents in ecosystem soil; ratio of pure N,P,K to N,P,K contained fertilizer; price of various fertilizers	Local studies Benefit transfer
Air purification	Cost saving	Annual unit pollutant absorption of coniferous and broadleaf forest； Annual particulate adsorption of coniferous and broadleaf forest per unit area; Area of coniferous and broadleaf forest of all climate types in China; Treatment cost of pollutants particulates	Local studies Benefit transfer

3 Summary Values of Ecosystem Services in Selected Biodi-versity Corridors of Xishuangbanna

The total value of ecosystem services assessed in the Xishuangbanna biodiversity corridor segments of a) Nabanhe – Mangao (including Nature Reserves) and b) Mengla – Shangyong (including Nature Reserves) amounts to $1.162 billion annually (see table 3 below), which translates into just over $7,047 per ha, if we take into account the total forested area of both corridor segments and nature reserves to be 164,913 ha. However, the result is very sensitive to carbon pricing, if we take a range between $20-$50 per ton of CO2, the total value will reach $1.524-$2.61 billion annually with a unit value of $9,421-$15,827 per ha.

Table 3 Overview of Summary Value of Tropical Forest Ecosystem Services in Xishuangbanna(in million USD)

Ecosystem Services	Mengla-Shangyong (135,932 ha)	Nabanhe-Mangao (28,981 ha)	Total value	Unit Value ($/ha/yr)
1. NTPF	0.2	0.8	1.0	-
2. Carbon Sequestration	303	59	362	2195
3. Oxygen Generation	130	25	155	938
4. Watershed Protection (Storage/ Quantity)	74	15	89	540
5. Water Quality regulation	156	29	185	1123
6. Soil erosion protection	32	7	39	234
7. Nutrient Cycling	146	36	182	1104
8. Air purification	122	29	151	913
Total	962	200	1162	7047

The carbon sequestration service of the forest provides the highest value followed by water quality regulation and nutrient cycling. NTFP comes in low because several highly potential products such as oils, aromatic essences, and orchids are not well processed for value addition and also collected by fewer households in limited areas. Medical herbs and some bamboo types are assumed to be over exploited, which may need some domestication and production outside the forest for commercial use.

4 Scenarios and Analysis

4.1 Introduction of two types of scenarios

In the last session, we can see that a significant value is provided by the tropical forest ecosystem services in Xishuangbanna BCI pilot site. However, driven by the high market demand and economic incentives, rubber plantation and expansion remain the major threat to the forest conversion and fragmentation. The doubt rises in the questions of "are the rainforests providing ecosystem services valuable enough to justify conservation? And which development pattern is more beneficial to the society as a whole, business as usual or conservation?" Therefore, it is essential to analyze the trade-offs between the forest conservation and other competing land use options. Two scenarios of the BCI corridor development, namely, development scenario (without BCI) and conservation scenario (with BCI), are developed and stimulated for comparison together with the status quo in terms of their Net Present Value (NPV) together with the economic analysis of the costs and benefits of different land use options.

The scenarios' specifications for simulation are summarized in the table 5 below, and the vegetation areas data and corridor scenarios maps are generated from a geographic information system (GIS) modeling.

4.2 Scenarios design

The development of Xishuangbanna biodiversity corridor area may meet various constraints, regardless of the establishment of biodiversity conservation corridors in the area. The future development will be limited by a combination of factors, namely geographic conditions, market mechanism, existing forestry and land use policy, and other land use and human factors. Therefore, restrictive factors must be considered in designing the scenarios.

<u>Development Scenario (Without BCI)</u>

The Development Scenario simulates the maximum development activity in a corridor area with proper conditions such as market drive, policy permission and suitable growth conditions, assuming no corridor is constructed. Driven solely by economic interests, people will choose plantation projects in the following priority: rubber forest > other economic forest > agricultural production. Under the current forest right policy, farmers are permitted to autonomously manage collective forest allocated to individuals, and those without allocation are not allowed to make use of state-owned forest. Keeping in mind growth conditions, rubber plantations can only be grown at an altitude below 1500m (Jang 1982, Wang et al. 1992), and their growth will be affected above 1500m altitude; there are suitable economic forest and crops for areas at any altitude. However, this option is not a conducive one and runs against the current BCI philosophy.

<u>Conservation Scenario (With BCI)</u>

Under the Conservation Scenario, the corridor area is divided into core area and buffer area. In the core area, all non-forest area will turn into secondary forest in core area. In the buffer area, it will have the following changes:

i) State-owned forest will remain the same;

i i) Collective forest: Natural forest and other commercial crops remains; other forest at altitude>900m rubber plantation will be converted to economic forest; forest at altitude<900m rubber forest remain unchanged;

i i i) All shrub land will be converted to secondary forest;

iv) Farmland: can be considered to be converted to economic forest at steep slope (non-rubber forest);

v) Paddy field, built up and other land use remain unchanged.

Table 4 Summary of scenarios design

	Development Scenario (Without –BCI)	Conservation Scenario (With –BCI)
1 Natural Forest		BCI comprises of core area and buffer zones. All non-natural forests turn into to secondary forests in core areas; buffer area will have the following changes
1.1 State-owned forest	1. Altitude>1500m converted to commercial plantation or farmland 2. Altitude<1500m converted to rubber plantation	Unchanged
1.2 Collective forest	1. Altitude>1500m converted to commercial plantation or farmland 2. Altitude<1500m converted to rubber plantation	1. Natural forest and other commercial crops remains 2. Altitude>900m rubber plantation converted to other economic plantation 3. Altitude<900m rubber plantation remain unchanged
2. Shrub land	1. Altitude>1500m converted to commercial plantation or farmland 2. Altitude<1500m converted to rubber plantation	All converted to secondary forest (while shrub land belong to collective forest can be converted to other commercial plantation)
3. Commercial plantation	1. Altitude>1500m unchanged 2. Altitude<1500m non-rubber plantation converted to rubber plantation	Unchanged
4. Farmland	1. Altitude>1500m unchanged 2. Altitude<1500m converted to rubber plantation	Some are considered to be partially converted to commercial plantation
5. Paddy	Unchanged	Unchanged
6. Built-up and others	Unchanged	Unchanged

4.3 Scenario analysis

The net present value (NPV) of the costs and benefits associated with each scenario is calculated based a 35 years timeframe (a life cycle of rubber plantation), and with a 10% discounting rate which has been commonly used in other valuation studies (IIED 2007, De Lopez 2003, Mohd Shahwahid 1999). The higher bound of the prices and yields are taken into calculation for agricultural products, rubber and other commercial plantation. To simply the model, three broader category of vegetation are considered for valuation, namely, i)forest, ii)rubber plantation/other commercial plantation, and iii)agriculture, where rubber plantation and rice are selected for calculation as representatives for category ii) and iii) as they are the dominate vegetation within the category and generate the highest benefits, which follow the equations below:

Net Present Value (NPV)= $NPV_{Forest} + NPV_{Rubber} + NPV_{Agriculture}$

NPV_{Forest} = Forest area (ha) * NPV_{Forest} (\$/ha)

NPV_{Rubber} = Rubber area (ha) * NPV_{Rubber} (\$/ha)

$NPV_{Agriculture}$ = Agriculture area (ha) * $NPV_{Agriculture}$ (\$/ha)

The vegetation areas of two scenarios compared with status quo and NPV results of the two corridor segments are presented in the table 16 and 17 below.

Table 5 Scenario analysis of Mangao-Nabanhe BCI corridor segment NPV (inMillion USD)

Vegetation Area	Status Quo	Development Scenario	Conservation Scenario
Forest area (ha)	7517	4111	10255
Change (ha)		-3406	+2739
NPV_forest	511	279	591
Rubber/other commercial plantation (ha)	1377	5414	1074
Change (ha)		+4037	-303
NPV_rubber	25	97	19
Agriculture (ha)	6380	5749	3944
Change (ha)		-631	-2436
NPV_agriculture	81	73	50
Total NPV	617	449	660

Table 6 Scenario analysis of Mengla-Shangyong BCI corridor segment (in Million USD)

Vegetation Area	Status Quo	Development Scenario	Conservation Scenario
Forest area (ha)	1409	416	1589
Change (ha)		-992	+180
NPV_forest	96	28	101
Rubber/other commercial plantation (ha)	1007	2053	838
Change (ha)		+1046	-169
NPV_rubber	18	37	15
Agriculture (ha)	64	10	53
Change (ha)		-54	-11
NPV_agriculture	0.813	0.127	0.637
Total NPV	115	65	117

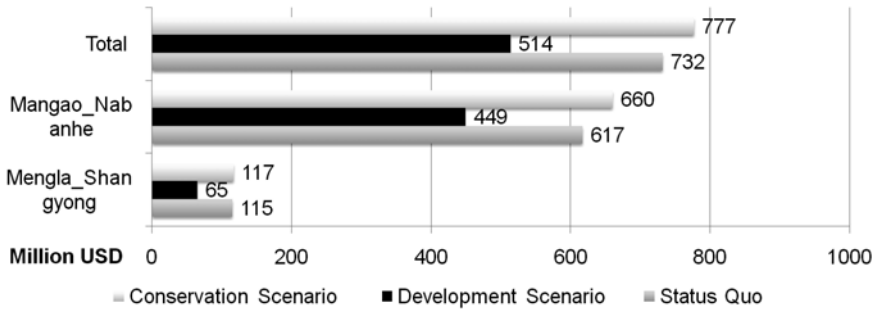

Figure 3 Results of scenario analysis

The results of both corridor Segments show that conservation scenario can better preserve the value of status quo even with further improvement, while the development scenario may incur a huge loss of value compared with status quo. NPV of the forests contribute to the biggest proportion and variance of the values under different scenarios.

A summary of NPV ($/ha) under a 10% discounting rate and 35 years timeframe is presented in the table 20. It demonstrates that maintaining forests or even restoring the degraded forests/reforestation provides much more value than other alternative land use options. However, the values of forest ecosystem services are not well recognized and received by people due to its environmental externality nature, rather the high economic return of rubber plantation (IRR=23.05%-34.91%) drives the rapid expansion of rubber plantation in Xishuangbanna. Meanwhile, although the economic value of agriculture is relatively lower, it plays a very important role in local livelihoods in terms of source of food and income.

Table 7 Summary of NPVs of land use options in Xishuangbanna BCI corridor pilot site

Land use options	NPV ($/ha) (10% discounting rate, 35 years)
Forest conservation	67,962
Forest restoration	29,294
Rubber Plantation	6,386 -17,923
Rice	3,558 – 12,708
Corn	8,895
Sugarcane	6,777
Tea	1,431-12,953

4.4 Sensitivity analysis

A number of variables and data sources are used in the valuation and scenarios analysis, to deal with the uncertainty of the results; four key variables are selected to conduct the sensitivity analysis, which are: i) discounting rate; ii) prices of rubber selling in the primary market; iii) prices of Carbon Dioxide trading under United Nations Framework Convention on Climate Change (UNFCCC) framework; and iv) yields of the rice productivity.

Table 8 Selected variables for sensitivity analysis

Variable	Base case	Alternative value (range)	Descriptive
Discounting rate	10%	8%, 6%	Lower discounting rate (10% discounting rate is regarded to be high for calculation)
Rubber Prices	20 RMB/kg	10 - 25 RMB/kg	Lower bound of rubber price: 10 RMB/kg (2009); higher bound of rubber price: 25 RMB/kg (2007)
Carbon Prices	10 USD/ton	20 - 50 USD/ton	IPCC Fourth Assessment Report 2007 suggest real prices of 20 to 50 USD/ton CO_2
Rice Yields	9 ton/ha	5.4 -12 ton/ha	According to the field consultation the range of rice yield is between 5.4 -12 ton/ha

The results of sensitivity analysis (see table 22 below) shows that the value of NPVs are quite sensitive to the carbon prices and discounting rate, and less sensitive to the rubber prices and rice yields. If the price of carbon dioxide is set at 50 USD/ton, the NPV values reach double of the values in the base case. 6% of the discounting rate leads to approximately 50% incremental NPVs increase. However, the incremental changes in NPVs by adjusting the values of selected variables do not affect on the outcomes of scenario analysis, in all the cases, NPVs of conservation scenarios remain the highest values in the comparisons with status quo and development scenario.

Table 9 Sensitivity analysis of scenarios analysis (NPV: Million USD)

Scenarios	Base case	Discounting rate		Rubber Prices		Carbon Price		Rice Yield	
		8%	6%	10 RMB/kg	25 RMB/kg	20 USD/t	50 USD/t	5.4 t/ha	12 t/ha
Mangao_Nabanhe BCI Corridor Segment									
Status Quo	617	749	938	601	624	776	1253	558	665
		21.43%	51.95%	-2.65%	1.22%	25.73%	103.10%	-9.53%	7.81%
Development Scenario	449	559	717	387	481	537	798	397	493
		24.59%	59.80%	-13.81%	7.06%	19.49%	77.64%	-11.62%	9.86%
Conservation Scenario	660	816	1038	648	667	848	1412	624	690
		23.62%	57.34%	-1.82%	1.00%	28.53%	113.92%	-5.41%	4.62%
Mengla_Shangyong BCI Corridor Segment									
Status Quo	115	142	180	103	120	144	234	114	115
		23.07%	56.58%	-10.45%	4.71%	25.61%	103.42%	-0.85%	0.08%
Development Scenario	65	85	114	42	77	74	100	65	65
		30.70%	75.17%	-36.15%	18.51%	13.85%	54.49%	0.15%	0.41%
Conservation Scenario	117	145	184	107	122	148	244	116	117
		23.52%	57.59%	-8.51%	3.88%	26.87%	108.19%	-0.66%	0.10%
Total									
Status Quo	731	891	1118	704	745	920	1487	672	780
		21.85%	52.89%	-3.74%	1.90%	25.88%	103.43%	-8.04%	6.74%
Development Scenario	515	644	831	428	558	611	898	462	559
		25.12%	61.43%	-16.80%	8.29%	18.55%	74.37%	-10.30%	8.46%
Conservation Scenario	777	960	1223	755	788	997	1655	741	808
		23.60%	57.38%	-2.82%	1.43%	28.28%	113.05%	-4.69%	3.94%

5 Conclusion and Policy Implications

5.1 Conclusion

The valuation results show a potential value of $1.162 billion could be provided annually by the forest ecosystem services of Xishuangbanna BCI Pilot Site, namely, Mengla-Shangyong BCI Segment and Mangao-Nabanhe BCI Segment. Carbon sequestration contributes the largest proportion of the benefits from ecosystem services, water regulation and nutrient cycling also provide significant benefits, while NTFP turns to be a minor factor due to its limited collection and marketing practiced in the corridor area, however, NTFP plays a very important role in people live and has the greatest potential to capture the value of the ecosystem services and improve local livelihoods. However, not all the ecosystem services are included and factored in the valuation framework, therefore, the total value of ecosystem services may have a higher value if data and model are further developed in the future.

The scenarios analysis simulates the costs and benefits of the future pictures in different development patterns. Conservation scenario stands out to be the better off option in both BCI corridor segments, while development scenario causes huge invisible loss of benefits in ecosystem services. Expansion of rubber plantation is the major driver and threat to forest conversion, though it is the most beneficial option for the local people to enjoy the short-term high economic returns, however, the risk of rubber related disease and current global economy downturn shows the great vulnerability and uncertainty of the monoculture in rubber plantation.

The value of ecosystem services, particularly the indirect use values, are not well reflected and factored in both individual household and governmental policy decision making, due to its environmental externality. Therefore, it is very essential to formulate corridor management policies and payment for ecosystem services (PES) scheme to provide the right incentives to secure and capture the value of ecosystem services.

The disappearance of forest cover as well as intensive and over exploitation of land resources (e.g. grasslands) will seriously accelerate soil erosion and water retention capacity. With anticipated increase in global temperatures and predictive models showing erratic weather conditions (excessive periods of dryness or drought and intensive periods of rainfall), climate change impacts may be recorded as mudslides or landslides in higher elevations and flooding downstream. At the same time, dryness and drought conditions may lead to scarcity of water, which in turn affects water availability for hydropower, agriculture and drinking. It is essential to conduct climate change impact studies to design and cost adaptation measures and secure funding. Above all, negative impacts of climate change will affect the livelihoods of forest dependent local people.

5.2 Policy implications

Giving a significant value over $1 billion annually is provided by the tropical forest ecosystem services in Xishuangbanna BCI pilot site, the value should be well considered and reflected into decision making in land use, forest management and BCI Corridor development.

The scenario analysis shows conservation scenario preserves the value with improvement, while development scenario causes huge invisible loss of benefits in ecosystem services. Therefore, it is essential to apply regulatory and economic instrument in the policy making for providing i) incentives for forest conservation, restoration and watershed protection; ii) disincentives for uncontrolled expansion of rubber and forest conversion on marginal soil and steep slopes.

In order to secure and capture the value of ecosystem services of Xishuangbanna BCI Site, several policy implications need to be considered:

1. Formulate legal framework and BCI management guidelines that includes:

a. Regulations on natural forest protection and restoration of degraded forest areas for maintaining important ecosystem services (i.e. watershed protection, soil erosion control, nutrient cycling, etc.)

b. Zoning the corridor area

i) Core area – reforestation and restricted development to ensure ecosystem connectivity and biodiversity conservation

ii) Buffer zone – sustainable forest management and livelihood activities (i.e. NTFP, fuel wood, agro-forestry, livelihood plantation, etc.)

c. Regulation on rubber plantation expansion and conversion back to agroforestry rubber, also known as "jungle rubber" or rubber-natural forest-mix (geographic location, slope, altitude, etc.)

2. Establish payments for ecosystem services scheme, such as:

a. PES for watershed services

b. A/R CDMs, Payments for REDD - Reduced Emissions from Deforestation and Land Degradation, Carbon credit trading (CER) and carbon offsets (nationally)

c. NTFP: eco-certification and eco-labeling of organically produced goods

d. PES for biodiversity and ecosystem restoration (livelihood interventions/incentives including promotion of agro-forestry and livelihood plantations in return for conservation contracts for maintaining natural forests; public reforestation program and payments, rural greening and promotion of wood based industries (i.e. The National Natural Forest Protection (NNFP) program and the Sloping Lands Reconversion Program (SLP))

e. Transfer payments from eco-tourism / nature based tourism.

5.3 Limitations and the way forward

There are certain limitations of this research. Some of the very important ecosystem services are excluded in the valuation framework, i.e. biodiversity, recreation/tourism, pollination and seed dispersal, social benefits (e.g. poverty reduction, employment), which the total value of ecosystem services may inevitably be undervalued. And it is not yet considered the costs of the negative impacts of rubber and its remaining values of ecosystem services in the valuation framework. It is estimated by the experts from XTBG that each hectare of rubber may incur soil erosion 22.5 ton/yr and loss of underground water 136.5 ton/yr. If certain costs and benefits can be properly estimated, it will be greatly helpful to better understand the trade-offs between rubber plantation and natural forest conservation. Also because of constraints of data availability and accessibility, most of the coefficients and values are taken from existing research findings, consultations and other secondary literature. Furthermore, valuation is based on a local framework without comparing or considering the regional and global level frameworks or values that may be higher.

In future, further research could focus on improving valuation framework wherever data is available and appropriate models can be applied. There is potential for incorporation of GIS data and computer simulation technique into the valuation model and develop a robust model for calculating values at prefecture, county, administrative village and farm levels with high resolution. The valuation methods applied here can be used in other BCI pilot sites (such as in Cambodia, Thailand and Vietnam or expand the valuation to cover the entire Xishuangbanna Prefecture). And a more systematic and programmatic PES mechanism for Xishuangbanna BCI site could be designed.

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Towards and Indicator System for Assessing Ecological Security in a Human Inhabited Protected Area at Korup, Cameroon
针对喀麦隆可鲁普有人居住的保护区生态安全评估的指示系统

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Abstract

A survey of the central region of the Korup national park, Cameroon took place from February to June of 2008. Our objective was to assess and evaluate the ecological security of the human inhabited central region since the creation of the park in 1986. Ecosystem change variables obtained from supervised classification of 1986 and 2000 satellite imageries, socioeconomic and ecological variables from household and the ecosystem surveys respectively, were integrated into an analytical hierarchical process. Our approach is anchored in a broader conception of threats to both human well-being and ecological goods and services. The results show that, while only 1.47% of the regions cover remains unchanged, over 50% decreased barely 14 years after the creation of the park in 1986. Furthermore, while the socio-economic statuses of the villagers remain uncertain, the index of ecological security (IES) of the area has moved from slightly damaged (4.1<IES<6), to moderately damaged (2.1<IES<4). With increasing pressure on the land, however, sustaining livelihoods through agricultural production in the area remains a critical challenge. While community forestry, change of direction in the fight against corruption, increase finance to management of the park to step up monitoring activities, eco-agriculture, capacity building and environmental education could be short term remedies, we also think that involuntary resettlement could be the best option given the ever increasing human population. Our results should contribute to conservation and diversification planning for both biodiversity and ecosystem services; appropriate policy interventions and follow-up steps to improve on the security of similar protected areas inhabited by man.

摘要

2008 年 2 月到 6 月，我们对喀麦隆可鲁普国家公园进行调查和研究，目的是为了评价这个人类居住中心区域自 1986 年建立国家公园以来的生态安全情况。我们分别从 1986 年和 2000 年的遥感图像，社会经济、生态因素的入户调查数据和生态系统调查数据中获取了反映生态系统变化的指数变量进行层次分析，并且同时考虑到了人类系统和生态服务功能的风险。结果表明，自从 1986 年建立国家公园这 14 年以来，这个区域的植被覆盖有 1.47%没有发生变化，超过 50%的

区域植被覆盖几乎没有减少。尽管这个区域的居民的社会经济状态没有详细数据，但是这个区域的生态安全指数（IES）从轻微受损(4.1<IES<6)变化到了中等受损(2.1<IES<4)。区域内人类活动对土地的压力不断增大，但通过农业生产解决温饱问题仍是一个挑战。林业部门加大了对国家公园的投资力度，加快监测系统，农业生态系统，能力建设和环境教育的建立。这些措施可以起到短期弥补生态安全的效果，但是我们认为对于一直增加的人口，非自愿移民是最好的。我们的结果对于考虑生物多样性和生态系统服务的保护区多样化规划和指导当地政策如何适当导向有一定意义，这对以后相似的保护区建设都有一定借鉴意义。

1 Introduction

In the last decades, humans have more than ever been changing the world's ecosystems to meet the growing demands for food, freshwater, timber, fibre, fuel and minerals (Millennium Assessment, 2005). Many forests in the tropics currently face a variety of threats, which include unsustainable harvesting practices, illegal encroachment, poor management, as well as degradation by the dependent communities (United Nations Development Programme [UNDP], 2006). The Living Planet Index report (WWF, 2008) shows that while biodiversity loss has leveled off in some temperate areas, the overall Living Planet Index continues to show a decline. It further noticed that humanity's demand on the Planet's living resources, its Ecological Footprint, now exceeds the planet's regenerative capacity by about 30 per cent. This global overshoot is growing and, as a consequence, ecosystems are being run down and waste is accumulating in the air, land and water. The resulting deforestation, water shortages, declining biodiversity and climate change are putting the well-being and development of all nations at increasing risk. This is indeed a major barrier to the attainment of the United Nations' Millennium Development Goals. In addition, it appears increasingly unlikely that even the modest goal of the Convention on Biological Diversity to reduce by 2010 the rate at which global biodiversity is being lost will be met.

Protecting pristine forests is irrefutably the most effective conservation strategy (Schulze *et al.,* 2004b) but protected areas comprise only 8% of tropical forests and their extension is almost impossible nowadays (Schulze et al., 2004b), while degradation is still ongoing due to many encroachments. Anthropogenic habitats are largely unknown in terms of their contribution to biodiversity conservation (Schulze et al. 2004b; Waltert et al., 2004). They may be important for ecological security and/or integrity which maintain and guarantee sustainable development between human society and Economy, thus avoiding the disadvantages from the decrease of natural resources, and environmental pollution. It is therefore an important base for the entire human security system, the cornerstone for human survival.

The concepts of security are no longer limited to military issues. It has evolved to include natural ecological security, economic ecological security, and social ecological security. The particular points of natural and semi-natural ecosystem security encompass the integrity and health of the ecosystem. Ecological security describes a state that the area, country, and even global ecological environment are not threatened, which may provide ecological guarantee for the sustainable development of whole ecological-economic system.

The assessment of ecological security evolved from the fields of ecological risk analysis (Critto *et al.*, 2007; Fernándeza, 2005) and ecological health theory has progressively matured (Huang, 2007).The study still needs measurable assessment standards and a scientific indicator system. Considerable breakthrough have been made been made in various domains particularly in China: landscape ecological security pattern (Fang *et al*., 2005; Huang and Ge, 2005), nature protected areas (Lin et al., 2006; Wang et al., 2006), and in urban ecosystem (Shi et al., 2005; Wang et al., 2007). Different results and indicator systems can be expected in Africa, since afro-tropical low land rainforests since biophysical characteristics, livelihood opportunities and human socioeconomic statuses, especially agricultural practices might be different leading to different results compare to China and elsewhere.

The purpose of this paper is to develop a preliminary list of indicator system and conduct evaluation of the ecological security in the central zone of Korup National Park, Cameroon using a multi-criteria analyses incorporating remote sensing, socio-economic, ecological and/or floristic data. The knowledge can be used for conservation, diversification, eco-regional monitoring, hence, sustainable resource management.

2 Materials and Methods

2.1 Study area

The study area (1,260 km^2) is located in Ndian Division, southwestern Cameroon, between latitudes 4° 54′ and 5° 28′ north; and longitudes 8° 42′ and 9° 16′ east at the Cameroon-Nigerian border and is contiguous with the Oban National Park-Nigeria. This area was chosen because very little or no research had been carried out there, probably because of its enclave nature. The mean annual rainfall is in excess of 5000mm (Zimmermann, 2000); temperatures range from 22^0C to 34^0C, while relative humidity averages 87% throughout the year. The highest point is Mount Yuhan - a horst, reaching 1130m. Currently, four villages are located inside the Park and 31 other villages are within 3km of the park. There are about 11,500 inhabitants (Schmidt, 2004). Shifting cultivation forms the basis of the farming system. Economic activities include hunting, gathering, processing and marketing of non-timber forest products.

2.2 Data sources and methodology

Ecological security was assessed based on a set of indicators obtained from field survey and literature search from peer and non-peer-reviewed journals and reports. The following conceptual model was adopted for the research (Figure 1).

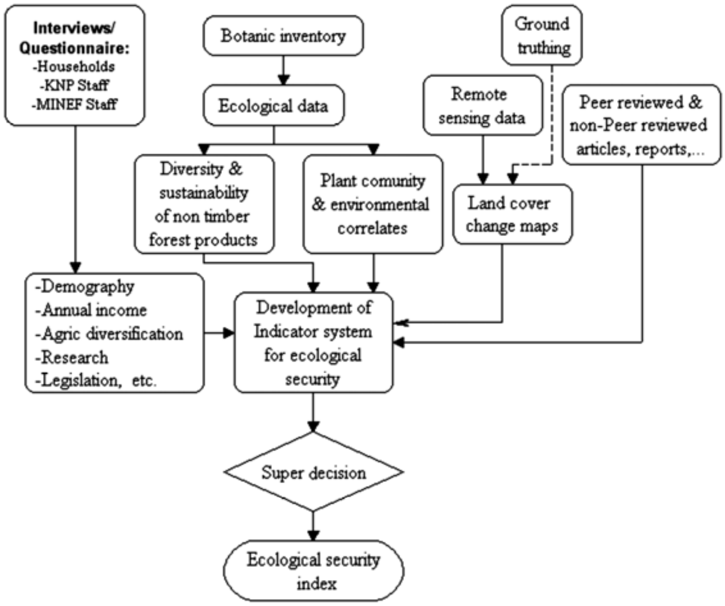

Figure 1 Conceptual framework for assessing and mapping biodiversity, ecosystem services and ecological security

The focus was on land-use changes, trends in crop yields, socioeconomic status of the indigenous people and population trends in the study areas, all factors that local people perceive as having been responsible for the land-use /cover changes, and management effectiveness (finance, staffing, research and so on). It should be noted that, in addition to the household survey**,** all stakeholders concerned with the management of Korup National Park were also surveyed.

2.3 Development of an indicator system

Field work took place from February to June of 2008. Both household surveys and focus group discussions were carried out using open-ended questionnaire. Village chiefs and sub-chiefs were contacted for most of our recall data. Other stakeholders included government and staff of Korup national park.

A sample size of 95 (age: 20-85 years; women: 60; Men: 35; average household size: 4 people), was drawn at random from three villages that make up the central region of the park (20 from *Ekundo-kundo*; 35 from Erat, and 40 from *Ekon1* villages). This paper adopted the probability proportional to the size-a multi-stage sampling methodology (clustering, stratification and simple random sampling).

2.4 Variables measured

The dependent variable used was “Land cover/ecosystem change”. It should be noted that a change in land cover implies a change in ecological security and integrity.

These are associated with land cover change. Freely available orthorectified Landsat-5 TM, for 1986 and Landsat-7 ETM+ May 2000; 187, rows 056-057 (available at Geocover and Landsat websites) were used to detect the state of the nature reserve 14 years after its creation. Both images were obtained in the dry season.

Taking into consideration the biophysical characteristics of the study area, the following independent variables for ecological security were measured:

- Ecological indicators;
- Socioeconomic indicators; and
- Management effectiveness indicators.

2.5 Data analyses

ERDAS IMAGINE 9.2 was used for image processing and database creation; ArcGIS 9.2 for database creation and GIS analysis; and SuperDecision (Saaty 2003) software for analytical hierarchical processing. Satellite images were layer stacked, mosaicked, and subset. A radiometric enhancement technique was used for image enhancement. Our classification scheme adopted four main broad classes: forest; farms and settlements; water bodies; bare/exposed surfaces.

2.6 Framework for determining indicators for assessing ecological security

2.6.1 Framework for determining ecological indicators

Ecological sustainability or the process of development which is compatible with quality and security of food supplies was assessed based on three indicators:

- Soil fertility status,
- Risk and uncertainties(diversification and profitability from economic activities,-farming, collection and sale of non wood forest products etc), and
- Land-cover change.

To arrive at soil fertility indicators, elements associated with soil fertility (organic matter, available phosphorus, pH, nitrogen, cation exchange capacity etc.) were investigated from a total of 100 soil samples collected during a vegetation survey.

Risk and uncertainty in agriculture production was modeled using the Herfinhahl index (HI) and the index of profitability (IP) of economic activities. The index is a function of the area allocated to a particular enterprise (Llewelyn and Williams, 1996). Mathematically,

$$HI = \sum_{i=1}^{n} P_i^2 \ ,0 \le HI \le 1 \qquad (1)$$

where, P_i is the proportion of farm area allocated to a particular enterprise, in this case, the local farmer. HI= 0 denotes perfect diversification, and if 1, perfect specialization.

For economic activities, an index of security (IS) based on profitability of a household enterprise was developed and employed to estimate the risk of uncertainty.

$$IS = \left(1 - \frac{BEP}{Sales}\right) * 100 \ , \qquad (2)$$

where,

$$BEP = \left(\frac{FC}{CMR}\right) \equiv \left(\frac{FC * Sales}{(Sales - \Delta C)}\right), \qquad (3)$$

BEP denotes a break even point,
FC, the fixed costs of production;
CMR, the Contribution Margin, and
ΔC , the variable cost from economic activities.
Costs of inputs were computed on the basis of respective local market price.
All calculations are based on income from each farming season (financial year).

2.6.2 Framework for determining economic indicators

Economic sustainability requires that development be economically feasible. Therefore, economic security was measured based on three indicators: Only three are given.

- Employed members in the family,
- Annual agricultural income and,
- Food sufficiency.

Total production multiplied by the current market price within the study area was used to calculate average household incomes from different sources.

Information of the trend in food yield and employed number of people in the family were obtained using household interviews and questionnaires.

2.6.3 Framework for determining social indicators

Social livelihood security was assessed in terms of the following indicators:

- Access of safe drinking water and sanitation;
- Access to market, health and educational services.

These indicators are relevant both from societal and individual perspectives; for long-term livelihoods security, it is necessary to provide equity in social services to reduce the vulnerability of livelihoods. The information was obtained using questionnaires.

2.6.4 Framework for determining management indicators

A protected area obtains a value for its management, through the sum of all the values of all the management fields, expressed as a percentage of the optimum value. The results were ranked as unsatisfactory, marginally satisfactory, moderately satisfactory, satisfactory, or very satisfactory depending on its score (table 1).

Table 1 Ranking responses from questionnaire

Number	Optimal %	Description
0	<=36	Unsatisfactory
1	36-50	Marginally satisfactory
2	51-75	Moderately satisfactory
3	76-90	Satisfactory
4	91-100	Very satisfactory

Adapted from Ervin, 2003

2.7 Pressure–State–Response (PSR) model

This paper adapted the "Pressure-State-Response (PSR) Framework (OECD, 1993) as the foundation of an indicator system for assessing ecological security (figure 2).

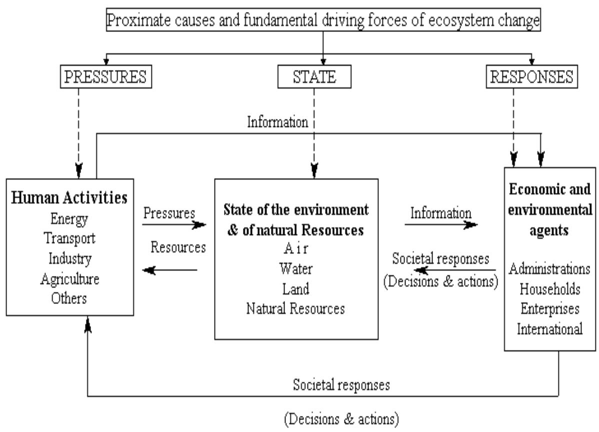

Figure 2 The Pressure-State-Response (PSR) concept model for the regional ecological security assessment

The PSR model shows the causality between pressures on the environment and the resulting environmental degradation. The model's results thus have an obvious and close relationship with sustainable development which is the basis for ecological security.

Mean annual temperature, mean annual humidity, and mean annual precipitation (which represent water and heat conditions), population, trend in crop yield, hunting and collection of non timber forest products (NTFP's), mean annual income of households, (which represent the impact of human activity on the environment) as seven aggregate indices for use in the pressure layer.

The changes in land use and cover type and the statuses of water and soil are the main problems driving changes in most threatened ecological systems and the central KNP in particular. For this reason, I selected the degree of land use; exposed surfaces, unused land, water bodies, status of animals and socioeconomic plant species (or NTFPs) and forested land, bare soil as the representative synthetic indices for the status layer. In order to represent the status of the ecosystem of central KNP, soil fertility was also included in this layer.

Because the integrity of the ecological system depends on how well the system is managed, the indices for the Response layer included: national policy, research technological development and application, Finance to management, development of agricultural diversification techniques such as eco-agriculture, and community involvement in planning and natural resources management.

2.7 Pairwise comparison matrix of criteria/weighting the indices

The SuperDecision (Saaty, 2003) software was used to pairwise compare the different criteria and sub-criteria framework. The analytical hierarchical process (AHP) was used to determine the weights of each indicator. Indicators were compared in pairs for their relative importance with respect to another element to establish priorities for the element being compared. Ratings follow the fundamental 1–9 scale (Saaty, 1997) of AHP (Table 2). The AHP consists of three parts: the hierarchy structure, the matrix of pair-wise comparison ratios and the method for calculating weights. It is a powerful management science tool that has proven useful in various disciplines, e.g. public policy, strategic planning, viability determination, forecasting and project management.

Table 2 Scale used for pairwise comparison

1	Equal
2	Between Equal and Moderate
3	Moderate
4	Between Moderate and Strong
5	Strong
6	Between Strong and Very Strong
7	Very Strong
8	Between Very Strong and Extreme
9	Extreme
	Decimal judgments, such as 3.5, are allowed for fine tuning, and judgments greater than 9 may be entered, though it is suggested that they be avoided.

The procedure then requires that the principal eigenvector of the paired comparison matrix be computed to produce a best fit set of weights. These weights will sum up to one as is required by the weighted linear combination procedure. Since the complete paired comparison matrix contains multiple paths by which the relative importance of criteria can be assessed, it is also possible to determine the degree of consistency that has been used in developing the ratings. Saaty indicates the procedure by which an index of consistency, known as a consistency ratio (CR), can be evaluated. CR indicates the probability that the matrix ratings were randomly generated. For CR>0.1 should be re evaluated (Saaty, 1997).

2.8 Standardizing the different indicator units

Ranking of alternatives is likely to be biased when attributes are measured in different units as is in our case. Hence, a multiple attribute evaluation method (Prato, 1999), which involves maximizing a multiple attribute utility function, is used here:

$$S_{ij} = \frac{x_{ij} - \min_j x_{ij}}{\max_j x_{ij} - \min_j x_{ij}} * 10 \text{; for } x_{ij} \geq \min_j x_{ij}, \quad (2)$$

$$S_{ij} = 1 - \left(\frac{x_{ij} - \min_j x_{ij}}{\max_j x_{ij} - \min_j x_{ij}} * 10 \right); \quad \text{for } x_{ij} \leq \min_j x_{ij} \quad (3)$$

where, x_{ij} is the raw value, and s_{ij} ($0 \leq s_{ij} \leq 1$), is the standardized value of the *j*th attribute for the *i*th alternative. The assumption here is that, the decision-maker is risk neutral.

It follows that, for any layer of security, the total insecurity (or index of eco-security) value, IES can be estimated as:

$$IES_{ij} = \sum_{j=1}^{j=m} w_j s_{ij}; i = 1,2,...,m, \quad (4)$$

where *m* is the number of attributes, and w_j ($0 \leq w_j \leq 1$) is the weight for the *j*th attribute, obtained by using the AHP model. $\sum_{j=1}^{j=m} w_j = 1$.

3 Results

3.1 Land change

Details of percentage changes in land cover as a percentage of land cover types for the spatial scale (1986-2000) are shown (Figure 3).

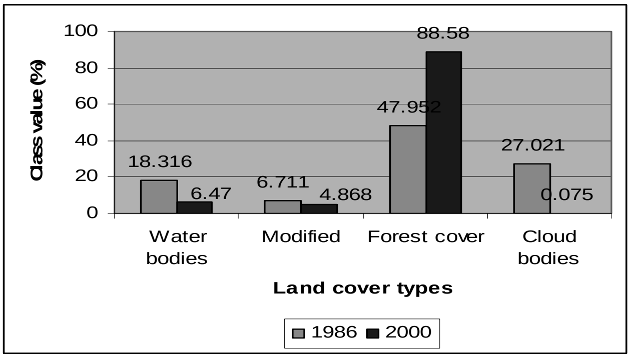

Figure 3 Land cover as percentage of total area

Modifications of land-cover occurred all over the central region. Most significant are the changes in forest, cloud cover, and water bodies.

Remarkable changes are those in cloud cover which decreased to 0.075% in 2000 from 27.021% in 1986 and the water bodies which decreased three-fold (18.316% in 1986 to 6.47% in 2000).

Combined, the changes in land cover (small-scale agriculture, cloud cover, water bodies and exposed land cover) have come at the expense of the ecological system.

3.2 Soil fertility status of central KNP

Soils are generally acidic (3.74<pH<5), sandy (70%-84%), have low levels of nutrients and organic matter (Table 3).

Table 3 Soil properties in the central zone of the Korup National Park

Soil properties	Unit	Range	Mean	Desirable range of % exchangeable cations	Comments
Sand	%	70-84	76.95		Very high
Silt	%	10-30	20.9		Medium
Clay	%	6-21	12.55		Medium
ECEC	meq/100g	3-5	3.706		
Ca	meq/100g	1-4(50-71%)	2.09	65% to 80%*	Normal
Na	meq/100g	0-0.05(1-2%)	0.05	0% to 1%*	Normal
Mg	meq/100g	0-1.5(10-20%)	0.63	10% to 20%*	Normal
K	meq/100g	0-1(19-30%)	1.23	3% to 10%*	Normal
H+AL	meq/100g	0-0.2 (0-5%)	0.14	less than 1%*	Normal
Organic matter	%	1.36-5.2	2.52		Very Low
Organic Carbon	%	1.06-4.0	1.89		Very Low
Available Phosphorus	mg/Kg	2.02-4.48	2.73		Very low
pH	pH-water	4.25-5.01	4.60		Acidic
	pH-Kcl	3.74-4.06	3.90		Very acidic
P(mg/Kg)	%	2-4	2.73		Medium
Saturate bases	%	24-39	31.85		High
Nitrogen	g/kg	0.6-2.38	1.23		Low
C/N ratio		10-32	16.12		Medium

3.3 Agricultural land–use patterns and types

A large part of the population in the Korup region depends on agriculture for their livelihoods. However, crop diversification is limited to the cultivation of Cassava, yams, plantains, bananas. The increase in prices of food crops has motivated households to increase hectares seeded to some crops especially cassava and palm trees (*Elaeis guineensis*).

The identified land-use/ cover types were: cultivated areas, fallow lands (characterized by fire clearing), sparse to dense tree cover, severely eroded areas, and coarse pebbles/sand rivers with outcrops of volcanic rocks in some places. Sand in most cases was still fresh signifying erosion. The sparse to dense, tree cover is defined as areas with more than 40% canopy cover (Lykke, 2000).

3.4 Risk and uncertainty

The average annual incomes were 142,220FCFA and 162,080FCFA for 1986 and 2000 respectively (1CFA Franc BEAC = 0.002270 US Dollar). This corresponds to an index of security 88.75% and 78.29% for 1986 and 2000 respectively. The encouraging indices however, corresponded to adverse impacts on the environment (Figures 4&5).

(a) Conversion of forest to agricultural land (b) Use of fire in forest clearing

Figure 4 Examples of activities threatening the ecological system in central Korup

Exposed surfaces and shrinkage of water bodies, especially during the dry season is a major characteristic of the ecological environment (Fig 5).

(a)

(b)

Figure 5 Shrinkage in river courses (a); more exposed surfaces (b)

Rivers do decrease in volume during the dry season but for a big River like Manna to shrink drastically just a few months away from the rainy season is a problem that is of ecological and environmental concern.

3.5 Socioeconomic threats to the ecological system

Hunting pressure is on-going and has greatly reduced the animal population. Apart from monkeys, it is really difficult to find other species of animals we read and hear about in papers. The villagers also complain of a gradual decline in the quantities of Non Timber Forest Products (NTFPs). The various activities carried out in the area and their contributions to biodiversity loss (ecological integrity) are summarized in table 4.

Table 4 Different economic activities and contributions impacts to ecological integrity in central KNP

Activity	Extent	Impact	Permanence	Degree	Description and rationale for scoring
NTFPs collection	Scattered (2)	Moderate ((2)	Permanent (4)	High (16)	Carried out by villagers in and out of the park. *gnetum africana* , for example, is highly marketable.
Poaching	Scattered (2)	High (3)	Permanent (4)	Severe (24)	Drills, monkeys and lots of other animal species. The meat could be seen in almost all restaurants.
Fuel wood collection	Scattered (2)	High (3)	Long term (3)	High (18)	All households need fuel wood for cooking.
Fires	Localized (1)	Mild (1)	Severe (4)	Mild (4)	Of late, fire is used to clear land for farming
Agriculture	Scattered (2)	Long term (3)	Long term (3)	High (18)	Many young and olds now involve in cocoa, cassava and palm oil plantation as their products now sell at good prices in national and international markets
Road construction	Localized (1)	Mild (1)	Short term (1)	Mild (1)	Only foot paths are available.
Settlement	Widespread (3)	Severe (4)	Long term (3)	Severe (36)	As households and immigration increase.

Note: A separate value was assigned to each quality, and the three values were multiplied to calculate the degree of each pressure or threat. A degree of 1 to 3 was considered mild, 4 to 9 moderate, 12 to 24 high, and 27 to 64 severe

Demographic changes in the central zone of KNP have been fundamental .The average population growth rate, following my field investigation estimates show that it is 2% for *Ekundo-kundo* village, 4.5 % at *Erat* and 2.5% for *Ekon1* village. *Ekon1* and *Erat* villages are very close to neighboring Nigeria-Calabar and its environs, which also provide good markets for non timber forest products, including animal species. Hence, apart from natural growth and positive fertility rates, the population growth in these areas can partly be explained by migration/immigration. This is posing serious threats to the Korup's ecological integrity.

3.6 Socioeconomic indicators

The crop diversification index (The Herfindhal indices for both years were respectively 0.309 or 309 per thousand and 0.306 or306 per thousand) revealed that both communities have significantly low crop diversification in their cropping systems (Table 5).

Table 5 Crop diversification index for 1986 and 1996

		1986			1996	
i	x_i	h_i	h_i^2	x_{1i}	h_{1i}	h_{1i}^2
Cocoyams & Cassava	46	0.469	0.220	71	0.455	0.207
Plantains & Bananas	21	0.214	0.046	39	0.250	0.063
Palms	18	0.184	0.034	26	0.167	0.028
Cocoa	7	0.071	0.005	11	0.071	0.005
Others	6	0.061	0.004	9	0.058	0.003
Total	**98**	1.000	**0.309**	**156**	**1.000**	**0.306**

'Others' here refer to crops occupying less than 0.1ha of farmland. As shown, they make up about 6% of the total cropland.

From the foregoing, and analyses of the questionnaires and interviews a total of 21 indicators (Table 6) were obtained for assessing the ecological security in central KNP.

Table 6 Indicator system for assessing the ecological security in central KNP

Index No.	Index Name	Unit	Data source
1	Population	One person	Village survey
2	Trend in crop yield	%	Village survey
3	Mean annual temperature	°C	Literature/Korup library
4	Mean annual precipitation	mm	Literature/Korup library
5	Hunting & collection of NTFPs	%	Village survey
6	Mean annual earnings	FCFA	Village survey
7	Mean annual humidity	%	Literature/Korup library
8	Soil fertility	%	Field inventory
9	Forest cover	%	Remote sensing
10	Bare/Unused land	%	Remote sensing
11	Water bodies	%	Remote sensing
12	Degree of land use	%	Remote sensing, village survey
13	Degree of cloud cover	%	Remote sensing
14	Wildlife status	%	Village survey
15	Stock of NTFPs	%	Village survey
16	Finance	%	Korup management
17	Research and monitoring	n/a	Korup management
18	Staffing	n/a	Korup management
19	Legal security	n/a	Korup management
20	Capacity building & empowerment	n/a	Village survey, Korup management
21	Eco-agric technics	n/a	Village survey, Korup management

*NTFP's: Non Timber Forest Products.FCFA is the unit of currency in Cameroon.1FCFA≈$470

3.7 Solution SuperDecision

3.7.1 Grouping criteria

The indicators were grouped into three main layers (Goal node, Criteria/objective node, and Sub-criteria/objective/ Index/alternative node) (Figure 6).

The question to be answered is, which of a given pair of criteria is seen as contributing more to overall ecological security of the central zone of KNP and what is the intensity or strength of the difference?

The Index of Ecological Security (IES) for central KNP is the 'goal layer', and is designed to synthesize the state of ecosystem security in the area. The second layer is called 'the criterion layer' (or 'sub-target layer'), and includes the main factors that threaten the ecological security of the area. Pressure used here refers to the proximate causes leading to ecological change. State used here refers to the current status of the ecosystem as obtained from field investigations, while response refers to the reaction or response from environmental and economic agents (the human society).

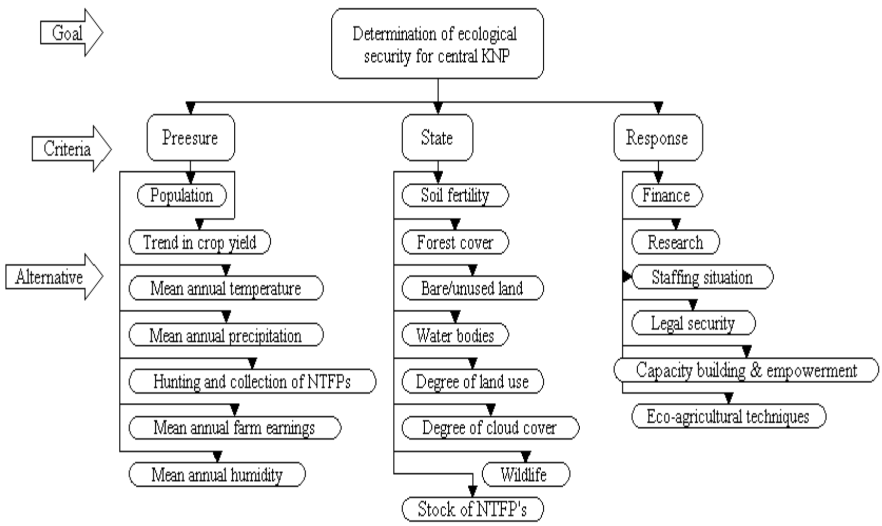

Figure 6 The AHP framework of regional ecological security assessment for central KNP

The third layer is 'the Sub-criteria or index layer', and includes all of the indices that can be measured directly and that serve as the foundation for the ecological security of central KNP.

3.7.2 Pairwise comparison

Tables (7)-(10) show the results of pairwise comparison.

Table 7 Pair wise comparison of sub-objectives of the objective "Pressure related"

Pressure	A1	A2	A3	A4	A5	A6	A7
A1	1	2	2	4	4	9	9
A2	½	1	5	2	2	7	7
A3	½	1/5	1	2	3	3	3
A4	¼	½	2	1	2	3	2
A5	¼	½	1/3	½	1	2	2
A6	1/9	1/7	1/3	1/3	½	1	2
A7	1/9	1/7	1/3	1/2	1/2	1/2	1

Table 8 Pair wise comparison of sub-objectives of the objective "State related"

State	B1	B2	B3	B4	B5	B6	B7	B8
B1	1	3	2	6	4	4	5	5
B2	1/3	1	1/2	4	2	2	3	3
B3	1/2	2	1	5	3	3	4	4
B4	1/6	1/4	1/5	1	1/3	1/3	1/2	1/2
B5	1/4	1/2	1/3	3	1	1	2	2
B6	1/4	1/2	1/3	3	1	1	2	2
B7	1/5	1/3	1/4	2	1/2	1/2	1	1
B8	1/5	1/3	1/4	2	1/2	1/2	1	1

Table 9 Pair wise comparison of sub-objectives of the objective "Response related"

Response	C1	C2	C3	C4	C5	C6
C1	1	2	3	5	7	9
C2	½	1	2	4	6	8
C3	1/3	½	1	2	5	7
C4	1/5	¼	½	1	2	4
C5	1/7	1/6	1/5	1/2	1	2
C6	1/9	1/2	1/7	1/4	1/2	1

Table 10 Pair wise comparison of main Criteria/objectives with respect to the goal

Criteria/Objectives	Pressure	State	Response
Pressure	1	1/8	1/3
State	8	1	4
Response	3	1/4	1

In tables 6, the judgment value pointed out in 3 on the first column – third row, for example, means that Pressure is more important when compared to Response, according to the decision maker. One third (1/3) would mean the reverse and 1 will mean equal importance. The same explanation holds for tables 4 through 5.

3.7.3 Standardization of index

The indices were standardized, and the value of the indices are presented in table 11.

This was done to overcome incompatibilities among the parameters when utilizing the indices.

$$IES_{ij} = \sum_{j=1}^{j=21} w_j s_{ij}; i = 1, 2, \ldots, 21$$.(Following equation 4).

Table 11 The final score for all indices in the two study periods

Index name	Y_86	Y_2000	Normalized By Cluster	IES_86	IES_2000
1 Population	9.882	9.524	0.010	0.096	0.093
2 Trend in crop yield	3.878	1.429	0.015	0.058	0.021
3 Mean annual temperature	9.150	8.434	0.029	0.266	0.245
4 Mean annual precipitation	6.250	7.500	0.040	0.252	0.303
5 Hunting & collection of NTFPs	6.250	7.000	0.069	0.429	0.481
6 Mean annual earnings from farming	4.286	6.154	0.060	0.259	0.372
7 Mean annual temperature	5.000	10.000	0.112	0.561	1.123
16 Finance	3.889	7.600	0.051	0.200	0.390
17 Research	12.500	5.143	0.035	0.432	0.178
18 Staffing situation	2.195	2.776	0.022	0.048	0.060
19 Agric. dev't techs.	4.545	3.311	0.011	0.050	0.036
20 Legal status	140.000	1.000	0.006	0.779	0.006
21 Community involvement	10.588	1.919	0.004	0.041	0.007
8 Soil fertility	40.000	2.778	0.012	0.471	0.033
9 Forest cover	6.364	6.667	0.005	0.033	0.035
10 Bare/unused land	3.846	2.308	0.008	0.031	0.019
11 water bodies	12.857	8.333	0.001	0.016	0.010
12 Degree of land use	3.846	7.436	0.004	0.014	0.026
13 Degree of cloud cover	4.000	1.429	0.003	0.011	0.004
14 Status of wildlife	5.000	4.444	0.002	0.010	0.009
15 Stock of NTFPs	24.000	2.857	0.002	0.050	0.006
SUM				**4.106**	**3.456**

Where Y is the value obtained from equations (2) and/or (3).

That is,
IES= Population*0.096+...+stock of NTFPs*0.05, for the year 1986.
The same procedure holds for the year 2000. All values are multiplied by '10' as a scale factor since they are naturally small.
The results show that IES_86= 4.106 and IES_2000 = 3.456.
Since the scale factor was 10, the results were distributed stochastically as follows over the closed interval [0, 10] as follows (table 12).

Table 12 Criteria for the classification of ecological security in central KNP

Grade	*I*	*II*	III	IV
Range	$0 < U_{ij} < 2$	$2.1 < U_{ij} < 4$	$4.1 < U_{ij} < 6$	$U_{ij} \geq 6.1$
Status	In secured	slightly damaged	relatively safe	Secured/safe

Consequently, these grades let us quantitatively evaluate the status of the area.

Modified surfaces are farmlands, areas formally cultivated, settlements or old settlement sites.

The approximate proportionate share in the ecological status of the area up to the year 2008 as per the indicators developed and used in this thesis is as shown in figure 7.

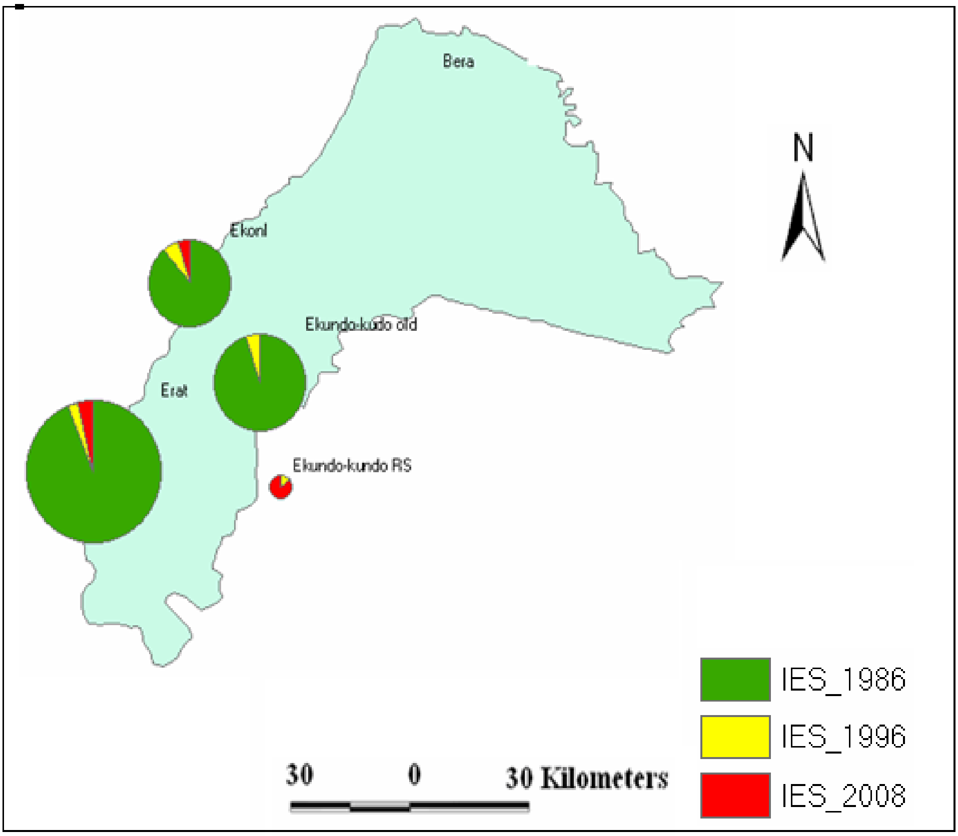

Figure 7 Ecological security map of central KNP

NOTE: The land cover classification used only the available 1986 and 2000 images. From the trend observed and my in-depth field investigations, the current human activities in the park, I came up with projected values for 2008. The results show that Erat and EkonI are threats to the ecological system.

4 Discussion

4.1 General discussion themes of this research paper

Ecological and livelihood security in the central zone of the Korup national park are the results of a variety of ecological, economic, social and changes.

The change in landcover is partly due to a result of successional species from the old site *(Ekun-Kundo)*, following the involuntary resettlements of the early 2000. Also, it might be the result of the recent agriculture of palm and cocoa plantations especially around Erat and Ekon I areas.

Soil is the base material required for the survival of plant ecosystems, and plays an important role in an ecosystem by means of its physical and chemical characteristics and its ability to regulate heat and water balances. The soils in the central region of KNP are generally low in nutrients.

The Analytical Hierarchical Process applied here is essential in making useful decisions for the future management of the KNP. However, since given weights may vary from person to person. Each individual in an organization may respond differently to this selection problem. The weights assigned above were all personal ideas upon the subject, even though they were designated to be as realistic as possible. Now, let's examine two different positions in the Korup region and how they may solve our sample problem.

4.2 Specific discussion perspective

4.2.1 Park managemnt perspective

Assuming that park management focuses on the ecological security of the region, an index of ecological security to be implemented should provide better research directions and monitoring programs. Priority would be given to pressure elements such as hunting and collection of non timber forest products, and how to control anthropogenic pressure on the ecological system. Relatively, the weights he would assign to the criteria would probably as shown in table 7. This falls in line with the results of sensitivity analysis which show that, by reducing the pressure on the system, hunting and collection of non timber products will also be reduced. To attain this goal, management would have to encourage community participation in natural resources management through empowerment and education.

Can resettlement be the best option for management? Some schools of thoughts think this is the best way to save the ecological system. But should the ecological system be protected at the expense of human life? What is needed is a win-win situation, whereby the ecological system together with the services it provides can exist as long as humans live. Of course in some parts of the world, such as in Latin America, 80% of national parks have people living inside their borders (Amend and Amend 1995). In India alone, the number of people living inside protected areas is estimated at 3.5 million to 4 million (Kothari et al. 1995). What the park authorities need to do as a first step is to define the status of these communities more comprehensively as legal residents. The park management then needs to link with these local communities by providing information on policies and environmental problems and by supporting their decision-making institutions and income generation potential

4.2.2 End user perspective–the villagers

What villagers would want from management are alternative sources of income if they must stop hunting and collecting non timber forest products. This is really a difficult situation especially where there are limited finances. According to this school of thought, the least weight would be given to the pressure criterion. However, the situation could be overcome if research geared towards ecologically friendly agriculture and capacity building and if education of the population vis-avis natural resources management and community involvement in natural resources management were encouraged. Alternatively, management may go the hard way, seeking ways of relocating the people.

4.2.3 Damage by humans, lack of management

The population increase that has occurred in this region in recent decades is an important reason for the current ecological problems being experienced in the region. According to statistics obtained from my household survey, the number of households (average size, 4people/house) in the region put together has increased since 1986. This increase is partly due to an increase in birth rates, and immigration. Most of the immigrants come from neighboring Nigeria. This explains why the regions around Erat and Ekon have experienced degradation in land cover over the years. The increase in the population (see study area) significantly decreased the per capita area of farmland. When asked whether there had been any important aspects in the village land use in the last 20 years which had a significant effect on rural livelihood, one of the respondents wrote, "The demarcation of temporal use zone for villages that are found inside the KNP has been a problem. All villages inside the park should be provided access zone for farming and hunting while waiting for resettlement".

The creation of new agricultural land will significantly reduce the area of forestland, let alone the loss of biodiversity and emissions of green house gases. Human behaviors such as building houses from soil, chopping down large quantities of woody vegetation (mostly shrubs) to provide fuel, and so on, have also damaged the environment. The creation of new agricultural land (which can be explained by socioeconomic and biophysical factors determining the marginality of the area) has reduced the area of forestland and wild products. Such activities are the major causes of poverty and environmental degradation in watersheds (Paudyal and Thapa, 2002) and may lead to further social, political and economic problems (Seddon and Adhikari, 2003). The current management of available farmlands (especially the practice of using fire to clear the vegetation) will further impoverish the already nutrient poor soil, thus exposing the people to other risks such as food insecurity and other instabilities we may not know now.

Though indigenes complain of the unavailability of hunting zones, this paper discovered several evidences of hunting pressure during its botanic survey. The most obvious were hunters' gun shots heard in the night and traps. The pressure on non timber forest products is also high. Unfortunately, no domestication or agricultural techniques that allow for the domestication of some of these products exist as of now. Though the lifestyle could be sustainable at the current low population densities in the region, it will be unsustainable in the future and might cause serious environmental degradation. Unfortunately, there has been insufficient investment to permit reconstruction of this environment.

5 Conclusion and Policy Recommendations

Our judgment of ecological security was based on whether human activity damages the ecosystem, and whether the resulting ecosystem threatens the existence and development of humanity. Based on the calculation model described in this paper, while the socio-economic statuses of the villagers remain uncertain, the ecological security of the area has moved from slightly, to moderately damaged in the past decades. Human population growth and activities through hunting, collection of non timber forest product, the use of unsustainable farming systems on already infertile soils, etc., are damaging the ecosystem, thus threatening their own future.

Restraining population increases offers the most basic means of preventing further degradation of the ecological environment of the region. However, because such issues are often sensitive and complex, a compulsory population-control policy cannot be adopted by the government. As a result, the impact of the population explosion upon the ecological environment will only increase in the future. It is therefore imperative for government to establish compensating policies and regulations for constructing and protecting the ecological environment. For example, governments could implement an 'Environmental Protection Act', a 'Land Act', a 'Forestry Act', and other relevant laws or regulations designed to promote the construction and protection of the ecological environment. Moreover, employees, of which the local people should be part, must be hired to enforce these acts and regulations, and offences that damage the ecosystem must be treated seriously. Monitoring stations and police posts especially around the Erat-Ekon I area which are neighbors to Nigeria will be an asset. This will monitor the trade in wild products and reduce pressure on the ecological system.

There is also need for a defined tenure system in the area. The current system which is believed to be in the hands of the government is gradually giving birth to a Res nullis property regime, open access resources and tragedy of the commons (Hardin, 1968), hence, unsustainable management of resources and environmental insecurity. A lack of understanding of the conceptions and operations of property systems in other societies is a frequent cause of conflict, injustice, and exploitation (Netting, 1982).

Furthermore, agroforestry will be uniquely suited to provide ecologically friendly solutions that successfully combine objectives for increased food security and biodiversity conservation gains, especially by promoting greater use of native tree species in agroforestry systems. Women and children, who are the main actors in collection of non timber forest products, hunting and farming, should be the major targets. This process does not end yet and our results may be considered as a first step.

Managing landscapes requires the awareness that human communities can have strong and non-static relationships with ecological processes, from farm to ecosystem scale. Extensive evidence shows that local people's knowledge and experience of natural processes in landscapes offer deep lessons on how to adapt to ecosystem shifts and manage biological diversity (Gadgil *et al.* 1993; Berkes and Folke 2002).The complex nature of these socio-ecological relationships requires a revision of the misconception of a global steady-state, in which the effects of human actions on ecosystems are linear, predictable and controllable.

Managing change in landscapes is an essentially anthropogenic process; it requires flexible and open institutions that allow for dynamic learning and actions through information generation, communication and feedback. It is by mastering such knowledge and information generation and flows that different parts of a landscape can communicate with each other, so to speak. And it is by using such systematic information generation and analyses that we, as we pursue better standards of living, can begin to see how to reduce the system's vulnerability to change, stresses and shocks.

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Analog Forest Eco-System as a Sustainable Land Use for Development of Rural Green Economy; an Experience from South Western Wet Zone of Sri Lanka

作为农村绿色经济发展的可持续土地利用方式的类森林生态系统
——以斯里兰卡西南部湿地为例

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Abstract

Large scale clearing of natural forests for human settlements as well as in the form of tea, rubber and cinnamon plantations is the main reason for forest fragmentation in most natural ecosystems in the wet zone of Sri Lanka. In addition, illegal logging and over-exploitation of natural resources have posed enormous threats to both nature and the humans. These include the loss of biodiversity, heavy erosion, landslides, flash floods, land degradation and increasing poverty of the humans. This paper discusses about the potential to develop the rural green economy as a result of consolidating these agricultural lands into analog forests as a sustainable land use practice in a participatory approach model. Analog forests, as a concept is accepted by agronomists and conservationists, bringing profits on a long-term, sustainable basis. Various interventions have been made in the view of addressing the issues such as; the mobilization of local communities to form CBOs and through them, educational awareness programs were conducted; encouraging local farmers to change into sustainable community based cultivation of timber, lesser known edible fruits, spices and medicinal plants, paying them for the environmental services they render and enhancing their income through green employment. Crop diversification helped to stabilize the economy of the local farmers and minimize the current environmental impact that resulted from mono-crop cultivation. The introduction of new sustainable agricultural activities, such as bee keeping and planting fruits resulted in the production of value added farm products and organic fruits

to be sold in the market. Through environmental based tourism activities such as providing accommodation, eco guidance, food and fruit for tourists, landowners can earn an extra income which trends to the development of the green economy of the country.

摘要

在斯里兰卡湿地当中，人为活动如茶树、橡胶树和桂树种植园的建立，作为一种大规模代替自然森林的方式是大部分自然生态区森林减少的主要原因。此外，树木的非法砍伐和自然资源过度开采给人类和自然带来了巨大的威胁。这些威胁主要包括生物多样性的减少，大量的侵蚀，山体崩塌，山洪暴发，土地退化和人类贫困的增加。该研究旨在通过一种可共享的方法模型，讨论通过合并这些土地为可以持续发展的类森林生态系统发展一种绿色经济的可能性。类森林生态系统，作为一种理念已被农学家和环境保护者接受，能够带来长期且可持续的利益。作出各种干预来解决问题，比如动员当地群众组成社区组织，通过他们实施，鼓励当地农民参加基于养护木材，种植较少知道的可食水果，香料和药用植物等可持续公众团体，支付他们提供的环境服务，并且通过绿色职业增加他们的收入。庄稼的多样化帮助当地农民稳定经济并最小化由于单一耕作制带来的环境影响。引进新的农业活动如养蜂和水果种植将会增加农民的收入并且会增加有机蔬果对市场的供应。通过开发生态旅游业如为旅行者提供住处，生态导游，食物和水果，土地拥有者将会获得额外收入，这些都将都会带动乡村绿色经济的发展。

1 Introduction

Since the alarm of the biodiversity crisis in the 1970s, most conservationists have focused on establishing protected areas to conserve endangered habitats and species. Agricultural production areas have been seen as useless for conservation activities and their growth viewed as a threat (Scherr and Shames 2006). In recent decades, sustainable farmers and researchers around the world have responded to the extractive industrial model with ecology- based approaches variously called eco-agriculture, agro-forestry or analog forest (Earles 2005, Scherr and Shames 2006). All of those, representing thousands of farms, have contributed to our understanding of what sustainable systems are, and each of them shares a vision of “farming with nature,” an agro-ecology that promotes biodiversity, recycles plant nutrients, protects soil from erosion, conserves and protect water. Also non-farmed portions of mainly agricultural landscapes can provide patches of habitat for forest wildlife and form corridors that connect protected areas and allow species to continue genetic contact with populations that would if not be isolated (Scherr and Shames 2006). For example, millions of hectares of multi-strata ‘agro-forests’ in Indonesia produce commercial rubber, fruits, spices and timber. The number of wild plant and animal species in these agro-forests is often nearly as high as in natural forests (Scherr and Shames 2006, Gamage *et al.* 2006; Gamage *et al.* 2007).

Sri Lanka has one of the densest human populations in Asia especially in the wet zone. A burgeoning population, demand for subsistence land and a high proportion of endangered and endemic species within the wet zone of Sri Lanka have resulted in its being declared a critically endangered eco-region; designated as one of the world’s 11 biodiversity ‘hyperhot’ hotspots (Brookes *et al.*, 2002) in requiring extensive conservation investment. However large portion of the wet zone consists of human managed ecosystems such as agricultural systems, plantation forests and human settlements (Pemadasa, 1996; Ashton *et al.,* 1995; Bambaradeniya *et al.*, 2004). Therefore, the importance of such managed ecosystems cannot be overlooked. The habitat quality and subsequently the richness and abundance of naturally occurring species in such managed ecosystems can be improved further through planned management. This will not only help biodiversity conservation but also improve the productivity of these ecosystems through stabilizing natural processes such as nutrient recycling, pollination, soil conservation and control of pest populations.

Vast extents of Sri Lanka's biodiversity rich lands that were transformed into mono-crop plantations during the colonial era are regenerating in many places due to various reasons, both natural and anthropogenic. Bangamukande Estate is an example of an 18 hectares plantation land (tea, rubber and cinnamon) that has been deliberately reclaimed as an analog forest as a direct result of the far sighted, land use policy of Sri Lanka during 1970 - 1977, which introduced crop diversification in uneconomic tea plantations. Bangamukande Estate is situated in Pitigala, Galle, Sri Lanka (06^0 20' 46" N - 080^0 16' 26" E). The land is formed into an undulating terrain that consists of a series of ridges and valleys with an altitudinal range from 100m to 300m. In 1904, the predecessor of the present owner planted agricultural mono-crops such as cinnamon, rubber, and tea. This practice continued to 1973. It was changed in 1973 and 12 hectares of cinnamon and tea land was transferred to analog forest using a government subsidy, under crop diversification of uneconomic tea lands. The remaining rubber field of 6 hectares is presently been allowed to regenerate into forestland while been cropped (Wimalasuriya, 2006).

Analog forest is a tree-dominated ecosystem that is analogous in structure and function to the original climax and sub-climax community. With time, the natural succession of any undisturbed forest community is to increase in diversity and stability until a highly complex ecosystem or Climax State is reached. When an ecosystem is designed to mimic the indigenous Climax State, the efficiency and dynamics of the natural processes can be replicated; such forests are referred to as analog forests. As well to their ecological distinctiveness, analog forests are considered to provide economic benefits. A wide range of supplies can be produced that may include: fruit, nuts, herbs, cut flowers and cut-foliage, pharmaceuticals, timber and bees honey. Therefore, this system helps to develop environmentally friendly income generation which is described as green employment in the rural areas of the country.

This paper discusses about the potential to develop the rural green economy as a result of consolidating these agricultural lands into analog forests as a sustainable land use practice in a participatory approach model.

2 Materials and Methods

2.1 Restoration techniques using in the private lands

Two village divisions (the smallest administrative unit of Sri Lanka, also called GN divisions) named Bangamukande and Liyanagamakande were included to this restoration programme (figure 1 and table 1). The terrain is mostly mountainous and is about 100m - 600m above MSL situated in the south western low land wet zone of Sri Lanka. The average temperature in the area is 27^{o}C, with an annual rainfall of between 3500mm - 4500mm.

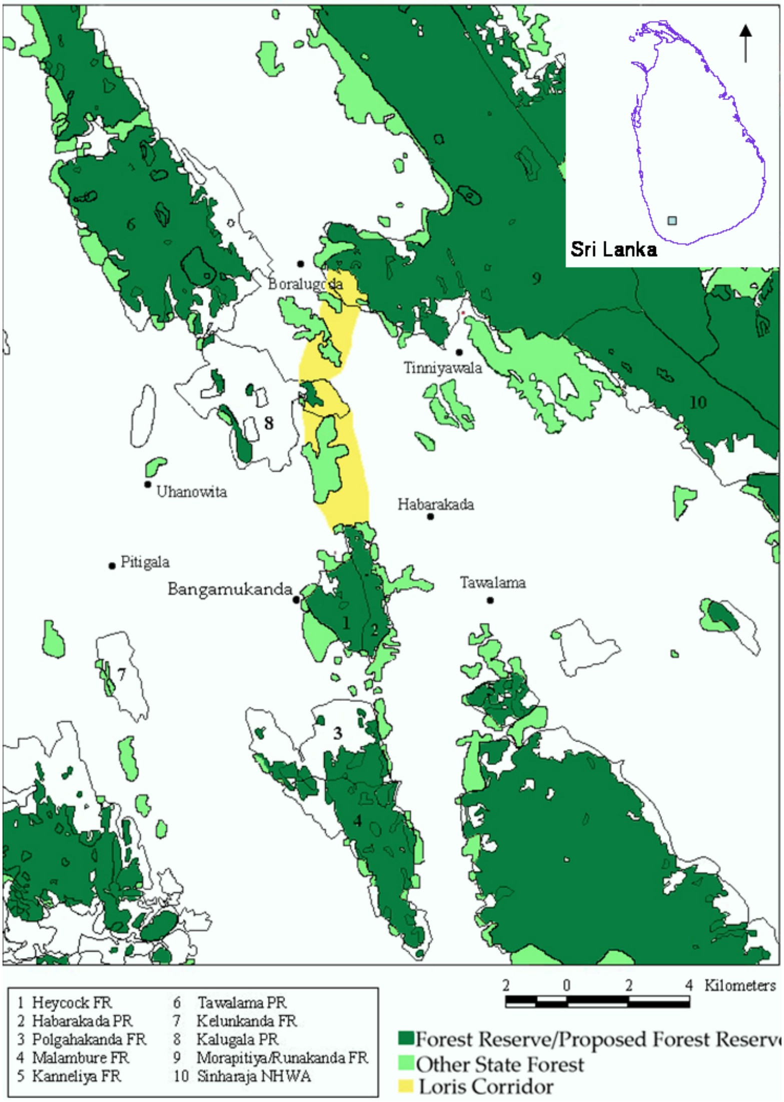

Figure 1 Location of Bangamukande and Liyanagamakande showing the surrounding forsted areas

Table 1 Detailed locality of analog forest establishment including GN divisions

GN Division	GPS location		Height above MSL
Liyanagamakande	080^0 16' 539" E	06^0 19' 862" N	147 m
Bangamukande	080^0 16' 259" E	06^0 20' 455" N	120 m

A total of 100 acre land area which includes 20 acres of home gardens, 50 acres of plantations, 15 acres of state lands, 3 acres of stream reserves, 5 acres of road reserves, 5 acres of land belonging to the temples and 2 acres of school gardens were selected for the project. Several tree planting campaigns were organized with the help of the CBOs. Suitable plants were selected according to the topography of the land, type of the crop and the requirements of the land owners. Timber plants, medicinal plants, fruit plants, food plants, shade plants, bamboo plants for the river-banks and some threatened endemic plants were selected for planting (Appendix 1). Timber plants were also distributed among the villagers of surrounding areas to plant in their home gardens which are located out of the forest corridor. The aim of this action was that the villagers could obtain their future timber requirements from their home gardens, without having encroachment to the forested areas and consequently help to conserve the forest indirectly. While much community based re-forestry projects exist, none of them are designed to address the need of timber for construction and firewood, by the villagers, while concurrently establishing a corridor to move wild animals. The analog forest restoration proposed in this project is both economic and ecological. It provides an alternative income to the participants. It also buffers the primary forests from activities such as logging, and the collecting of medicinal plants and fire wood, since the villagers are able to use the multipurpose analog forest area for these purposes. In this sense, the program is an effort towards habitat enrichment with the view of serving both human and wildlife needs. Over a long term, such an approach would be successful and cost-effective, unlike the attempt at implementing punitive measures, which has failed so far. The programme was started in year 2002 and still continuing.

2.2 Social mobilization

Two CBOs were formed in each GN division and the CBOs based on the village temple and Chief Buddhist monk in the temple acts as the patron. Two awareness programs were conducted in the fields of eco-friendly farming activities and the importance of the conservation of biodiversity in the area to increase their knowledge about analog forestry, biodiversity and its importance. Furthermore, it includeds importance about crop diversification and long term impact from mono-crop cultivation. The participation of the villagers in these two programmes proved to be highly satisfactorily, and the encouragement given to the people to take part in this project was resulted in their active participation in many components of this project.

2.3 Introduction of bee keeping

Bee keeping boxes were distributed among 30 selected villagers who were very keen to participate in this project component. Bee keeping helps to enhance insect pollination, which leads to the protection of plant diversity. In addition, villagers will obtain an extra income from the sale of the bee honey, which is a non-timber forest products.

2.4 Monitoring and evaluation

The progress of the project was monitored by conducting field visits and interviewing people of the area. One socio-economic survey was done at the beginning of the year 2002 when conducting field visits for site selection. Another two surveys were conducted on 2006 and 2008 to gain information on social mobilization of the project.

3 Results

3.1 Increasing forest cover in the area

The analog forest restoration programme was done in the southwestern lowland region of Sri Lanka in two GN divisions belongs to Niyagama Divisional Secretariat administrative division. Two CBO s were established as one in each village based on the village Buddhist temple since the total population of the area are Buddhists. Two environmental awareness programmes were done in these temples and the target group for this awareness programmes were school children, village farmers and house wives who are active in *Dayaka Sabhas* in village temple. The school children were more effective to take the conservation message to the public. They showed their active participation in planting activities in community areas and reservations throughout the project. The female community in the villages joined to the temple *Dayaka Sabha* or Women's society (*Mahila Samithiaya*), were another effective group for awareness activities as they showed their utmost interest in planting fruit and food plants as well as forest plants in their home gardens. Therefore, students and female community should be considered as a target group in priority when planning any conservation activity or awareness programme.A total of 4500 plants belongs to 35 species were planted so far in the forest corridor by this ongoing project, including 10 edible fruit plant species, 16 timber plant species and 10 medicinal plant species (Appendix 1). According to the monitoring results, the plants are growing well since the ecological conditions of the region are favorable to those species. However, the survival rate of the plants was approximately 68% and replanting was also occurred for filling the gaps. Some plants in the selected list for planting activities provide nectar for honey bees. In addition there are many flowering wild plants in the area which bees are using for nectar. The flowering seasons of these plants are overlapping and continue year round; hence the bee keeping could be managed in a sustainable manner. A set of plants which could be selected for this purpose is given in table 2 with their flowering seasons.

Table 2 Plants producing nectar for honey bees showing their flowering calendar

Plant species	January	February	March	April	May	June	July	August	September	October	November	December
Cocos nucifera	■	■	■	■	■	■	■	■	■	■	■	■
Artocarpus heterophyllus	■	■	■	■	■	■	■	■	■	■	■	■
Coscinium penestratum	■	■	■	■	■	■	■	■	■	■	■	■
Schumacheria castanaefolia	■	■	■	■	■	■	■	■	■	■	■	■
Caryota urens	■	■	■	■	■	■	■	■	■	■	■	■
Areca catechu	■	■	■	■	■	■	■	■	■	■	■	■
Fahrenheitia zelanicas	■	■	■	■	■	■	■	■	■	■	■	■
Acronychia pedunculata	■	■	■									
Hevea braziliensis		■	■	■								
Harpullia arborea		■	■	■								
Elaeocarpus serratus		■	■									
Vitex altissima		■	■									
Prunus walkeri		■	■									
Calophyllum trapazifolium		■	■									
Mangifera zaylanica			■	■								
Mesua thwaitesii				■	■							
Mesua ferrea				■	■							
Symplocos cochinchinensis				■	■							
Bridelia retusa				■								
Shorea megistophylla								■				
Dipterocarpus gardneri								■				
Horsfieldia tryghedi										■	■	
Stemonoporus canaliculatus												■

3.2 Social impact of the program

This project helped to stabilize the economy of the local farmers (stake holders) and minimize the current environmental impact that resulted from mono-crop cultivation. Through education and awareness programs, the local community was assisted in accessing science and technology for their everyday life. The project also results in the creation of a passage for the movement of animals from one forest patch to another, which will help to reduce inbreeding depression among animals.

Hunting of many wild animal species is prohibited in Sri Lanka, however it happens illegally. Before the project begins there were 12 hunters in the area and lot of wild animals such as sambur (*Cervus unicolor*), purple faced leaf monkey (*Semnopithecus vetulus*), porcupine (*Hystrix indica*), pangolin (*Manis crassicaudata*), wild boar (*Sus scrofa*) and hare (*Lepus nigricollis*) etc. were faced to threat of illegal hunting. The leopard (*Panthera padus kotiya*) has not been reported in this area for about 30 years as they were isolated in dense forests due to absence of secured path for moving. However as a result of increasing awareness of the people about the importance of biodiversity for sustainable ecosystem, the illegal hunting was reduced about 92%. Also the illegal encroachments of the forested lands were completely stopped as since 2003, there was no any encroachment reported (table 4). Before 2002, the illegal logging of trees was about 176 trees/ year. When it comes to 2006, the felling rate was reduced about 84% and in 2008 it was about 94% (table 4).

Table 4 Summary of information obtained from pre and post socio-economic survey

Socio-economic factor	2002	2006 (Progress %)	2008 (Progress %)
No. of persons engaged in illegal hunting	12	6 (50.00)	1 (91.67)
Illegal encroachments reported (ha/ year)	4.25	0 (100.00)	0 (100.00)
Logging (tress/ year)	176	29 (83.52)	10 (94.32)

3.3 Emerging new paths for green employment

Development and poverty alleviation are very important for any sustainable project. In this project we addressed these issues in a different way. Crop diversification helped stabilize the economy of the local farmers. The introduction of new sustainable agricultural activities, such as bee keeping and planting fruits resulted in the production of value added farm products and organic fruits to be sold in the market. Some stakeholders have made bee keeping boxes following the model of the distributed bee keeping boxes and increased their production of bee honey, could be considered as a multiplier effect of the programme. Through environmental based tourism activities, (providing accommodation, eco guidance, food and fruit for tourists) stakeholders are earning a better extra income. Table 5 shows the development of green employment in the area.

Table 5 The development of green employment in the area

Green employments	2002	2008 (Progress %)
Bee keeping	2	45 (2750.00)
Fruit farmers	1	10 (1000.00)
Medicinal herb collectors	10	15 (150.00)
Toddy tapping	5	12 (240.00)
Ecological research assistants	0	4
Eco tourism	0	10

4 Discussion

Degraded soil conditions, low productivity from cash crops, lack of water retention capacity of the soil are having a direct impact on the local family income. Through analog forest restorations the pattern is to be reversed by increasing the forest cover which will naturally regenerate the area with suitable biodiverse habitats allowing animal passage between these lands to the protected areas. As well to their ecological distinctiveness, analog forests are considered to provide economic benefits. A wide range of supplies can be produced that may include: fruit, nuts, herbs, cut flowers and cut-foliage, pharmaceuticals, timber and bees honey. Furthermore this type of concept can be used to link the fragmented forest patches in the wet zone of Sri Lanka.

5 Conclusion

The planting activities and the increasing of the tree canopy of the area by this project has satisfied the basic component of the Green Village program conducted by the Ministry of Environment and Natural Resources of Sri Lanka and the recommendations of the GAP analysis programme of the protected area management project conducted in Sri Lanka with government participation in 2006. In addition, the project addressed a range of fields such as community mobilization, the changing of farming activities from mono-crop cultivation to crop diversification, the making of strategies for future sustainability of the project by establishing nurseries, the educating of the younger generation on environmental issues and the surveying of the biodiversity in the area. It also addressed the taking of measures on poverty alleviation related programs such as promoting organic crops, bee keeping, and introducing other eco friendly income generators which trend to a sustainable development of the society. Therefore, this project addressed a bulk range of fields that are essential for sustainable development and environment management as well as the development of rural green economy of the country.

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Appendix 1 List of plant species and the amount established in the analog forests

Name of the plant species established	Usage	No. of plants
Rambutan (*Nephelium lappaceum*)	Edible fruit	200
Wal Jambu (*Syzygium aqueum*)	Edible fruit	50
Jambu (*Syzygium malaccensis*)	Edible fruit	100
Goraka (*Garcinia quaesita*)	Fruit/ Spice	50
Mangosteen (*Garcinia mangostana*)	Edible fruit	100
Aligeta-pera (*Persea Americana*)	Edible fruit	100
Del (*Artocarpus altilis*)	Edible fruit	100
Jak fruit (*Artocarpus heterophyllus*)	Edible fruit/Timber	250
Etamba (*Mangifera zeylanica*)	Edible fruit/Timber	50
Coconut (*Cocos nucifera*)	Edible fruit/Timber	100
Nedun (*Pericopsis mooniana*)	Timber	350
Mahogany (*Swietenia macrophylla*)	Timber	600
Bu-hora (*Dipterocarpus hispidus*)	Timber	50
Hora (*Dipterocarpus zeylanicus*)	Timber	50
Eeriya (*Enicosanthum acuminatum*)	Timber	50
Walukeena (*Calophyllum bracteatum*)	Timber	50
Batukeena (*Calophyllum thwaitesii*)	Timber	50
Hedawaka (*Cheatocarpus coriaceus*)	Timber	50
Milla (*Vitex altissima*)	Timber	100
Pihimbiya (*Filicium decipiens*)	Timber	150
Diya-naa (*Mesua thwaitesii*)	Timber	100
Naa (*Mesua ferrea*)	Timber/Medicinal	50
Wenivel (*Coscinium penistratum*)	Medicinal	100
Sudu handun (*Santalum album*)	Medicinal	200
Kekiriwara (*Schumacheria castanaefolia*)	Medicinal	100
Ankenda (*Acronychia pedunculata*)	Medicinal	150
Pinibaru (*Lijndenia capitella*)	Medicinal	50
Ruk (*Horsfieldia iryghedi*)	Medicinal	200
Welipiyanna (*Anisophyllea cinnamomoides*)	Medicinal	50
Keta-kela (*Bridelia retusa*)	Medicinal	100
Kebella (*Aporosa lindleyana*)	Medicinal	50
Walla patta (*Gyrinops walla*)	Handicraft	50
Kitul (*Caryota urens*)	Traeckle/Jaggery/Toddy	100
Puwak (*Areca catechu*)	Medicinal/chewing/Boundary demarcation	200
Bamboo (*Bambusa spp.*)	River bank conservation/ Timber	400
Total plants established		4500

Integrating Climate Adaptation in Resource Management: A Case in the Heihe River Region of Northwest China
将适应气候纳入资源管理体系——中国西北部黑河流域案例研究

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Abstract

In this paper, a case study that promotes the integration of climate change adaptation into sustainable resource development plan with multi-stakeholders participation is introduced. The case study is for the Heihe River region in northwest China. The region includes predominantly arid and semi-arid areas with extremely fragile ecological conditions, few financial resources, poor infrastructure, low levels of education, and restricted access to technology and markets. The region suffers from climate variations and may experience severer impacts of climate change on water resources, food production, and ecosystem health in the future. Moreover, the region's adaptive capacity is lower than that in the coastal region of China. People in the Heihe River region are facing substantial and multiple stresses, including rapidly growing demands for food and water, poverty, land degradation, and other issues that may be amplified by climate change.

Most policy makers and communities across Heihe River region have limited knowledge of the current adverse effects and impacts associated with climate change in water resource management and planning. It is also uncertain whether their water use infrastructure and measures have the capacity to respond quickly and effectively to future climate change. Effects of climate change on water shortage may be so significant that a comprehensive adaptive action or strategy is required, involving the participation and coordination of federal, provincial and local authorities and other stakeholders engaged in water resource planning and management.

Climate change will affect the regional ability to achieve the poverty reduction and sustainable development (SD) objectives. Thus, SD action plans should make climate change adaptation policies an integral part of the regional planning process. The best practices and measures of adaptation policies or options should be implemented to ensure regional or community sustainability.

To achieve this goal, appropriate tools and methods were developed and applied to address climate risks in resource systems and to prioritise adaptation responses. A range of adaptation measures that address various aspects of the water shortage problem were evaluated against a water SD indicator system. These adaptation measures included comprehensive water use planning, pay for water systems, water pricing to limit water consumption, government policies for water recycling, pollution control and water-efficient technology. The study recommended desirable adaptation options to improve water use efficiencies and to enhance regional SD. In the study region, the Ministry of Water Resources introduced the first pilot project to build a water-saving society in Zhangye City. Some adaptation measures were introduced to the region including overall water supply control, water permits, water right certificates, farmer water use association, water pricing adjustment, and better water allocation policy. Results of the pilot project have shown some positive effects in dealing with water shortage problem.

摘要

本文以西北黑河流域为例，介绍了将适应气候变化纳入多方利益相关者参与的可持续资源开发计划。该地区以干旱和半干旱极其脆弱的生态条件为主，资金缺乏，基础设施落后，教育水平低下，限制了市场和技术的发挥作用。今后，该地区继续遭受气候变异和恶劣气候变化对水资源、食品和生态健康的影响，而且，该地区适应能力低于中国沿海地区，黑河人民正面临着日益增长的食品和水需求、贫穷、土地退化等多重压力和可持续发展问题，而且这样情况受气候变化的影响有可能继续恶化。

黑河地区许多政策制订者和群众，还没有深刻认识到气候变化对水资源管理和计划的影响及其副作用。水利用的基础设施和管理是否能够迅速有效的响应未来气候变化仍不确定。气候变化在水短缺上的影响十分显著，我们必须采取综合的适应性行动和策略，包括国际、省际、当地政府部门以及参与水资源计划和管理工作的相关人员的参与与配合。

气候变化将会影响一个地区消除贫困和实现可持续发展目标的能力。因此，可持续发展计划要求我们必须把气候变化适应工作列入该地区发展计划。为保证该工作的顺利进行，我们必须优化管理技术，实现区域或社会的可持续发展。

为了达到这个目的，应当使用合适的方法和手段来描述资源系统的气候风险，区分适应性反应的优先次序。制定了一些列解决水资源短缺问题，同时适应水资源可持续发展体系的相关措施。这些措施包括综合性水利用计划、水付费体制、限制消耗的价格、水循环政策、污染控制和水高效利用技术。该研究对提高水利用效率和促进地区可持续发展提出了建议。在该研究地区，水利部已经在张掖市建立了第一个节水型社会实验基地。提出该地区的一些适应性措施，包括全面的水供应控制、用水执照、水权利证书、农业用水协会、水价格调整和更好的水分配政策。该引领工程已经在解决水资源短缺问题上发挥了出色的作用。

1 Introduction

It is recognized internationally that climate change will affect the regional ability to achieve their sustainable resource management goals. Thus, resource management plans or strategies should make climate change risk information and climate adaptation policies an integral part of the planning process. The best practices and measures of climate adaptation policies should be implemented to ensure rural community and resource sustainability.

There have been a growing number of initiatives and programs underway that address various aspects of water conservation and natural resources degradation problems, such as comprehensive water conservation program, reducing of habitat fragmentation, payment for ecosystem services and maintaining biodiversity. Meanwhile, government established policies to improve ecosystem health. What seems to be missing, however, is an overarching strategy that brings the climate change concern into resource management planning and decision making process. For the most part, the impacts of climate change on natural resource systems have received scant attention from government agencies and others responsible for ecosystem and resource management and planning.

A partial explanation for the limited response to take consideration of climate change adaptation in natural resources management might be the lack of knowledge and information, or awareness of the issue among policy makers and general public. There are very few (if any) completed case studies in China on the integration of climate adaptation and natural resources sustainability. Most policy makers and communities have limited knowledge of the current adverse effects and impacts associated with climate change in ecosystem and resource management. It is also uncertain whether ecosystem conservation infrastructure and measures have the capacity to respond quickly and effectively to future climate risks. Effects of climate change on ecosystem's functions and resilience may be so significant that comprehensive adaptive actions or strategies are required, involving the participation and coordination of national/federal, provincial and local authorities and other stakeholders engaged in natural resources planning and management.

In this respect, a participatory integrated assessment (PIA) framework is presented in this paper to provide an effective means to address how water resource management challenges can be integrated through PIA research with climate change adaptation policy evaluation. The PIA approach includes relevant aspects of sustainable resource management (e.g. rural livelihood, conservation, wildlife, recreation, and ecosystem health), multi-stakeholder participation, environmental science, economic analysis, and multi-criteria decision making policy evaluation. The PIA will mainly address two questions:

- What are the challenges facing resource managers and policy makers at local, regional and national level in addressing issues related to climate variation and change?
- How can we mainstream effective and desirable climate change adaptation actions into resource management strategies, which can be implemented in the immediate and long term to address climate change and natural resource sustainability?

The PIA approach includes a series of research activities required to assess climate risks in resource systems, and to prioritise climate change adaptation options. A range of resource use options that address resource resilience and adaptation concerns can be evaluated against resource sustainable development (SD) indicators.

The PIA approach was applied in a case study to identify desirable adaptation options which could be implemented to improve resource ecosystem sustainability and to enhance rural livelihood in a changing climate. The case study that promoted the integration of climate change adaptation, and sustainable resource management (SRM) actions with multi-stakeholders participation is introduced for illustration purpose. The study region suffers from climate variations and may experience severer impacts of climate change on resource system health, community wellbeing, climate risks, and food security in the future.

2 Need for Linking Climate Change Adaptation and SRM

Natural resources are important in climate regulation and deliver a range of other goods and services of importance to human wellbeing. In addition, diverse ecological systems tend to be more dynamic and resilient to climate change. Failure to halt the losses of ecosystem services and resources functions caused by overexploitation, pollution, invasive species and habitat change, and to manage the impacts of climate change on resources, will therefore have increasingly significant implications for human health and wellbeing, as well as rural livelihoods. The messages provided by IPCC Fourth Assessment Report (4AR) are clear, natural resources, biodiversity and ecosystem resilience are necessary for climate change mitigation, adaptation and human wellbeing (IPCC, 2007).

Climate change is one of the main contributers to ecosystem damage including productivity loss, species distributions shifts, and the changes of species population sizes, the timing of reproduction (Reid et al., 2005). Loss of biodiversity will have a number of direct consequences to human wellbeing.

The significant threats that climate change poses to the achievement of China's MDGs point out the urgent need for China to integrate the adaptation strategy into the new post-2012 climate policy framework. Climate change poses a threat to ecosystem sustainability and natural resource conservation through erratic rainfall patterns and decreasing ecosystem services, contributing to increased poverty. Furthermore, adverse climate change impacts on ecosystems and natural resources, infrastructure, and agricultural productivity may slow doun economic growth and exacerbate poverty.

Since resources resilience, adaptive capacity, and ecosystem's functions are all affected by resource use plans, resource makers can expect the choice of policies for resource development to have implications for climate adaptive capacity. Moreover, resource management and use policies also have potential impacts on the rural communities' livelihood. It is important for resource experts and policy makers to understand the connection between climate adaptation options and resource management strategies.

It is clear that SRM need to take climate change into consideration and incorporate climate change adaptation policies. In the absence of adaptation measures to reduce climate changes risks, drought, flood, and water shortages are expected to increase water ecosystem vulnerability and cause food insecurity and rural well-being loss.

3 Participatory Integrated Assessment (PIA)

Since the economy of most parts of rural China is largely based on natural resources, understanding the impacts of climate change and the effectiveness of alternative adaptation options on rural poor communities' livelihood is critical to regional sustainable development. Decision makers and resource planners need more information about the socio-economic and environmental implications of climate change adaptation for SRM. However, knowledge of the diversity and complexity of the climate change adaptation is inadequately developed, which makes it difficult to select the more effective adaptation practices and options necessary for ensuring higher climate resi-lience and local sustainability.

In China, for example, the water systems have been suffered from many severe environmental and socio-economic stresses (such as drought, flood, and water pollution, water shortage). As a result, China has developed numerous measures and practices in dealing with different types of environmental and socio-economic stresses. These practices and experience are relevant to climate change policy making, and should be take into consideration in order to effectively resolve climate change challenges.

All too often, climate change studies in China are mainly focusing on evaluating the impacts of alternative climate change scenarios on one specific resource sector. Research methods which have been applied in China are frequently based on the conventional scenario driven impact assessment. As such, these methods are often unable to deal with important intersectoral relations which typically represent many interest groups and multiple stakeholders. Any attempt to better integrate the diverse uses of natural resources must therefore adopt methods to incorporate a wide range of objectives, preferences, resource sectors, and intersectoral relations into an integrated assessment (IA) framework (Yin and Cohen, 1994).

Successful integration of resource management, ecosystem conservation and climate change adaptation policies will require new approaches built upon a foundation of better research into the links between the climate change and sustainable resource management. One challenging issue in evaluating natural resource sustainability under climate change conditions is to design the effective climate change policies that can reduce potential damages to resource systems and ecological functions associated with global warming. This will be facilitated by participatory integrated assessment (PIA) and policy evaluation.

4 Background of the Heihe River Case Study

Integrating climate adaptation options into rural sustainable development strategies is a new direction in climate change impact, vulnerability and adaptation research. There are very few real cases available internationally in this new research area.

In this section, an international case study that promote the integration of climate change adaptation and water system sustainable development (SD) actions with multi-stakeholders participation are presented. Based on experience from the case study, the design and implementation of a PIA approach is illustrated with a real world context. The case study is presented briefly given the limit of the space. More detailed information regarding the case can be obtained from references cited.

4.1 Research problem, objectives, and study area

The AS25 project, being carried out in northwest China with financial support from the Global Environmental Facility (GEF), is one of 24 such projects taking place in developing countries around the world under the global project "Assessments of Impacts and Adaptations to Climate Change (AIACC)" (Leary et al., 2007). The purpose of this study was to provide decision-makers with the information needed to reduce resource vulnerability and to improve the adaptive capacity of the region in order to cope with climate change.

The study region is the Heihe River Basin in northwest China and the key sectors included in the research project are: water resources, agriculture, and dryland ecosystem (see Figure 1). Heihe River Basin includes predominantly arid and semi-arid areas in the north and is dominated by mountains in the south. With barriers such as extremely fragile ecological conditions, fewer financial resources, poorer infrastructure, lower levels of education, and lesser access to technology and markets, the region has been suffering from climate variations and may experience severer impacts of climate change on water resources, food production, and ecosystem health. Moreover, the region's adaptive capacity is lower than in the coastal region of China. People in the region are facing substantial and multiple stresses, including rapidly growing demands for food and water, large populations at risk to poverty, degradation of land and water quality, and other issues that may be amplified by climate change.

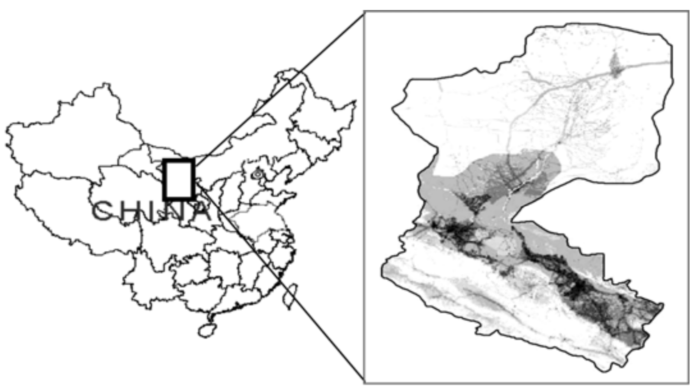

Figure 1 Map of the Heihe River Basin

The project addressed three major questions:
1) How vulnerable is the Heihe River Basin in north-western China to current and future climate stresses in some sensitive sectors?
2) What can the vulnerabilities of these key sectors teach us about future vulnerability? and
3) What are the desirable adaptation options to deal effectively with future climate changes?

4.2 Research activities

The AS25 project examined the extent to which three key sectors in the Heihe River Basin were vulnerable to climate variations and change, and adaptation options desirable to deal with climate vulnerabilities. In particular, the study carried out the following activities:

- Developed a participatory integrated assessment (PIA) approach to identify the societal vulnerabilities to climate change scenarios.
- Applied the PIA in the study region to assess current and future climate vulnerability and risks, and to identify a number of resource sustainability indicators.
- Evaluated a number of adaptation options that could be undertaken to reduce vulnerabilities associated with climate change in the study region.
- Held a series of workshops and policy surveys with participation by a broad range of public and private stakeholders, to identify sustainability indicator priorities, as well as a series of desirable adaptation policies.
- Improved the understanding and knowledge of the interactions between regional sustainability and climate change adaptation.
- Suggested a list of desirable and practical adaptation options and/or plans to effectively handle climate change risks and to ensure sustainable development.

4.3 The PIA approach for the case study

The PIA approach was designed in the case study to provide a research framework for integrating climate change scenarios, socio-economic scenarios, current climate vulnerability identification, resource sustainability indicator specification, adaptation option evaluation, and multi-stakeholder participation. Different computer modeling and non computer-based methods were adopted to form the PIA approach. These included survey, workshops, multi-stakeholder consultation, general circulation models (GCMs) and regional climate model (RCM), ecological simulation modeling, GIS, remote sensing, and multi-criteria decision making (MCDM). The PIA was applied to the case study to examine societal vulnerabilities to climate variations and change, and to evaluate alternative adaptation options for alleviating vulnerabilities in the Heihe River Basin. Figure 2 shows the general approach of the study.

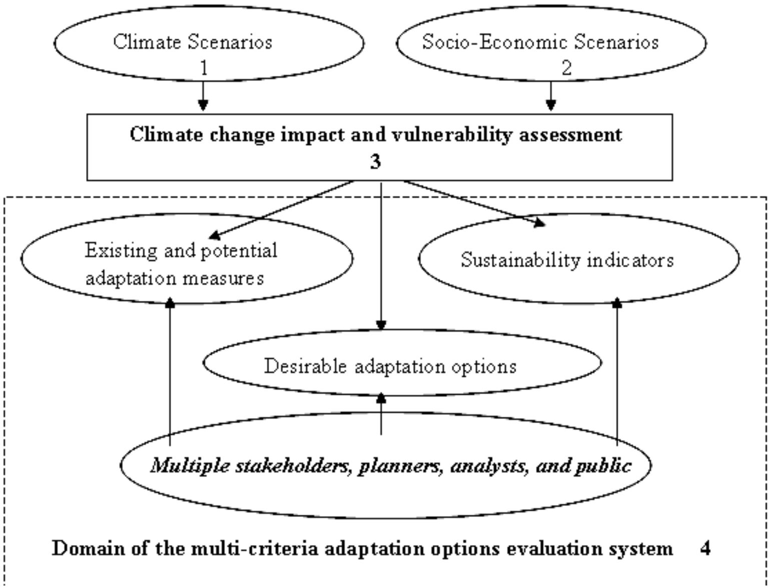

Figure 2 Flow-chart showing the research structure of the project

5 Implementation of the PIA Approach in the Case Study

5.1 Climate change and socio–economic scenarios setting

The climate change scenario setting in 50 years over Western China was conducted by National Climate Center (NCC) of Chinese Meteorological Administration (CMA) using the model simulation results provided by IPCC data distribution center. Climate scenarios for this study focused on temperature and precipitation projection under various IPCC socio-economic scenarios (IS92a and SRES). Meanwhile, the simulation experiments were conducted by using the global atmospheric-oceanic coupled model of China National Climate Center (noted as NCC/IAPT63) under the SRES A2 and B2 scenarios. The global climate model results were also been processed to provide the initial and boundary fields for climate prediction in Northwestern China with a regional climate model (RCM).

Changes in socioeconomic conditions, such as population, income, technology, consumption rates, and China’s new Western Region Development Strategy, were taken into consideration in developing baseline socio-economic scenarios. Various methods were used to set future population increase and economic growth scenarios. Chinese government development strategies and plans were reviewed to collect additional data for socio-economic scenario design. To improve quality of scenarios, workshops and community consultations with multi-stakeholders in the region were held to identify regional concerns related to socio-economic scenarios. Those economic sectors such as agriculture, water, and fragile ecological systems that are sensitive to climate change in the region were included in the study.

5.2 Climate vulnerability and impact assessment

Assessment of current resource system vulnerability and analyses of social, economic, and both negative and positive environmental impacts of alternative climate change scenarios for different economic sectors were undertaken for the three key sectors that are sensitive to climate change. In vulnerability and impact assessment, expert judgement, vulnerability indicators, and various crop models, ecological simulation or statistical models, GIS, developed for other climate impact studies and for studies in Western China were employed to identify impacts of climate change scenarios (Yin and Wang 2004; Yin et al., 2003; Yin et al., 2000; Yin et al., 1999; Kang et al., 1999; and Cheng, 1997).

The vulnerability assessment focused on methodology development for estimating land and water system vulnerability. The study adopted approaches for the formulation of indicators for agricultural land and water resource system vulnerability to climate variation and change. Indicators were selected in relation to their specificity, descriptive power, thresholds, and capacity for geographic allocation using ancillary or modeled data. Each system was addressed individually, with a description of applicable indicators, literature references, and geo-spatial data requirements for the mapping of the indicators.

5.3 Adaptation policy evaluation

One key task of the study is to identify effective adaptation options or policies which would lead to a reduction risks or taking advantage of opportunities associated with climate change. The adaptation policy evaluation in this study was assisted by analytic hierarchy process (AHP), a multi-criteria decision making (MCDM) technique develo-ped by Saaty (1980). The adaptation policy evaluation research started with the sustainability indicator setting. These indicators were used as multi-criteria by which the strengths and weaknesses of the various adaptation options can be evaluated. Then, the AHP was adopted to develop an adaptation evaluation tool to identify the priorities of sustainability indicators, and to rank desirability of adaptation options (Yin, 2001). In policy evaluation, the sustainability indicators were used as criteria against which alternative adaptation options were evaluated to identify more effective or desirable options.

An inventory of existing and possible adaptation options to deal with climate risks was identified for multi-stakeholder consultation and multi-criteria evaluation. Numerous potential adaptation options were available for dealing with vulnerabilities to climate change. An initial screening process was conducted to reduce the number of options for further detailed evaluation.

The AHP application in the case study included a series of workshops and household surveys with participation of a broad range of stakeholders, and policymakers from different affected sectors to identify sustainability indicator priorities, as well as a series of desirable adaptation policies. The AHP facilitated the participation of regional stakeholders in climate change adaptation option evaluation. Results of the AHP analysis are presented in the project final report (Yin, 2006).

The adaptation evaluation results indicated that reform cropping structure was ranked the most desirable adaptation option for the Heihe River Basin. The option of establishing farm water user society also scored fairly high. The moderate performance levels for improve water allocation policies, establish water permits and trade, and increase awareness and education options were due to the fact that these were relatively new measures in water resource management in the study region. The scores for apply water save equipment and technologies and implement water price system options were ranked near the bottom of the list by most participants especially from an economic perspective and were not considered to be desirable adaptation options. It appears that regional stakeholders consider the two options are expensive alternatives for dealing with water shortage and farmers do not want experience higher water prices. Construct water works option was judged to be the most inefficient option from an economic perspective, and it was ranked at the bottom overall among regional respondents.

6 Conclusions

Worked in partnership with local, provincial and national governments and other key stakeholders (water use professionals, farmers, and other organizations), the study identified alternative effective adaptation measures which could become practical options to deal with water vulnerabilities which would likely become more severe in the study region due to the impacts of climate change. A properly developed and implemented adaptation action plan consisting of various effective measures could have positive benefits to the well-being and productivity for people living in the region.

Findings from the AS25 study have indicted the potential effects of climate change on water resources (Yin et al., 2007a), the vulnerability of water users and options for adapting to the changes. The case has identified adaptation measures considered by stakeholders to be potentially effective for reducing vulnerability of water users by increasing economic efficiency of water use, improving environmental quality, promoting equality and reducing water costs. Through public consultation activities, stakeholders' understanding of adaptation options and their possible effects was greatly enhanced. The increased awareness among local officials will facilitate the successful implementation of alternative adaptation policies (Yin et al., 2007b).

These effective adaptation measures can help reduce water resource risks and water use conflicts. Since water is the key determinant which influences all the economic activities and livelihood of the region, a reduction in water resource vulnerability will mitigate the impacts of climate change on agricultural sector and protect the livelihood of farmers. Water system sustainability can also improve ecosystem health and reduce sandstorms which have created a global environmental impact. The study has generated the information for decision-makers to improve the adaptive capacity of water system to cope with climate risks in Heihe River Basin.

As a reasonable follow up, a pilot adaptation action project should be carried out in selected rural communities across the study region to reduce climate risks and rural poverty, and thus to improve livelihood in poor regions. Building on the AS25 project results, experience, partnership and networks, the pilot action project can strengthen efforts to establish and maintain a skilled body of expertise in the Heihe River Basin to support efforts to implement desirable climate adaptation options to cope with climate variation and change. The follow up study will be able to provide decision-makers with the information needed to improve the adaptive capacity of water resource system to cope with climate change in Heihe River Basin of north-western China. The follow up study will implement effective adaptation measures in the region to enhance regional sustainability.

Acknowledgement

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Vegetable Intercropping in the North China Plain – Traditional System with Future Potential
华北平原的蔬菜间作
——传统制度和未来潜力

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Abstract

Highly intensive agricultural practices during the last decades led to a dramatic degradation of arable land in the North China Plain, severely endangering sustainability. In recent years a steady shift from cereal production systems into vegetable production systems can be observed, which aggravates environmental degradation. Intercropping is a traditional production system in the region, which can use environmental resources more efficiently. A qualitative inquiry was conducted, interviewing researchers, extensionists and farmers on occurrence, methods, chances and constraints of vegetable intercropping. A huge variety of vegetable intercropping systems was found. Often vegetables are intercropped with maize, e.g. chili, cauliflower and celery. Relay intercropping is practiced with onion and cotton and also pure intercropping like spinach-garlic systems occur. If these intercropping systems should provide a sustainable option for the future new systems that can be mechanized have to be developed. Additionally intensification of communication between science, policy-makers and extension service is essential for the promotion of sustainable agricultural production systems in the region.

摘要

过去几十年中高度集约耕种导致华北平原可耕地急剧退化，这严重威胁着当地的可持续性。近年来，当地正从谷类生产系统持续转化为蔬菜生产系统，这更加重了环境退化。间作是这一地区的传统耕作方法，它能够更有效的利用环境资源。本文采取的定性调查，就产地，方法，风险和蔬菜间作的局限性访问了研究者，推广者和农民， 发现了一个巨大的种类繁多的蔬菜间作系统。像红辣椒，花椰菜和芹菜等蔬菜通常与玉米间作。交替的间作系统种植洋葱和棉花，也

有纯粹的间作系统，比如菠菜和大蒜间作。如果这些间作系统要为将来提供可持续发展的空间，就必须开发一种新系统。同时，加强科学，决策者和推广服务之间的沟通对促进这一地区的可持续农业生产制度是至关重要的。

1 Introduction

The North China Plain being East Asia's largest alluvial plain is of high importance to food security in China, accounting to one fifth of China's total food production. To feed the ever increasing population, food security and along with it increasing yields were the key issue for the Chinese agricultural policy in the last decades. Due to the abolishment of the grain procurement quota and a change in food habits a steady shift from cereal production systems into vegetable production systems can be observed in the last years. The production of vegetables increased from 59 million tons in 1991 to 147 million tons in 2007 (FAOSTAT, 2008). As most vegetables have much higher water and nutrient requirements environmental degradation caused by vegetable production is many times over that of cereal production systems. To counteract depleting water and land resources, more sustainable ways of production have to be found.

Intercropping, the simultaneous cultivation of two or more crops on the same field is a traditional system in the North China Plain. Intercropping can use environmental resources more efficiently, weed and pest pressure are lowered and the risk of crop failure is reduced (Altieri, 1994; Liebmann & Davis, 2000). Intercropping can lead to higher yields (Innis, 1994) and at the same time environmental degradation can be minimized by controlling erosion and leaching of nutrients (Whitmore & Schroeder, 2007). Intercropping of vegetables is a promising tool, which provides farmers with high incomes and at the same time saves natural resources.

2 Material and Methods

Due to the lack of literature and data, a qualitative inquiry was conducted to create an overview of existing vegetable intercropping systems in the North China Plain. Researchers, extensionists and farmers were interviewed on occurrence, methods, chances and constraints of vegetable intercropping. Semi-structured in depth interviews, as described by Berg (2005) were used to examine where the ideas for the systems are generated, and how the dissemination is taking place. As the goal of the study was to obtain the greatest possible information from the cases in the sample, the snowball sampling was applied. The survey was conducted from October 2007 to April 2008 by the first author and previously trained interpreters. Finally, more than 60 hours of recorded interviews and written down interview reports were analyzed.

3 Results

A huge variety of intercropping systems are practiced in the North China Plain. In general, two kinds of intercropping occur, intended intercropping and unconscious strip intercropping. In the first case, farmers plant two or more types of crops in the same field intentionally, being aware of certain benefits of intercropping. The case of unconscious strip intercropping happens due to the small plot sizes. Farmers in the NCP generally cultivate about five plots of some 0.5 ha in total. Thus it often occurs that farmers grow different crops in neighboring fields. The crops of the neighboring plots influence each other above and below ground, especially in the rows near to the neighboring crop and can be considered as intercropping. In Figure 1 two examples of unconscious strip intercropping are given.

Figure 1 Unconscious strip intercropping of cotton with maize and garlic with wheat

Depending on the region, different intended systems are prevailing. In Botou county, Hebei province, farmers intercrop chili with maize, and sell the dried chili for export to Japan and Korea. Chili is planted beginning of April and harvested end of October. Maize is sown at the beginning of May and harvested at the end of August. Four and a half tons of dried chili and five tons of maize cobs are achieved. Farmers reported that in the chili monocropping systems disease and pest problem is very serious and that the quality of the final product hardly meets the quality standards. However, the chili of the intercropping system produces a much better quality even without any pesticide application. Farmers in the region intend to increase the area of chili-maize intercropping in the future. The two cropping systems are displayed in Figure 2 and a comparison of mono- and intercropped chili fruit can be seen in Figure 3.

Figure 2 Inter- and monocropping of chili in Botou county, Hebei province

Figure 3 Fruits of intercropped (left) and monocropped (right) chili

In Feixiang county relay intercropping of onion and cotton is a popular system (Fig.5). Onion is planted middle of October and grown over winter. Middle of April, one month before the harvest of onion, two rows of cotton are sown in between. In the system eight tons of onions and four to five tons of seed cotton are harvested. In other areas of the North China Plain pure vegetable intercropping systems like spinach-garlic and fruit intercropping systems like strawberry-water melon exist.

Figure 4 Onion-cotton relay intercropping before (left) and after harvest of onion (right)

When looking at the reasons for farmers to practice intercropping reduced pest pressure and making full use of limited land are the main factors. Environmental benefits of intercropping had in no case been a reason for farmers to practice intercropping. On the other side farmers report that intercropping is often not convenient and one has to invest more time and labor. This also seems the main reason for the fact that intercropping is more widely practiced in rural compared to sub-urban areas, where off-farm income possibilities make farmers spend less time on their fields.

The intercropping systems are in most cases developed by the farmers themselves, or their ancestors, and are later adapted by farmers inside the village and in neighbouring villages. Some systems, which proved to be successful are also picked up by the local and regional state extension service and are disseminated among farmers. Transfer of the systems to other extension stations inside and outside the province was also reported. Due to its interesting features, agricultural researchers also recognize certain intercropping systems practiced by farmers. However, after being examined by researchers, improved systems are not redistributed to extensionists and farmers. Extensionists claim that "researchers don't know about farmers' problems" and that "they keep the results in their labs". On the contrary researchers state that most extension technicians lack of agricultural knowledge and "should be re-educated".

4 Conclusions

Due to various reasons farmers practice vegetable intercropping in the North China Plain. Highly elaborate systems developed and are still optimized by extensionists and researchers. However, for a successful future and a further dissemination of this sustainable system strong efforts are necessary. Systems which produce higher yields compared to monocropping are apart from governmental incentives the only convincing factor for farmers to practice intercropping. The rapidly increasing use of agricultural machinery puts strong pressure on adapting the common systems and developing new systems which can easily be mechanized. Therefore communication between researchers, extensionists and farmers has to be improved. Listening and understanding farmers' needs will be a key issue for China's agricultural development and the future of intercropping systems in particular.

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Pesticides in China and its Sustainable Use –Review
中国的杀虫剂及其可持续利用——综述

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Abstract

China is the world's biggest user, producer, and exporter of pesticides. Pesticides are biologically active substances that are directly released to the environment during the use phase of their life cycle. This article attempts to review the usage of nine pesticides included in the 12 Stockholm Conventions persistent. The high body loading of DDT in Chinese populations is also related to the high dietary intake due to contamination of food organic pollutants (POPs) in China. China has become one of the pesticide production centers in the world. It is also a large pesticide consumption country. Amount of pesticide technical consumption in China reached 517,762 tones in 2007, with CAGR 16.30% from 2003-2007. Acute pesticide poisoning is still a major public health problem in china. An estimated half million people are poisoned by pesticides each year, 500 of whom die. The current trends in pesticide development in China. On the basis of the environmental risk assessment, 10 pesticides which the amount of application is large, the toxicity is high, the environmental pollution is serious, were considered as the first priority monitoring pesticides in China.

摘要

中国是世界上最大的杀虫剂使用、生产和出口国。杀虫剂是在其使用周期中直接释放到环境中的生物性活性物质。本文试图回顾 9 种杀虫剂的使用历程，它们都在 12 次的斯德哥尔摩会议中持续提及。在中国由于有机污染物（POPs）对食物的污染，高度的饮食摄入量导致人群中 DDT 在人体的高度富集。中国已经成为世界杀虫剂生产中心之一，同时也是世界上最大的杀虫剂消费国。中国杀虫剂的工艺消费在 2007 年达到了 517，762 吨，2003~2007 年的 CAGR 为 16.30%。在中国农药的急慢性中毒仍然是一个主要的公共健康难题。据估计每年有 50 万人农药中毒，其中约 500 人死亡，中国当代杀虫剂的发展趋势。基于环境风险评价，10 种用量大、毒性高、环境污染严重的杀虫剂要考虑在中国优先加以监控。

1 Introduction

Pesticides are one of the major organic contaminants in the environment because of its heavy use in agriculture and industry. Soils play an important role in the environment by controlling the fate and availability of organic compounds because of their sorption capability (Chiou 1998, Gunasekara 2003). Major organochlorine pesticides (OCP) were extensively produced and used in agriculture and vector control in China between 1953 and *1993. Agricultural* application has been banned for agricultural use since the early 1980s for technical HCHs and early 1990s for DDTs and lindane (Chen,1990). Residuals of these pesticides in various environmental media have declined considerably but large amounts still remain in the environment due to high persistency, possible illegal use, or occurrence of DDTs as an impurity in widely applied dicofol (active ingredient: 4-chloro-a-(4-chlorophenyl)- a-(trichloromethyl)benzene-methanol) (Chen et al., 2005; Wu et al., 2005). Investigations showed that PAH concentrations in the water, sediment, and atmosphere can be very high in the Pearl River Delta, Southern China (Qi et al., 2001; Mai et al., 2001, 2002, 2003; Bi et al., 2003; Luo et al., 2004).The total production of technical HCH (4.9 million tons) and DDT (0.4 million tons) in China, respectively, accounted for 33% and 20% of the global output (Hua and Shan, 1996). Being a large agricultural country, China has been a major producer and consumer of POP pesticides. Their persistence has left residual amounts in the soil in many areas (Zhao Ling and Ma Yongjun, 2001; Gong and Gao, 2003; Ma et al., 2003). At present, the use of DDT is still allowed to control mosquitoes, particularly in the malarial transmission zones in China. Accordingly, China still produces a small amount of DDT and China is also allowed to export DDT to other countries for the same purpose, based on Prior Informed Consent (PIC) procedures established under the UNEP (2002). In addition to these original sources of DDT, the use of Dicofol, which contains DDT as impurities, is still allowed. Therefore, existing sources of diffuse contamination should be eliminated as much as feasible and should be addressed by public policy.

In implementing the Convention, Governments will take measures to minimize and eliminate the production, import, export, disposal and use of POPs in order to reduce the release of POPs into the environment (UNEP-Chemicals, 2004). Of the twelve Stockholm Convention persistent organic pollutants (POPs), nine are organochlorine pesticides: aldrin, toxaphene, DDT, chlordane, dieldrin, endrin, heptachlor, mirex and hexachlorobenzene (which is also classified as an industrial chemical). These pesticides have been extensively used worldwide after World War II for crop protection and disease vector control, with considerable success. However, like other POPs, these pesticides are organic compounds that, to a varying degree, resist photolytic, biological and chemical degradation making them remain intact in the environment for long periods, and becoming widely distributed geographically. The negative impact of these pesticides on agro-ecosystems, as well as on the environment and human health has become increasingly evident since the 1950s.

The rapid industrialization during the last century, the increasing number and volume of chemicals produced in this century and the growing global market for chemicals in the recent decades have dramatically accelerated the range of chemicals and types of exposure experienced by individuals and populations. There are over 6 million chemical substances commercially available. China is a big consumer and producer of chemical products. Currently, more than 45,000 chemical products are enrolled in China. Given the increase in the production and use of chemicals, it is therefore not surprising that the potential for inadvertent chemical exposure has increased, giving rise to a greater risk to human health and the environment. The consumption of pesticides has increased during the last few years. There are 771 pesticide products on the approved list in China. More than one million tonnes of finished pesticide products are spread on agricultural land. Herbicides account for nearly 56% of the total pesticides. Most of these are of high toxicity. According to the estimation of experts the ratio of under-reporting of acute occupational diseases is about 70–80%.Therefore this paper is aimed to review the pesticides, specially POPs (persistent organic pollutants) distribution in china and its acute health poisoning to the Chinese peoples. To achieve a more sustainable use of pesticides by reducing risks and impacts of pesticide use on human health and the environment.

2 Usage of Pesticides Specially POPs in China

Among the nine Persistent organic pollutants (POPs) pesticides, six (DDT, toxaphene, HCB, chlordane, heptachlor and mirex) were produced on an industrial scale and three (aldrin, dieldrin and endrin) were produced on a small scale for research purposes and considered essentially not used (APCI, 2002) (Table 1). China produced 24,000 tonnes of toxaphene from 1964 to 1980. There has been no usage and no stockpiling of toxaphene in China after toxaphene was banned from all purposes in 1987. HCB has not been used as a pesticide in China, but as an intermediate for the production of other chlorinated substances such as Na-PCP. Of the pesticides produced on a commercial scale, four are still being produced in China, which includes DDT, HCB, chlordane and mirex. China has requested for specific exemption of these four pesticides under the Stockholm Convention. Chlordane had been used in China as an agricultural pesticide, but that usage was no longer permitted in 1999. It is being produced and used locally as a termiticide in structures such as buildings and dams. Mirex has also been registered for exemption under the Stockholm Convention for local production and use as a termiticide (Wong et al., 2002a; GEF Project Brief, 2005). Being one of the largest agricultural production country, China has been a major producer and consumer of pesticides, until its ban on production and agricultural use were enforced in 1983. China had been a significant producer and user of DDT since the 1950s. During its 30 years of production, 0.4 million tones of DDT were produced, accounting for 20% of the total world production (Hua and Shan, 1996; Fu et al., 2003). The total quantity of DDT used was estimated to be 43,520 tonnes from 1960 to 1983, with large scale usage in agricultural practices (Nakata et al., 2002; Fu et al., 2003; Jaga and Dharmani, 2003). The highest consumption of DDT was in 1970s close to 1.9 thousand tonnes, while there is officially no DDT consumption as insecticides until 1990 (Hua and Shan, 1996). Even after the ban of technical DDT in 1983, its production continued in the production of dicofol, which contains 3–7% DDT as impurities (Qiu et al., 2004). Up to 300 million ha of farmlands and forests received pesticide applications for disease, insect, and weed control. According to spot checks, the consumption of pesticides rose rapidly from 4.65 kg ha-1 in 1985 up to 15.9 kg ha-1 in 1991, an annual rate of increase of 41.8% (Xu et al., 2003). The Pearl River Delta, one of the most prosperous regions in China, has a record of the highest pesticide application in the country. The average annual application from 1980 to 1995 reached 37.2 kg ha-1, four times higher than China's average annual application (Huang, 2000).

Table 1 Data on usage, ban and exemtion from Stockholm Convention of POP pesticides in china and Hong Kong (Wong et al.,2002a; GEF Project Brief, 2005; UNEP,2005)

POPs pesticides	**China**				**Hong Kong Ban of usage**
	Starting of usage	Ban of usage	Production quantity (tones/year)	Request for Specific exemption	
Aldrin	Not used	1983 (2)	None		1988 (2)
Chlordane	1945	1999	160 (1998) 500[a]	Produced and used locally as a termiticide (building and dams)	1991 (2)
DDT	1950s	1983 (1)	4000-6000 3000-4000[a]	Use for control of mosquito and export to countries needed, based on prior informed consent proce-dures (PIC)	1988 (2)
Dieldrin	Not used	1983 (2)	None		1988 (2)
Endrin	Not used		None	Produced and used locally as a intermediate	Not registered
Heptachlor	1948	1982	1 (1969)	in the production of other chlorinated substances	Not registered
Hexachloro-benzene (HCB)	1945	No information	1000-10000 3000-4000[a]	Produced and used locally as a termiticide	Not registered
Mirex	1958	Banned as pesticide 1982(2)	10-30[a]	with limited produ-ction and some local use	1997 (2)
Toxaphene	1948		3000 (maximum Quantity in 1970s)		1984 (2)

Note: banned from agriculture (1); banned from all purposes (2).
[a] UNEP (2005).

Besides its use as pesticide, DDT has played an important role in disease vector control. For the prevention of the spreading of malaria in China, the country has a small amount of DDT stored and readily available. At the same time, if other countries need to prevent the occurrence of the disease or upon emergency situations, China can export DDT to them, based on prior informed consent (PIC) procedures. In Hong Kong Special-Administrative Region (SAR), DDT was banned from use on 31 December 1987, and currently can be traded only under permit (Wong et al., 2002a). From 1979 to 1982, however, between 5032 and 5380 kg of DDT pesticide were imported into Hong Kong annually. Furthermore, there was a net gain of 736 tonnes of DDT between 1986 and 1988 in Hong Kong (Ip, 1990). DDT, HCH, toxaphene, HCB, chlordane, heptachlor, and mirex were produced in China. Historically, there were about 60 POP pesticide-producing enterprises located in 18 provinces in China. The accumulated output of DDT, toxaphene, and HCB were 459,000, 20,660, and 79,278 MT, respectively, while the accumulated output of HCH was 141,366 MT during 1990-2003. In the 1980s, China set up the legal framework for controlling organochlorine pesticides, and the production and use of organochlorine pesticides for agriculture were banned. Presently, DDT and HCH can still be detected in air, water, sediment, field soil, grains, vegetables, fruits, meat, animals and human tissue in many areas. Suggest that government of china should keep the view about the pesticides problems and find the alternative ways to make sustainable environment. Pesticides were destroying the ecosystem and it brings the climate change issue in china.

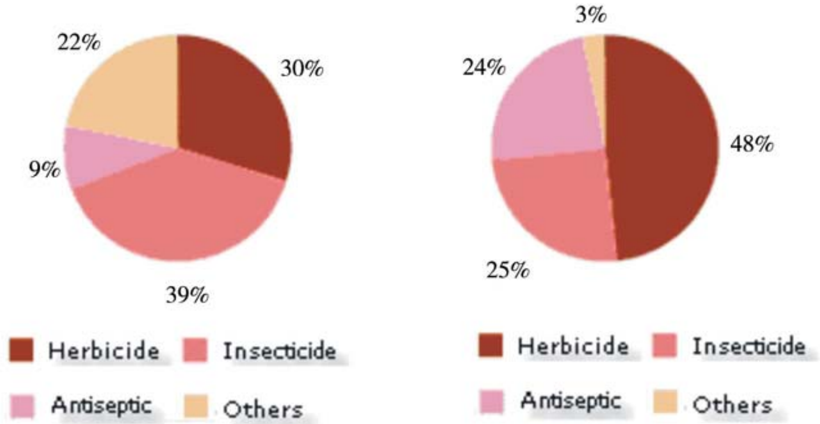

Figure 1 China pesticide product structure (Left) & global pesticide consumption structure (right)
Source: Research china 2007-2008

The total amount of pesticides demand in 2008 was 298,200 tons nearly same as 2007. The pesticide varieties with more than 10,000 tons demand amount all over China will include dichlorvos, acetochlor, copper sulfate, glyphosate, trichlorfon, disosultap etc, 5,000 to 10,000 tons varieties include phoxim, carbendazim, monosultap, butachlor, atrazine, omethoate, triophanate-methyl, chlorpyrifos, 2,4-D butyl ester, dimethoate, acephate etc. In addition, the provinces with more than 20,000 tons of pesticide demand amount are Heilongjiang and Hunan, and the following provinces are ranging from 10,000 tons and 20,000 tons, like Guangdong, Yunan, Shandong, Henan, Anhui, Hubei, Hebei, Jiangsu, Liaoning, Guangxi, Fujian, Jiangxi, and Zhejiang

3 Background Information on DDT

During World War II, DDT was used excessively to control insects that carry such diseases as malaria, dengue fever and typhus. Post World War II, DDT was widely used on a variety of agricultural crops (NRDC, 2001; Whylie et al., 2003). This insecticide has been commonly applied in the developing countries of Asia and Africa because of its low cost and versatility against various pests (Kannan et al., 1997; Konishi et al., 2001). In the 1960s, it was noticed that DDTs pervaded the environment in all forms of life; humans, plants, animals, and in water, air, and soil. DDT is known to damage wildlife by causing the thinning of eggshells of bald eagles in the USA, and reproductive failure in the other bird species (Wong et al., 2002a; Jaga and Dharmani, 2003). Since the 1970s, many countries have banned or restricted the use of DDT (NRDC, 2001). This pesticide is listed in Annex B of the POP Convention, meaning that this chemical whether it is produced or used, should be subjected to restriction (Whylie et al., 2003). However, DDT for control of disease vectors is exempt from the control in a number of countries, including China. The world production of DDT is not continuously recorded, and estimates of its usage vary (Wong et al., 2002a). Konishi et al. (2001) reported that the worldwide cumulative output of DDT was about 3,000,000 tonnes in the 1970s, while Whylie et al. (2003) suggested that annual world consumption from 1971 to 1981 was 68800 tonnes. In 1990, the production of DDT was estimated at 2,800 tonnes. The total usage of DDT in European countries decreased from approximately 28,000 tonnes in 1970 to zero usage in 1996. China and India have been suspected to be the biggest producers and users of DDT (Jaga and Dharmani, 2003; Monirith et al., 2003).

4 Factors Affecting Residue Levels

A number of factors appear to control the environmental fate and behavior of organochlorine pesticides. The concentrations of OCPs were higher in soils near the industrial parks, even some hotspots showed very high OCP contaminations which could cause ecological risk (Guang Wang,2009**).** Residue levels of organochlorine pesticides are affected by application history, agricultural practices, soil physico-chemical properties, as well as physico-chemical properties of agrochemicals and meteorological factors such as temperature and rainfall etc. (Szeto and Price, 1991; Boul et al., 1994; Spencer et al., 1996).

OCPs are hydrophobic and considered to be easily adsorbed by soil organic matter. A study carried out in mountain soils from the subtropical Atlantic (Teide, Tenerife Island) found that DDTs and HCHs exhibited a high dependence on soil total organic carbon (Ribes and Grimalt, 2002). Beijing is located in the temperate region. It is cold and dry in winter with the lowest temperature of 15.4 °C, while in summer it is hot and humid with the highest temperature of 38°C. Mean yearly precipitation is about 630 mm. The persistence of OCPs in soil is greater in temperate climates compared to the tropics (Iwata et al., 1994). I suggest climate change and pesticides persistence in the soil is directly relationship. The highest DDT ratios for the shallow subsurface soils and deep layer soils were located at the southwest and southeast sites, respectively (Youfeng Zhu 2005), where high DDTs levels were found. Extremely high ratios were found in the deep layer soils, probably because of the long-term leaching of p,p^0-DDT and retarded degradation of DDT to DDE in the deep layer soils (Miglioranza et al., 1999; Harris et al., 2000). Great proportions of p,p^0-DDT were also observed in agricultural soils of central Germany (Manz et al., 2001) and of southern Ontario (Meijer et al., 2003), and in some western USA soils (Hitch and Day, 1992). Another study carried out in Beijing reported that accumulative levels of DDT in the mothers milk declined irregularly, and the authors suggested that this might result from the possible use of dicofol which contains 5–10% DDT as impurity (Yu et al., 2001). Dicofol is classed as organochlorine pesticides, and DDT is one of the intermediate products during its manufacture. Now the use of dicofol was restricted in China because relatively high levels of DDT contamination were found in soils where dicofol was applied. These toxic chemicals should be restrict practically otherwise the homemaker rural peoples will use again.

Agricultural runoff is also becoming a major pollutant of rivers and coastal areas. For example, according to a 2004 China marine environment report, about 2,480,000 tons pesticide and fertilizer flow into the Zhu River every year, which has seriously polluted river and coastal waters in Guangdong Province. The use of high-toxicity pesticides also is killing beneficial insects, causing many pest disasters in China. For example, in 2001 over one million hectares of cotton fields in Xinjiang were attacked by aphids and spider mites, causing an $85 million loss.

5 Pesticide Poisoning

The consumption of pesticides has increased during the last few years. There are 771 pesticide products on the approved list in China. More than one million tonnes of finished pesticide products are spread on agricultural land. In China, pesticide poisoning during the 1990s was reported to be a major problem. For instance, in 1994, the newspaper China Daily reported that more than 10,000 Chinese farmers died during 1993 from pesticide poisoning. The report suggested that many died from poisoning by homemade chemical cocktails marketed illegally, and others died as a result of not following safety precautions. The Chinese government figures show that 53,300 to 123,000 people are poisoned by pesticides each year. Many Chinese farmers are not willing, or able, to invest in protective clothing and equipment for safe pesticide use, which has greatly increased the risk of pesticide poisoning. Thus, 300 to 500 farmers die each year due to improper use of pesticides. A survey indicates that many farmers suffer liver, kidney, nerve and blood problems due to pesticide poisoning, as well as eye problems, headaches, skin effects and respiratory irritations. Most of the time rural peoples were suffering from different diseases because of pesticides, I suggest it is due to the lack of awareness among the peopk form rural areas. Thus, the government should supply the safety materials to the farmers.

In 2002, more than 3,000 students were poisoned by drinking soy milk in Liaoning province. In 2001, a poisoning incident occurred in Yongxin county, Jiangxi province. More than 5,000 local residents suffered from wild mushroom poisoning. At least 10 people died. Organophosphorus pesticide poisoning occurs frequently in China and can be diagnosed easily based on the history of ingestion and the cholinergic toxic syndrome (Yi Li, 2008**).** In general, organophosphorous pesticides intoxication was significantly more common among rural exposed groups than urban groups. On the other hand, fatal poisonings caused by the use of illegal rodenticides has occurred quite often in China. Several outbreaks of pesticide poisonings have been reported. (Yi-Qun Wu, 2004). It has been estimated that there were thousands of tetramine poisonings, with hundreds of them resulting in deaths, number of cases are shown in fig 2.

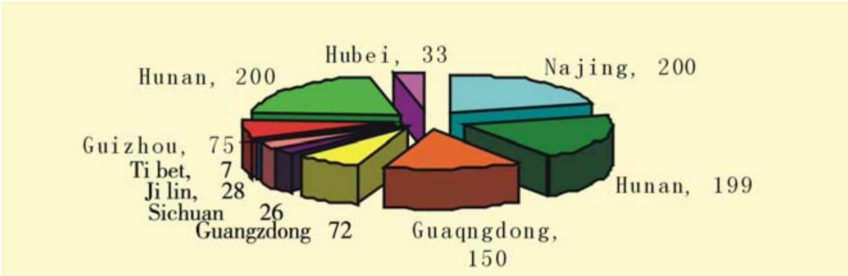

Figure 2 Tetramine poisoning (2002-2003), No. of cases data source: Wu,2004

Recently on 2009, Greenpeace found the highly toxic pesticides methamidophos and carbonfuran in fruits and vegetables which are banned from sale and use by the Chinese government. Greenpeace's findings suggest that pesticide contamination in food is a nationwide problem in China. Several thousand babies in China are seriously ill, having suffered acute kidney failure, with several fatalities, because of milk contaminated with the industrial chemical melamine. The toll is far higher than was previously admitted by the Chinese authorities.

Some of the food products made in China had actually been deliberately poisoned, either in Japan or en route to their market. In January 2008, dumplings made in China and poisoned with insecticides injured over 500 people. Later, in September, frozen beans made in China were also found to be contaminated with a pesticide; a hole in the bag indicated that the beans had been deliberately poisoned. Recently, fourteen babies have been hospitalised in China suffering from kidney stones and unable to urinate after drinking a cut-price milk powder.

6 Risk Assessment

Dietary risk assessment is more straightforward than occupational or residential risk assessment. It involves evaluating potential risk from single-route exposure similar to that used to generate most toxicology data. Dietary risk assessment generally is condu-cted by comparing estimated dietary exposure to results from toxicology studies in which the pesticide was administered orally (diet, stomach tube, or capsule). On the other hand, occupational and residential risk assessment usually involves evaluating multiple routes of exposure: dermal; inhalation; and, particularly for residential exposure to children, incidental oral ingestion. (fig3)

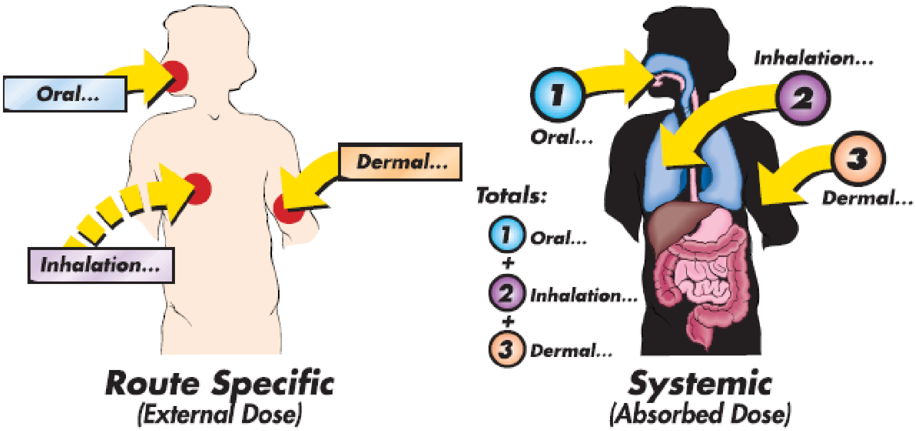

Figure 3 Occupational exposed to pesticides

Risk analysis is a systematic framework for understanding and actually managing diverse risks through the processes of risk assessment and risk management. It allows the incorporation of scientific and public health principles into decision-making and the setting of priorities. EPA intends the risk assessment process to provide the pesticide industry and the public at large with methods and criteria to estimate the level of risk posed by a pesticide. It is a science-based decision-making process. Ideally, risk assessment incorporates scientific knowledge with consideration of inherent uncertainties. More specifically, risk assessment is the process of quantifying and characterizing risk, i.e., estimating the likelihood of occurrence and the nature and magnitude of potential adverse effects. Risk management is the process by which decisions and judgments on the acceptability of levels of risk described in the risk assessment process are made. Risk managers must weigh policy alternatives by integrating risk assessment results with social, economic, and political factors. The following are examples of risk management approaches used to reduce human risk:

• Not registering the pesticide
• Restricting its use to certified applicators
• Lowering application rates
• Reducing the number of applications
• Increasing application intervals
• Providing longer intervals between application and harvest
• Using alternative application methods

These measures often take the form of label changes designed to reduce the amount of pesticide used and to lower exposure potential for farm workers and the general public.

EPA regulates carcinogens and considers cancer to be a nonthreshold effect. Therefore, cancer risk assessment in the United States usually does not compare anticipated human exposure levels to an RfD (Reference Dose), nor is an MOE determined. Instead, assessment provides an estimate (expressed as a probability) of the excess risk of cancer resulting from exposure to the pesticide.(fig 4)

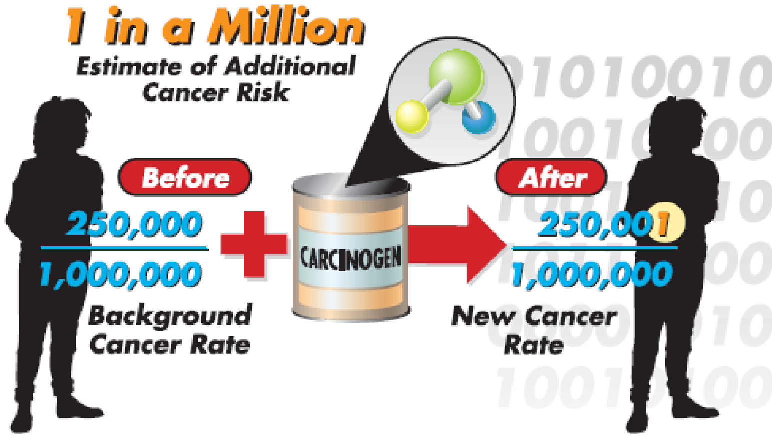

Figure 4 Risk Assessment for Non-Threshold Effects

For instance, a calculated risk of 1 x 10^{-6} (1 in 1,000,000) means that a person would have no more than a one-in a-million chance of developing cancer in excess of the background incidence in the general population. This level of excess cancer risk generally is considered acceptable for the general public, while higher estimated levels such as 1 x 10^{-5} (1 in 100,000) or even 1 x 10^{-4} (1 in 10,000) may be considered acceptable for some occupational exposures.

7 Sustainable Use and Control of Pesticides:

Sustainable Use of Pesticides is a useful step towards a strategy that will help reduce risks and hazards to health and the environment from the use of pesticides. China's environmental policy system currently found to be weakness (Kurrmin Zhang, 2008), so government should keep the view to monitor the environmental problems and policy. The use of less toxic chemicals and biopesticides will be the best way for the sustainable use of the environment. Agriculture Organization to create and oversee farmer training schools that encourage farmers to use Integrated Pest Management and control pests by introducing beneficial insects in lieu of pesticides. Reduce the dependence of agriculture on chemical pesticides and develop environmentally sound agricultural systems.

To control the pesticides use and to make pesticides usage more sustainable needs understanding between the public and government agencies. To enhance awareness of the public especially rural peoples (farmers), law should be well implemented. Legislations should be fully enforced for prohibiting illegal usage of POP pesticides. More sustainable alternative strategies for the reduction and elimination of POP pesticides are also needed. Integrated Pest Management (IPM) and Integrated Vector Management (IVM) should therefore adopted for crop protection and disease vector control.

In addition to supporting the monitoring/assessment programs required by the Stockholm Convention, there is an urgent need to establish coordinated research programs for environmental, sustainable use of pesticides and public health management of POPs in china.

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Determining Total N deposition in a Winter Wheat and Maize Cropping System
冬小麦-玉米体系中氮素总沉降的定量研究

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Abstract

Atmospheric N deposition is a serious problem in the North China Plain (NCP) because it imposes a considerable nutrient burden on the surrounding environment. A manual integrated total N input (ITNI) method was developed using 15N-labelled monitor plants grown in pots to obtain accurate measures of total N deposition to the agroecosystems in the NCP and improve N-fertilizer recommendations. Total airborne N input into the maize-wheat rotation system is 80-90 kg N ha^{-1} yr^{-1} in the NCP, and the plant available N from deposition for maize and wheat plants is c. 50 kg N ha^{-1} yr^{-1}. While total airborne N input is measured at almost 100 kg N ha^{-1} yr^{-1} when ryegrass is used as the monitoring plant, and the plant available N from deposition for ryegrass is c. 76 kg N ha^{-1} yr^{-1}, accounting for 77% of the total N deposition. Dry deposition is likely to be the major contributor to the total N deposition during wheat growing season in the dry and dusty NCP. In order to get reliable N deposition results especially when the plant density in small area pots (0.57 m^2) different from the one in the field, we found that a correction factor (e.g. 0.54 in this study) had to be used for maize to rectify values obtained from pot area.

摘要

由于大气氮沉降给周边环境很大的养分负荷，氮沉降已经成为中国华北平原一个严重环境问题。本文利用基于 15N 稀释法的手动 INTI 盆栽-砂培系统对华北平原进入农田生态系统得氮沉降总量进行了定量研究，进而为改进农田氮肥推荐提供依据。结果表明，小麦-玉米轮作体系中氮沉降总量为 80-90 kg N ha^{-1} yr^{-1}，其中约 50 kg N ha^{-1} yr^{-1} 可被玉米和小麦直接吸收利用；但当指示植物为黑麦草时这一氮沉降总量达 100 kg N ha^{-1} yr^{-1}，其中 76 kg N ha^{-1} yr^{-1} 为植物直接利用形态，相当于沉降量的 76%。干沉降很可能是小麦生长季的主要氮沉降来源，因为冬春干旱和频繁的沙尘暴天气有利于干沉降的发生。研究还发现，当玉米盆栽种植密度（盆钵：1 株/0.057m^2）明显不同于田间（大田：6 株/m^2）时，为了获得可靠的氮沉降总量信息，有必要对按面积获得的氮沉降量乘以一个 0.54 的矫正系数。

1 Introduction

With the development of intensive agriculture, characterized by over-fertilization, high stocking rates of domestic animals and rapid growth in energy consumption, more and more reactive N in both reduced and oxidized forms is being emitted into the atmosphere and re-desposited onto the surfaces of terrestrial and marine ecosystem (Galloway et al., 2008). It has been estimated that annually more than 55 Tg yr^{-1} NH_3-N was emitted from terrestrial ecosystems into the atmosphere, of which 50-75% came from farm animals and fertilizers (Mosier, 2001). The North China Plain (NCP) has particular problems of over-use of N resulting in with large reactive N emissions due to the rapid development of intensive agriculture as well as the transport industry. It is the major region in China for winter wheat-summer maize double cropping, with high fertilizer N application rates of >500 kg N ha^{-1} yr^{-1} (Kou, 2004). Annual bulk (i.e. mostly wet) inorganic N deposition is up to 30.6 kg N ha^{-1} yr^{-1} in the Beijing area and ammonium N is the main form of N in precipitation (Liu et al., 2006), being closely linked to reactive N emissions from agricultural activities, i.e. NH_3 volatilization from ammonium-based fertilizers and livestock. Total airborne N inputs will, of course, be much higher than bulk deposition, especially if both inorganic and organic N deposition and the direct uptake of atmospheric N species by aerial parts of plants are included (Russow et al., 2001; Cape et al., 2001; Ham and Tamiya, 2006). N balances from long-term field experiments in Changping have confirmed such high N inputs, i.e. about 83 kg N ha^{-1} $year^{-1}$ (He et al., 2007). Accurate determinations of the total N deposition into this agroecosystem are urgently needed so that China can more accurately gauge the scale of its pollution problems and farmers can make better predictions of N fertilizer requirements.

Currently methods are available to monitor wet/bulk deposition, and to measure and calculate gaseous deposition (Wyers et al., 1992; Sievering et al., 2000). However, all of them measure only a part of the total deposition and there are some uncertainties even in the state-of-the-art methods (Russow et al., 2001). The ITNI (Integrated Total Nitrogen Input) system, developed by Mehlert and Russow (Mehlert et al., 1995; Russow et al., 2001), was found to be the only technique to determine the total atmospheric N input, including wet, dry (particulate matter), gaseous deposition and direct N uptake by above-ground plant parts. It is based on the ^{15}N isotope dilution method and uses pot experiments. Thus the method of extrapolating values to the field scale is very important. Most extrapolations have been based on the vessel surface area (Weigel et al., 2000; Russow et al., 2001; Böhme et al., 2002, 2003), including methods using maize and sunflower, both of which have high space requirements per plant compared to crops such as wheat. Although several monitoring plants were used to overcome this, and mean values were calculated to quantify the total atmospheric N input in the whole year, this can still lead to an overestimation in the case of maize and sunflower if the data are not corrected for real field conditions.

The objective of the present study was to determine the best method of extrapolation using the ITNI system, simulating real field conditions, in order to obtain an accurate measure of total airborne N input into a typical maize-wheat rotation in the NCP. Total N deposition into the soil-maize plant system at key growth stages was also quantified in 2006 to supply data for fertilization recommendations. Some of the data published in He et al. (2007), were re-evaluated in this study.

2 Materials and Methods

2.1 ITNI system and biomonitoring crops

The ITNI system we used consisted of four components, a pot (inner diameter 27 cm and height 30 cm for wheat and diameter 22 cm and height 25 cm for ryegrass), quartz sand (18 or 12 kg in each pot), the indicator plant (maize, wheat, and ryegrass), and the ^{15}N-labelled solution. At the start of the experiment the sand-plant system was labelled with ^{15}N in the form of $Ca(^{15}NO_3)_2$, ^{15}N abundance 5 atom%. As the plants grew, the tracer was diluted by the input of atmospheric N and the amount of N deposited from the atmosphere was calculated from the dilution.

The N-free quartz sand was supplied with ^{15}N labelled nutrient solution, added manually and regularly from a buffer vessel. Surplus nutrient solution and rainwater were passed back into the buffer vessel. Thus, nutrients were recycled and the system was only exposed at the surface of the pot (area 0.057 m^2 for maize and wheat, 0.038 m^2 for ryegrass) or the concrete pond (area 0.98 m^2 for maize in 2006, described in section 2.2) and the aerial parts of the plants. The composition of the nutrient solution was (mmol L^{-1}): 0.75 K_2SO_4, 0.65 $MgSO_4$, 0.1 KCl, 2.0 $Ca(NO_3)_2$, 0.25 KH_2PO_4, 1×10^{-3} H_3BO_3, 1×10^{-3} $MnSO_4$, 1×10^{-4} $CuSO_4$, 1×10^{-3} $ZnSO_4\cdot7H_2O$, 5×10^{-6} $NaMoO_4$, 0.1 Fe-EDTA.

2.2 Evaluation of extrapolation from the pot to the field

The first pot experiment was conducted in Campus Experiment Field (CEF) of China Agricultural University in Beijing in 2004. Maize (Zea mays) was sown at the beginning of May and harvested in the middle of September. The rate of fertilizer N added to the pots was 3.6 g pot^{-1}. The pot experiments were then established at three other sites in 2005 described in section 2.3.

Maize is a plant with high space requirements, and the conventional density in the NCP is 6 plants m^{-2}. In order to simulate real field conditions, six maize plants were planted in a concrete pond, with surface area c. 0.98 m^2 and height 0.4 m, in 2006 in Dongbeiwang (DBW), Beijing. Fertilizer N was added to the pond at a rate of 3.0 g $plant^{-1}$. At the same time, a pot experiment was conducted with fertilizer N applied at a rate of 3.0 g pot^{-1} to compare the data with that from the pond. Maize was sown on 12 June 2006 and harvested on 30 September 2006.

2.3 Total N deposition and plant available N from deposition during the year May 2005 to May 2006

A summer maize-winter wheat (*Triticum aestivum* L.) rotation is the typical cropping system in the NCP. Therefore in the second experiment, to better simulate real field conditions and quantify the total airborne N input into the NCP agroecosystem, maize and wheat were used as the monitoring plants. The experiment was conducted at three sites in the NCP in 2005: DBW, about 5 km northwest of CEF in Beijing, Wuqiao (WQ) and QZ (QZ) in Hebei province, about 350 and 500 km southeast of Beijing, respectively. Maize was sown at the beginning of May 2005 and harvested in the middle of September 2005; wheat was then planted and harvested at the end of May 2006. As a reference, Italian ryegrass (*Lolium multiflorum*) was also used as a monitoring plant at the same three sites. Ryegrass was sown together with maize, but only half of the replicates were completely harvested, i.e. all components of the sand culture system (shoots, roots, sand and nutrient solution) were harvested separately in the middle of September 2005 together with maize (He et al, 2007). The remaining plants were partially harvested, i.e. only the shoots were recovered so that the stubble would sprout new leaves, and complete harvesting of the regrowth was performed at the end of May 2006 together with the wheat. From the data of 2004, we found that 3.0 g pot^{-1} provided enough N for maize to grow well. So fertilizer N was added to maize, wheat, and ryegrass at rates of 3.0, 1.5, and 0.8 g pot^{-1}, respectively. The amount of atmospheric N deposition to ryegrass during the same period as that for wheat (from September 2005 to May 2006) was calculated as described by He et al. (submitted).

2.4 Dynamic harvest stage

Total N deposition into the soil-maize plant system at key growth stages was also quantified at DBW in 2006 to supply data for calculating fertilization recommendations. Third-leaf expanded and Tenth-leaf expanded stages are two key growth stages when fertilizers are applied in the NCP, and grain filling is the growth stage at which N uptake is highest. Therefore maize was sown on 12 June 2006; the first harvest was taken on 4 July 2006 after the third leaf was fully expanded; the second harvest was taken on 2 August 2006 after the tenth leaf was fully expanded; the third harvest was taken on 30 August 2006 during grain filling; and the final harvest was on 30 September 2006 at maturity.

In all of these experiments, the pots of maize, wheat, and ryegrass were placed on the soil surface at a plant density that simulated commercial field conditions. After harvest, ^{15}N abundance in the various parts of the plants and in the sand and nutrient solution was analyzed by mass spectrometry (DELTA^{PLUS}XP, Thermo Finnigan) and calculated as described by He et al. (2007) and Russow et al. (2001).

3 Results and Discussions

3.1 Extrapolation of total N deposition from the pot to the field scale

It was noted above that, because the ITNI method is based on a pot experiment, the method of extrapolation from the pot to the field is critical with three basic ways of extrapolation as follows (Russow and Böhme, 2005):

(I) Area method (ratio between the area of the field and the pot)

$$ANDa\ [g\ N\ ha^{-1}\ day^{-1}] = AdTN\ [mg\ N\ pot^{-1}\ day\text{-}^{1}] \times 10/Apot\ [m^{2}] \qquad (1)$$

Where Apot - pot area (0.057 m^2 for maize and wheat, 0.038 m^2 for ryegrass); AND - total atmospheric N deposition; AdTN – net N input, including that in the sand and solution (AdSN) and plant (AdPN).

This is regarded as the simplest because the fewest additional parameters are needed, namely just the pot area Apot. It has been used since the ITNI system was developed (Weigel et al., 2000; Russow et al., 2001; Böhme et al., 2002, 2003). The influence of the monitored plant's DM production is neglected, which is the main disadvantage of this method.

(II) Plant number method (ratio between the number of plants in the field and in the pot)

$$ANDn\ [g\ N\ ha^{-1}\ day^{-1}] = AdTN\ [mg\ N\ pot\text{-}1\ day^{-1}] \times ZF \times 10/\ Zpot \times Apot\ [m^{2}] \qquad (2)$$

Where ZF - number of plants in the field per m2; Zpot - number of plants per pot (plant per m^2).

The number of plants per pot (Zpot, e.g., converted to 1 m^2 as in Eq. (2)) and the actual plant density in the field, ZF, are required as additional parameters in this extrapolation. This method was also tested when the ITNI system was developed and resulted in identical values for N deposition only when cereals (e.g. spring barley and winter rye) were used as monitor plants (Russow and Böhme, 2005).

(III) Combined area/dry matter method (ratio between aboveground DM in the pot and that on average in the field, plus the fraction within the sand and solution)

$$ANDb\ [g\ N\ ha^{-1}\ day^{-1}] = AdSN\ [mg\ N\ pot^{-1}\ day^{-1}] \times 10/\ Apot\ [m^{2}] +$$

$$AdPN\ [mg\ N\ pot^{-1}\ day^{-1}] \times 10 \times DMF\ [g\ m^{-2}]/\ DMpot\ [g\ m^{-2}] \times\ Apot\ [m^{2}] \qquad (3)$$

Where DMF - dry matter on the field; DMpot - dry matter per pot; AdSN – net N input into the sand and solution; AdPN - net N input into the plant.

Three additional parameters are required for extrapolation: the pot area Apot, the dry matter production in the pot DMpot, and the actual dry matter production in the field, DMF. This method was tested and regarded as the best compared to the other two if the DM production in the pot and field are similar (Russow and Böhme, 2005). But it is difficult to grow plants for the whole of their growth cycle in quartz sand with a limited nutrient supply. There are usually large differences in DM production between plants in pots and the field. In addition, DM figures in the field are usually unavailable if the monitoring crops in the pots are harvested early to avoid N losses. Therefore this extrapolation technique was not tested in this paper. The extrapolation results of using the area method and the plant number method on the pot experiments carried out from 2004 to 2006 are shown in Table 1.

Table 1 Comparison of extrapolation from pots to the field per ha using the area (ANDa), plant number (ANDn)

Monitoring crops	Period	Days	N applied [g N pot^{-1}]	Monitoring Sites	ANDa		Number of plants m^{-2}		ANDn		ANDn /ANDa
					g N ha^{-1} day^{-1}	kg N ha^{-1}	Pot	Field	g N ha^{-1} day^{-1}	kg N ha^{-1}	
Maize	May-Sep. 2004	113	3.6	CEF	1083	115.9	17.5	6	370.5	39.6	0.34
	May-Sep. 2005	108	3.0	DBW	785	84.7	17.5	6	268.4	29.0	0.34
		110		WQ	683	73.7	17.5	6	233.5	25.2	0.34
		117		QZ	846	91.4	17.5	6	289.3	31.2	0.34
	May-Sep. 2006	110	3.0	DBW	799	87.9	17.5	6	273.2	30.1	0.34
		110	3.0*	DBW*	433	47.6	6.1	6	423.8	46.6	0.98
Wheat	Oct. 2005-May 2006	247	1.5	DBW	181	44.8	421	450	193.8	47.9	1.07
		245		WQ	182	44.6	421	450	194.6	47.7	1.07
		244		QZ	165	40.2	421	450	175.9	43.0	1.07
Ryegrass	May-Sep. 2005	108	0.8	DBW	420	45.3	421	450	448.5	48.4	1.07
		110		WQ	507	54.8	421	450	542.0	58.5	1.07
		117		QZ	422	45.6	421	450	451.2	48.7	1.07

Comparing the area method (ANDa) with the plant number method (ANDn), similar results are found when the plant density in the pots approximates to the one used in the field, e.g. for wheat, ryegrass planted in a pot with a surface area of about 0.057 m^2 and 0.38m^2, respectively, and maize in a pond with a surface area of about 0.98 m^2. However, the ratio of ANDn /ANDa is only 0.34 when there was a large difference in plant density between the pots and the field as for maize. For the area extrapolation approach, the ANDa value of maize planted in a pond is only 0.54 of that planted in a pot. But for the plant number approach, the ANDn value of maize planted in a pond is 1.55 times that planted in a pot. So both of the extrapolation methods fail for plants, with high space requirements like maize. The area extrapolation method would lead to an overestimation and the plant number extrapolation method would lead to an underestimation. Therefore it is necessary to correct all the values. However, it is more convenient to extrapolate using the area method than the plant number method using the factor of 0.54 obtained above.

3.2 Total N deposition and plant available N during the whole year of May 2005 to May 2006

Figure 1 shows the total airborne N input in these three sites during the whole year of May 2005 to May 2006, covering a full summer maize-winter wheat rotation. Extrapolation of the airborne N input from the pot to the field using the correction factor of 0.54 gave a total N input of 88.2 kg N ha^{-1} yr^{-1} on average for the whole rotation, which corresponds very well with the result of 82.8 kg N ha^{-1} yr^{-1} measured at the Changping long-term experiment (He et al., 2007). The mean N deposition was 98.8 kg N ha^{-1} yr^{-1} over the same period when estimated using with perennial ryegrass (Fig.2). There were no statistical differences in deposition between the three sites (data not shown). Thus the results of both the ITNI pot experiments and the long-term experiment suggest an N deposition of 80-90 kg N ha^{-1} yr^{-1} to a typical maize-wheat rotation at DBW, WQ and QZ in the NCP.

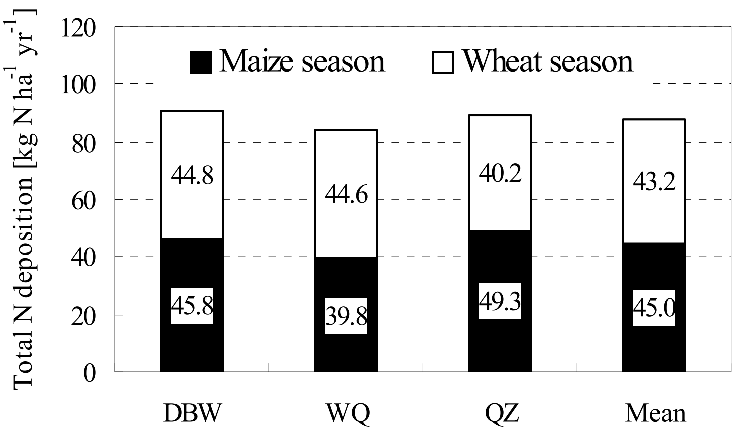

Figure 1 Atmospheric N deposition to a complete maize-wheat rotation from May 2005 to May 2006

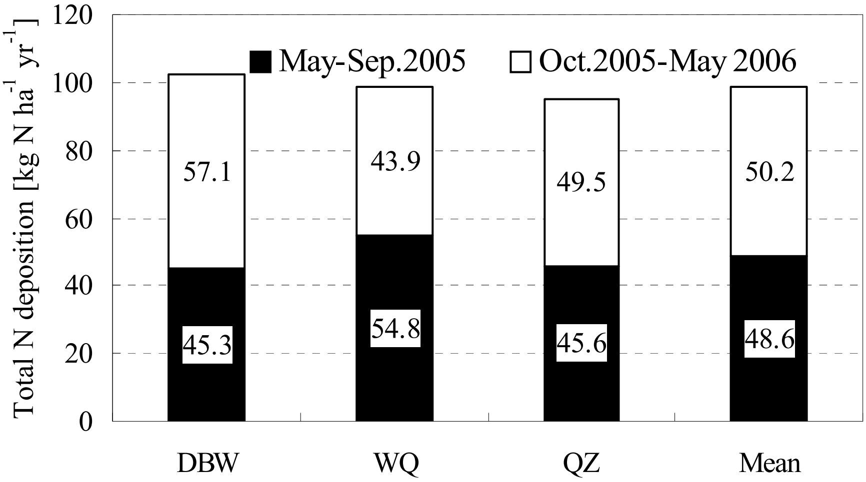

Figure 2 Atmospheric N deposition to ryegrass from May 2005 to May 2006.

The bulk deposition of organic N and inorganic N was also measured using a rain gauge by Zheng (2006) at these three sites over the maize growing season (Table 2). The value varied from 12.5 to 34.5 kg N ha^{-1} yr^{-1}, accounting for about 30% of the total N deposition measured using the ITNI system in WQ and QZ and 75% of that at DBW. Bulk deposition made a large contribution to the total N deposition in DBW, only 25% of which can be attributed to dry deposition and/or direct uptake by the aerial parts of plants. However, the amount of precipitation in WQ and QZ was much lower than that at DBW, resulting in the smaller contribution of bulk deposition to total N deposition (30%). The remaining 70% of the N deposition at WQ and QZ came from dry deposition and/or direct uptake by the plants.

Table 3 Results of different N deposition measurements from May to September

Monitoring site	Precipitation (mm)	Input (kg N ha^{-1})			Bulk/ ITNI-maize	Bulk/ ITNI-ryegrass
		Bulk [a]	ITNI-maize	ITNI-ryegrass		
DBW	429	34.5	45.8	45.3	75.4	76.2
WQ	265	12.5	39.8	54.8	31.3	22.7
QZ	246	14.0	49.3	45.6	28.4	30.7
Mean	313	20.3	45.0	48.6	45.0	43.2

Bulk [a]: including organic N and inorganic N, data adapted from Zheng L.X., 2006.

Liu et al. (2006) reported that the annual bulk (i.e. mostly wet) N deposition of up to 30.6 kg N ha^{-1} yr^{-1} (only inorganic N) and more than 80% of the total bulk deposition occurred mainly from April to September in the Beijing region of China, coinciding with the maize growing season. N deposition of up to 43.2-50.2 kg N ha^{-1} during the wheat growing season from October 2005 to May 2006 (Figs. 1 and 2) accounted for about 50% of the total N deposition during the whole year from May 2005 to May 2006 in these three sites. This is because, with strong winds with very little precipitation, dry deposition dominates in this region during wheat production (all of the winter and spring and part of the autumn), especially in Beijing, where dust storms occur in spring because of its location downstream of northwest China and the Loess Plateau. Therefore dry deposition is likely to be the major contributor to total N deposition in the NCP during the wheat growing season (He et al., submitted).

Although a total N deposition of 88 kg N ha^{-1} yr^{-1} was measured for the maize-wheat rotation, only 50 kg N ha^{-1} yr^{-1} was used by the maize and wheat (Fig 3), accounting for 57% of the total N deposition (Table 3). The remaining 43% was found in the sand and solution and was not utilized by the current crop. By comparison, 76 kg N ha^{-1} yr^{-1} was available for ryegrass (Fig 4) and the ratio of plant available N from deposition to the total N deposition (99 kg N ha^{-1} yr^{-1}) was 77% over the whole year (Table 3). We also noted that this ratio for ryegrass was up to 96% during the wheat growing season (from October 2005 to May 2006), much higher than that utilized maize and wheat plants. The reason may be that ryegrass can grow in relatively infertility soil and make better use of environmental N. Thus it is a better biomonitoring / bioindicator plant (Zavaleta and Hulvey, 2004). Furthermore, the contribution of atmospheric N to the total N content of the sand-plant system per pot was 33.7%, 20.5%, and 50.5% for maize (May to September 2005), wheat (October 2005 to May 2006), and ryegrass (May 2005 to May 2006), respectively, suggesting a higher efficiency of use of atmospheric N for ryegrass (Table 3). This percentage falls within the range found in other studies of about 4 to 77% for NH_3 (Lockyer and Whitehead, 1986; Wollenweber and Raven, 1993) compared to 10 to 15% for NO_2 (Muller *et al.*, 1996).

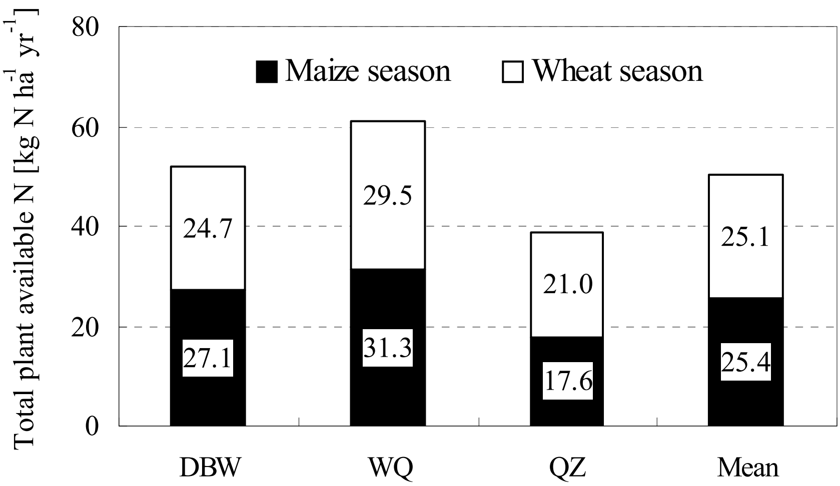

Figure 3 Total plant available N from atmospheric N deposition for a complete maize-wheat rotation from May 2005 to May 2006.

Table 3 Ratio of plant available airborne N to the total N deposition and the ratio of N from deposition to total N content per pot (%)

Period	Monitoring crops	DBW	WQ	QZ	Mean
Ratio of plant available N from deposition to the total N deposition					
May-Sep. 2005	Maize	59.3	78.7	35.8	56.4
	Ryegrass	59.9	66.2	61.2	62.7
Oct. 2005-May 2006	Wheat	55.0	66.3	52.2	58.0
	Ryegrass	87.6	84.1	100.0	95.8
May 2005-May 2006	Σ(Maize + wheat)	57.2	72.1	43.1	57.2
	Σ(ryegrass)	75.3	74.2	81.4	76.9
Ratio of N from deposition to total N content per pot (%)					
May-Sep. 2005	Maize	36.8	28.9	35.6	33.7
Oct. 2005-May 2006	Wheat	19.4	22.4	19.7	20.5
May 2005-May 2006	Ryegrass	53.4	48.8	49.1	50.5

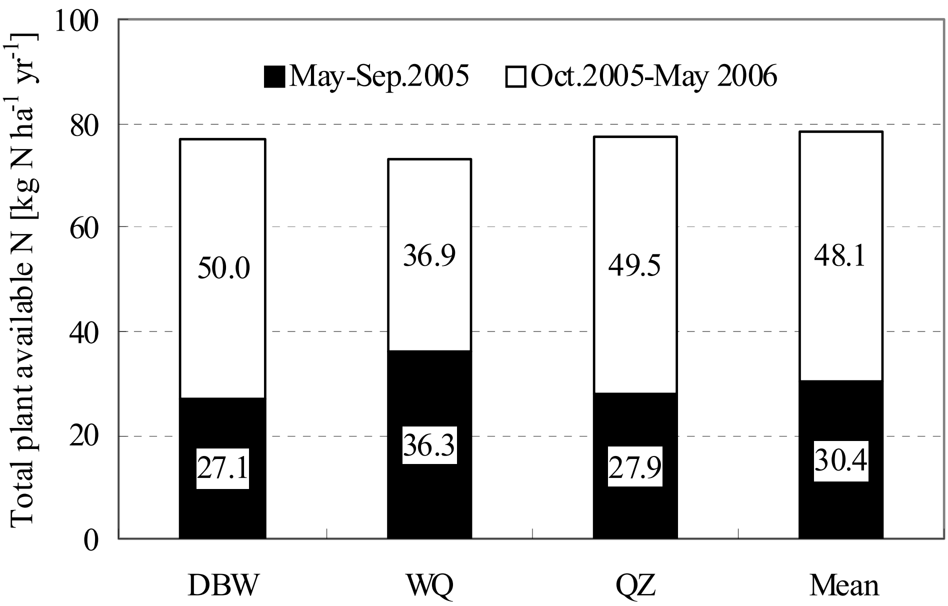

Figure 4. Total plant available N from atmospheric N deposition for ryegrass from May 2005 to May 2006.

3.3 Total N deposition and plant available N deposition at key growth stages of maize

Table 4 shows the total N deposition and plant available N from deposition for maize, corrected by the factor of 0.54 when extrapolated into the field scale, at key growth stages. Estimated total N deposition, plant available N from deposition, and the ratio of plant available N from deposition to the total N deposition during the whole maize growing season were 47.4 kg N ha^{-1}, 27.8 kg N ha^{-1} and 59%, respectively, which agree well with the values measured in 2005 in DBW (44.8 kg N ha^{-1} for total N deposition, 27.1 kg N ha^{-1} for plant available N, and 56% for the ratio of plant available N from deposition to the total N deposition). When maize was harvested at the third-expanded leaf stage, it was too small (with a very small dry matter content of about 0.28 g pot^{-1}) to absorb much airborne N. The estimated total N deposition and plant available N from deposition were only 1.2 and 0.3 kg N ha^{-1} during the period from sowing to third-expanded leaf stage. During the period from three-expanded leaf stage to ten-expanded leaf stage, maize needs more nutrients from the environment to supply its vegetative growth. Here the value of net total airborne N deposition was the highest about 21.4 kg N ha^{-1} and the value of net plant available N was 9.4 kg N ha^{-1}. Afterwards, the maize gradually moved into its reproductive stage and the reproductive organs began to utilize N transferred from the leaves and straw. Only 40% of the N in the maize grain was derived from external sources; the remaining 60% came from inner transfer from leaves and straw during grain filling (Chun et al., 2005). Therefore the value of net total N deposition during the period from ten-expanded leaf stage to grain filling and the period from grain filling to maturity dropped to 12.1 and 12.7 kg N ha^{-1}. However there were no large variances in plant available N from deposition; the values were 10.1 and 8.1 kg N ha^{-1} during the two periods, respectively.

Table 4 Total N deposition and the N from this available to plants for maize at key growth stages from May to September, 2006.

Harvest stage	Days	Dry matter (g pot^{-1})	Total N deposition (kg N ha^{-1})	Plant available N (kg N ha^{-1})	Ratio of plant available N from deposition to the total N deposition (%)
Planting to Three-expanded leaf	15	0.3	1.2	0.3	23
Three-expanded leaf to Ten-expanded leaf	51	23.4	22.6	9.6	43
Ten-expanded leaf to Grain filling	79	90.2	34.7	19.7	57
Grain filling to Maturity	110	126.9	47.4	27.8	59

Substantial NH_3 (Yamulki et al., 1996; Olsen et al., 1995; Husted et al., 1996), NO_2 and NO (Wellburn, 1990) emissions from agricultural crops to the atmosphere were reported during senescence (protein degradation), even at early growth stages (Asman, et al., 1998, Böhme et al., 2003). However, in our experiments the net total N deposition increased with the growth stage despite losses during maturity (Fig 5), which corresponded well with our earlier findings (He et al, 2007).

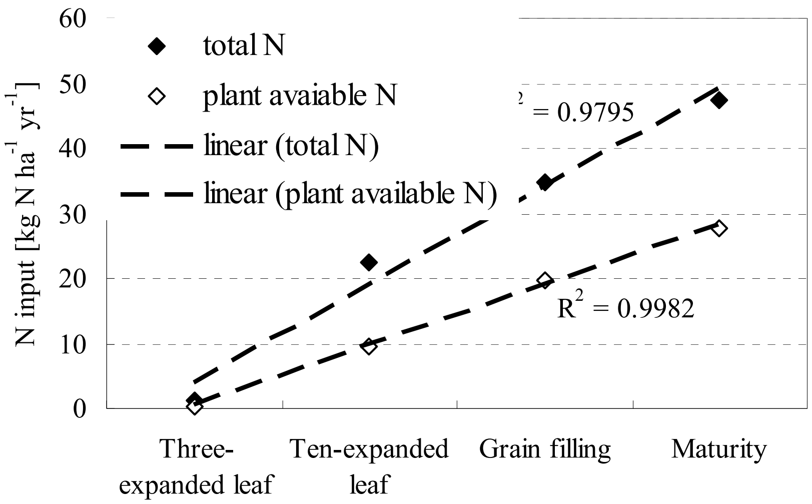

Figure 5 Atmospheric N deposition and the N from this available to maize in the period from May to September, 2006.

4 Conclusion

When using the ITNI method and extrapolating from the pot into the field scale, the area method and the plant number method achieve similar results only when the plant density in the pots approximates to the one used in the field. In order to get reliable results for a plant like maize with high space requirement, a factor of 0.54 had to be used to correct values when area method is used to extrapolate from the pot to the field.

Total airborne N input into the maize-wheat rotation system in the NCP is 80-90 kg N ha^{-1} yr^{-1}, and the plant available N from deposition for maize and wheat is c. 50 kg N ha^{-1} yr^{-1}, accounting for 55-60% of the total N deposition. Dry N deposition can be the main contributor to the total N deposition during wheat growing season in the NCP.

The N deposition was 20-25 kg N ha^{-1} from N deposition during three-expanded leaf stage to ten-expanded leaf stage of maize and similar deposition occurred from ten-expanded leaf stage to maturity of maize. Thus N deposition should be taken into account when calculating the N fertilizer requirements for maize. Further studies are needed to quantify the total N deposition and plant available N from deposition under major wheat growing stages.

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Anthropogenic Nitrogen Processing in River-Estuarine Systems: Case studies from Europe
河口系统的人为氮素矿化过程 来自欧洲的个案研究

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Abstract

The N loading in European rivers has doubled since the pre-industrial levels and the extent to which this N load reaches the coastal zone by-passing estuaries is unclear. Estuaries mediate and transform land to sea N fluxes and are vulnerable environments sensitive to human perturbations. The presentation will elucidate the sources and fate of ammonium (NH_4^+) and nitrate (NO_3^-) in two northeastern English Tyne and Tweed river estuaries draining catchments with contrasting land use patterns (Urban, Agricultural). Stable nitrogen isotope ratios ($\delta^{15}N$) will be used to fingerprint key N sources and transformation processes. In addition, example will be drawn form other European case studies (e.g. the Humber, the Schelde) to place these results in a wider context.

The dominant feature of NH_4^+ in the heavily urbanised Tyne estuary was a plume arising from a single point source; a large sewage works. Although the NH_4^+ concentration (ca. 30-150 μM) in the plume emanating from the sewage outfall varied considerably between winter and summer, its $\delta^{15}N$-NH_4^+ signature was remarkably constant (10.6 ±0.5‰) and could be tracked across the estuary. In the more rural Tweed, NH_4^+ concentrations were low (< 7 μM) compared to those in the Tyne and $\delta^{15}N$-NH_4^+ values were consistent with mixing between riverine and marine sources. In the Tweed catchment agricultural activity resulted in large seasonal NO_3^- fluxes that gave rise to significant seasonality in $\delta^{15}N$-NO_3^- signatures. Higher NO_3^- fluxes in winter characterised by ^{15}N-depleted $\delta^{15}N$-NO_3^- were attributed to increased contributions from agricultural soil and fertiliser sources. In the Tyne, where agricultural inputs are less important compared to the Tweed, light $\delta^{15}N$-NO_3^- (ca. 0‰) detected in the estuary during one winter survey implied potentially significant inputs of atmospheric NO_3^- during high river discharge associated with a winter storm event. In both estuaries, most of the variability in NO_3^- and NH_4^+ concentrations and in $\delta^{15}N$ were explained by simple mixing between sources, implying very little estuarine processing of dissolved inorganic nitrogen (DIN). Nevertheless, ^{15}N-depleted $\delta^{15}N$-NO_3^- observed close to the mouth of the Tyne provided indirect evidence for coastal nitrification triggered by anthropogenic NH_4^+ arising from sewage discharge.

The more or less conservative behaviour N in NE English estuaries considered here contrast with that of large European estuaries such a Schelde, where significant N losses occur due to denitrification and sedimentary burial of organic-N, illustrating the importance of fresh water

residence time in N-processing in estuaries. In addition, the role of wetlands (tidal flats, salt marshes) in increasing N retention is illustrated by Humber Estuary (Eastern England) where N loss has declined due to loss of bordering wetland habitats. This highlights the importance of sustainable management of wetlands associated with estuarine systems.

摘要

欧洲河流中的氮素含量比工业革命前增加了一倍，而且这些氮素含量通过河流转移至海岸流域的总量程度不明晰。河流的入海口区域促成并调节氮素在陆地和海洋之间的转换，这些区域的生态环境往往很脆弱，很容易受到来自人类活动的破坏。本文将对来自欧洲的相关个案进行分析，从而在更广泛的范围内充分分析这些相关的研究成果。

泰恩河流域城市化集中地区河水中铵态氮含量主要受到一单一源头—— 一个大型污水处理中心排放的影响。这一污水处理厂冬季和夏季铵态氮排放量的浓度 30—150μM 之间存在巨大差异 。同位素 δ15N 不但排放量相对恒定在 10.6±05 之间，并且在整个流域都可以检测到。与泰恩河相比，位于乡村地区的特维德河中铵态氮的含量的相对低且稳定，其铵态氮不但来源于河流且来源于海洋。特维德河水库农业活动导致了硝态氮通量的季节性变化明显，从而也导致了δ15N 标记的硝态氮显著的季节性变化。冬季δ15N 稀释法标记的较高的硝态氮通量主要来自与农业土壤和肥料的增长。在受农业活动影响小于特维德河的泰恩河流区，一个冬季由δ15N 标记的硝态氮调查结果显示了大气中硝态氮是可以成为河流氮素的主要来源之一，这两条河流的大多数硝态氮、铵态氮的浓度和δ15N 变异都可以用简单的氮素来源以及氮素来源之间的混合来解释，这一过程跟可溶性无机氮的关系很小。尽管如此，在对泰恩河口流域稀释的δ15N 硝态氮的观测提供的一些间接证据表明，污水散发到大气中的铵态氮促发了沿海流域的硝化过程。

欧洲其他几大河流如斯特尔特河正面临着严重的氮素流失，这主要是由于反硝化作用和有机氮的沉积引起的。与之形成鲜明对比的是文中所涉及的英国东北地区的河流中氮素或多或少地得到了很好的保存，这更证明了淡水存在对河流氮素含量重要性。另外，湿地如沿海湿地和盐沼地在增加氮素含量中的作用也越来得受到关注。在英国东部的亨伯河口湾的湿地栖息地人造边界的取消减缓了河流中氮损失的速度，这有力地证实了湿地对氮素保持的作用。这些都突出表明了对与河口系统关系紧密的湿地进行可持续管理意义重大。

1 Introduction

The marine and terrestrial nitrogen cycles are closely linked through biogeochemical processes in estuaries. An Estuary is defined as part of the river confluence that experiences reversing landward flow due to tides. Estuaries come in all sizes and shapes ranging from large drowned river valleys, deep glacial excavated silled-Fjords, tectonic depressions and much smaller and shallower longshore bar-build coastal lagoons. Whatever the size the estuaries are characterised by large salinity gradients resulting from the mixing of riverine freshwater from land with tidal inflow from the seawater. Apart from the plethora of sizes and shapes, the challenge in studying nitrogen transformation processes in estuaries stems from the large temporal and spatial variability inherent to these systems requiring unique understanding of each estuarine system.

Estuarine circulation patterns are highly variable influenced by size and shape, tidal mixing and fresh water flux (Fig. 1). The basic premise, however, is that there is a downslope seaward flow of lower-density fresher water at the surface and an inflow of saline water at depth. Entrainment of salt water into the outflowing upper layer is replaced by the underlying inflow from the sea. The distinct landward bottom flow of salt water that develops in some estuaries is called a salt wedge. The characteristic two-layer circulation plays a pivotal role in N transformation in estuaries by trapping particles and nutrients. With the exception of very fine-grained material, sedimentary particles that are carried downstream to the estuary settle as the flow velocity decreases when the confined river flow discharges into the relatively open coastal zone. The landward-moving net bottom flow acts to carry particles up-estuary, so that particles settling from the surface outflow can literally be carried back up the estuary at depths. In addition, when the particles are introduced to saltier water, a high ionic strength medium, they tend to aggregate to form larger and thus faster-settling particles. This process, termed flocculation, promotes sedimentation of riverine particulate organic matter in estuaries. Finally, wet land systems bordering estuaries (tidal flats, reed beds, salt marshes etc.) retards flow and retains particles particularly when the estuaries overflow into adjoining wetlands due to high tides and flood conditions. The net result is that estuaries effectively trap particulate organic matter delivered from river and within the estuary preventing it from reaching the open sea.

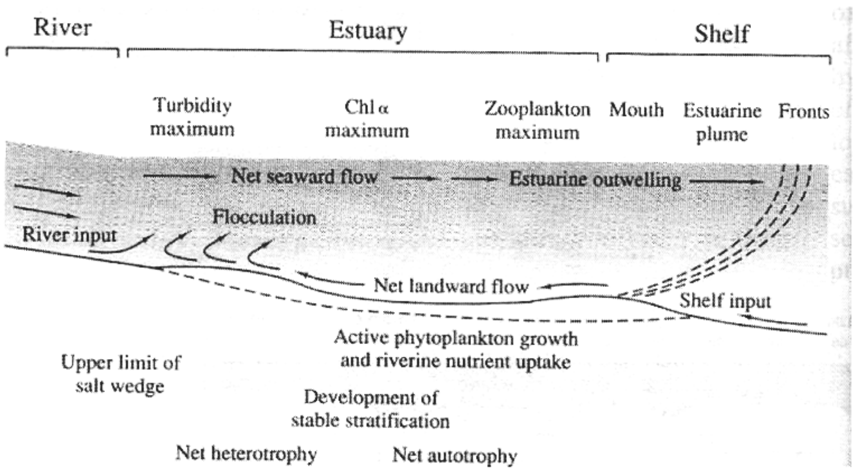

Figure 1 Biogeochemical processes and estuarine circulation.

One noteworthy feature of estuarine sedimentation is the turbidity maximum (Fig.1) . This feature is maintained by the residual circulation, and is intrinsic to the idea that estuaries trap particles. The turbidity maximum consists of sediments settling from the river input plus resuspended bottom sediments brought up estuary by the saline bottom flow mixed with estuarine algal material and other anthropogenic discharges. The high concentrations of particles promote flocculation within the turbidity maximum. Some of the particles (characteristically those that are relatively fine-grained) are mixed upward into the outward-flowing surface layer, only to settle later back into the bottom inflow. Thus, a turbidity maximum should be viewed as a dynamic feature. In extreme cases, the turbidity maximum may stretch many kilometers and maybe so concentrated that it becomes a fluid mud lens. Example of this is the Gironde Estuary in Southern France.

2 N transformation Processes in Estuaries

In much the same way that estuaries act as sediment traps, they also trap nutrients including nitrogen. Dissolved Inorganic Nitrogen (DIN; mainly ammonium (NH_4^+) and nitrate (NO_3^-)) captured by primary producers in estuaries, and regenerated back into solution at depth, either in the water column (largely via excretion by heterotrophs), or more importantly, by bacterially-mediated degradation in the turbidity maximum and also at the sediment-water interface. N regenerated in the turbidity maximum in the upper estuary undergoes mixing and upward diffusion. The dissolved N is entrained in the net seaward flow and advected to the lower estuary to be primary producers. The settling organic detritus is then entrained in the net landward flow at depths, and advected up-estuary thus sustaining the cycle. The net heterotrophy of estuaries and the fact that they trap organic matter and nutrients provides the capacity for estuaries to processes N. It is estimated that up to 40% of N entering estuaries are processed through biological utilisation, sediment burial, nitrification and denitrification thus reducing N inputs to the open ocean (Andrew et al., 2006).

Anthropogenically and terrestrially-derived N enters estuaries through riverine transport or via atmospheric deposition, including both direct deposition to the surface of estuaries and indirect watershed runoff (Castro and Driscoll, 2002). In addition estuaries are historical population centres and today's urban settlements release N-compounds also through direct discharge. Excess N input can lead to eutrophication, whereby overall increases in primary production are accompanied by major shifts in the dominant flora (Duarte, 1995) and fauna (Heip, 1995). A N-budget for the coasts confirms the dominant role of the river inputs (66Tg N yr^{-1}) over other N-sources (atmospheric deposition, N_2 fixation, fish landings) for the overall N- delivery to the ocean (Galloway et al., 2004). Only roughly half of the input is from natural sources, the other half human derived. The fact that estuaries trap and recycle particulate and dissolved species of N makes them prone to severe oxygen depletion and in some extreme cases they can become anoxic. This is further acerbated by the two-layered circulation in estuaries which causes salinity and temperature differences within the structure of a water body and a stable stratification inhibiting mixing and diffusion of oxygen. Particulate material like phytoplankton aggregates, faecal pellets from zooplankton etc. sink through this interface and are degraded. The microbial degradation leads to the accumulation of nutrients and the depletion of oxygen below the interface. If the oxygen consumption is higher than the renewal of the deep waters, anoxia can develop with large scale die-offs of benthic animals. This has been reported as a severe process spreading along many coastal areas (Diaz and Rosenberg 2008).

Such changes also alter N transformation processes and the capacity of estuaries to retain N (Horrigan et al., 1990). The heterotrophic bacteria need hypoxic conditions (<10 μM), use nitrate as final electron acceptor during respiration and produces N_2 gas as final end product and as intermediate product N_2O. The extent of this process is strongly controlled by temperature, nitrate concentration and the availability of organic carbon (Hulth et al., 2004), which makes the process seasonally variable (Tuominen et al., 1998). Autotrophic denitrification with CO_2 as a carbon source may also at times be a dominant process at anoxic – oxic interfaces (Hannig et al. 2007). Here a tight coupling between nitrification and denitrification, and the nitrate generated during nitrification in the oxic sediment layer diffuses downwards in suboxic sediment regions where it is rapidly denitrified (Herbert, 1999).

Large accumulation of ammonium from anerobic condition and discharge from sewage and urban sources can also have a significant impact on N transformation processes in estuaries. Most of the ammonium is taken up by phytoplankton; and some oxidized to nitrate during nitrification, an obligate aerobic two-step process. The first step is the oxidation of ammonia to nitrite by ammonia oxidizing bacteria and in the second step nitrite is oxidized to nitrate by nitrite oxidizers. The rate of nitrification is controlled by temperature unless there is a insufficient supply with oxygen and ammonium. At oxygen concentrations below 10 μMol the process additionally produces N_2O, which is a strong greenhouse-gas (Jorgensen et al. 1984, Hynes and Knowles 1984) Nitrification occurs in the water column as well as in oxygenized sediment layers, and the generated nitrate is either assimilated by phytoplankton and algae or is reduced to N_2 and N_2O during denitrification. Intertidal and subtidal mud flats and salt marshes are areas of enhanced capacity to retain N through sedimentation resulting from retarding water flow. For instance in the Humber estuary (UK), organic N burial is estimated to be 216 t annually. The intertidal area of the Humber also enhances N processing by denitrification (Andrews et al., 2006).

3 Case Study of Dissolved Inorganic Nitrogen (DIN) Processing in Tyne and Tweed Estuaries (NE. England)

This Case study illustrates the sources and processing of dissolved inorganic nitrogen (DIN: NH_4^+, NO_3^-) two relatively small northeastern England mesotidal estuaries draining the North Sea- the Tyne and the Tweed estuaries (Fig. 2). The River Tyne has a total drainage area of ca. 2900 km^2 of blanket peat and pristine moorlands with an average freshwater flow of 48 m^3 s^{-1} and is estuary is 30km long. This urban estuary receives a significant load of urban waste, particularly NH_4^+ from the Howdon sewage works located in the bordering city of Newcastle. In contrast, the combined catchment area of the Tweed and Its tributary Whiteadder is ca. 4900 km^2 of rural, sparsely-populated moorland and arable agricultural lowland in the border region between England and Scotland with an average freshwater input of 84 m^3 s^{-1} and the estuary is about 13km long. The relatively intensive agricultural activity within the rural Tweed catchment leads to large riverine NO_3^- fluxes (Fig. 3). Thus the two estuaries provide a contrast in inorganic nitrogen sources and fluxes due to differences in land use.

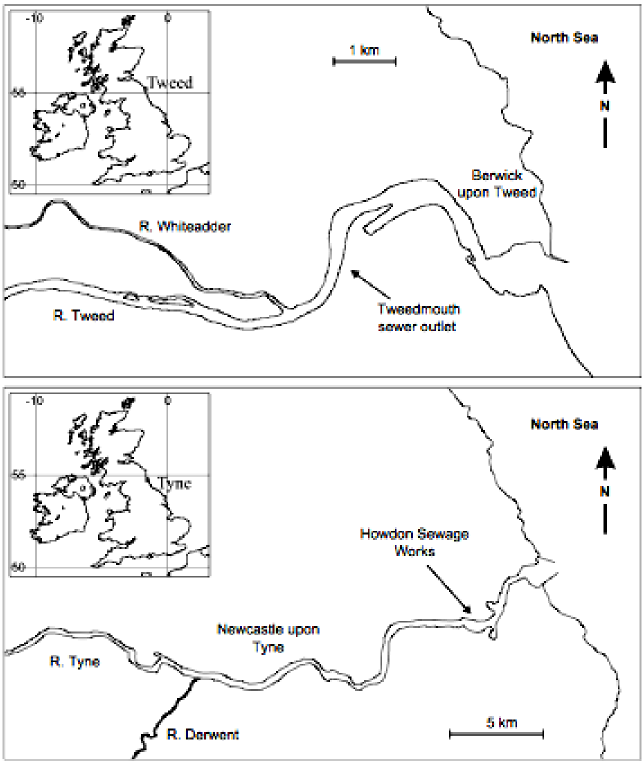

Figure 2 Map of the Tyne and Tweed estuaries.

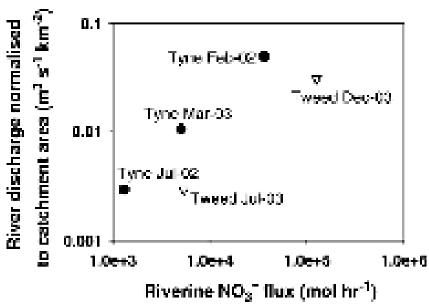

Figure 3 River discharge normalised to catchment area (m^3 $s^{-1}km^{-2}$) in the Tyne (circles) and Tweed (triangles) plotted versus riverine NO_3^-flux (mol h^{-1}). The much higher NO_3^- fluxes in the Tweed relative to the Tyne indicate the predominance of agricultural sources in the Tweed catchment.

The important question that is addressed is the extend DIN processing in these partially mixing rapidly flushed estuaries . Despite the large differences in fluxes of riverine DIN, most of the NO_3^- variability in both estuaries can be explained by simple end-member mixing model between river and marine sources during all surveys, implying very little estuarine processing (Fig. 4). Although some additional nitrate inputs are discernable particularly in the Tweed estuary these are attributed to in-estuarine point sources triburaies such as the whiteadder draining directly into the estuary. The remarkable lack of nitrate processing in these estuaries even in summer months is attributed to the short residence time of fresh water, which is less than 30 days and 1 day for the Tyne and the Tweed estuaries respectively. Additionally, light limited conditions in these humic-rich estuaries may also be an important factor in inhibiting N assimilation by autotrophs. This interpretation is supported by the marked heterotrophy relative to autotrophy and small chla levels in these estuarine (Ahad et al., 2008). Therefore, these estuaries merely act as a conduit supplying anthropogenic terrestrial nitrate to the coastal zone.

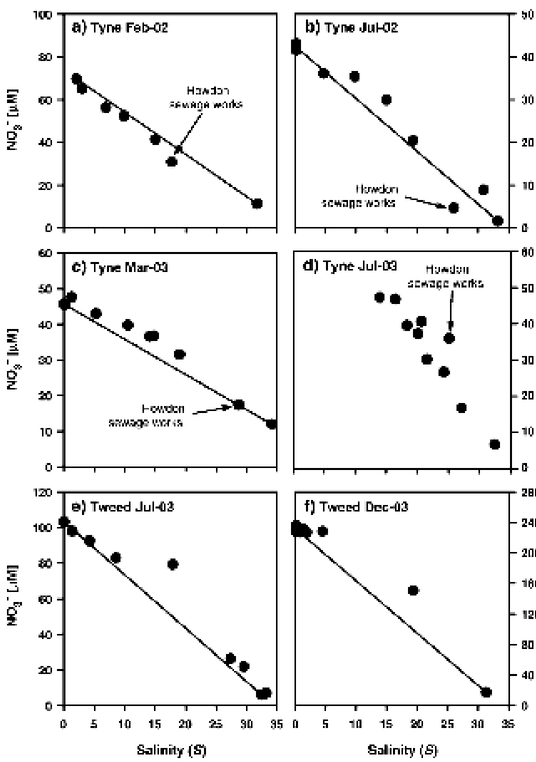

Figure 4 Concentrations [µM] of $NO3^-$ in the Tyne estuary during (a) Feb-02, (b) Jul-02, (c) Mar-03, and (d) Jul-03 and in the Tweed estuary during (e) Jul-03, and (f) Dec-03 plotted versus salinity (S).

The straight solid lines represent the conservative concentration mixing curve between riverine and marine sources.

The general lack of estuarine processing also applies to NH4$^+$ (Fig.5). However, the dominant feature of NH_4^+ concentration distributions in the heavily urbanised Tyne estuary was a plume arising from a single point source; the large sewage works. This anthropogenic NH_4^+ concentrations ranging from 30–150 µM near the sewage outfall and could be tracked through out the estuary. Stable N isotope finger printing of natural and sewage derived NH_4^+ indicate that much of the concentration changes with in the Tyne estuary can be explained by mixing between river and sewage sources (Ahad et al., 2006). Although, very little of the anthropogenic NH_4^+ is processed with in the Tyne estuary itself its impact is discernable in the mouth of the estuary and the adjoining coastal zone. High N_2O emissions, perhaps due nitrification of NH_4^+ as suggested by isotopic evidence, has been reported in waters entering the mouth of the Tyne estuary from the coast (Ahad et al., 2006 and references there in). This phenomenon has been previously documented in temperate European estuarine and coastal zones affected by significant sewage inputs such as the Schelde estuary (e.g. de Wilde and de Bie, 2000). Further this isotopic study also suggests that the riverine sources of nitrate entering the Tyne ans Tweed estuaries varies with river. During high river flow (Fig.3). The isotopic concentration of nitrates is light (close to zero) indicating unprocessed nitrate derived from atmospheric deposition and fertiliser sources. In contrast during low river flow the nitrate isotopic composition is much heavier indicating processing in soil.

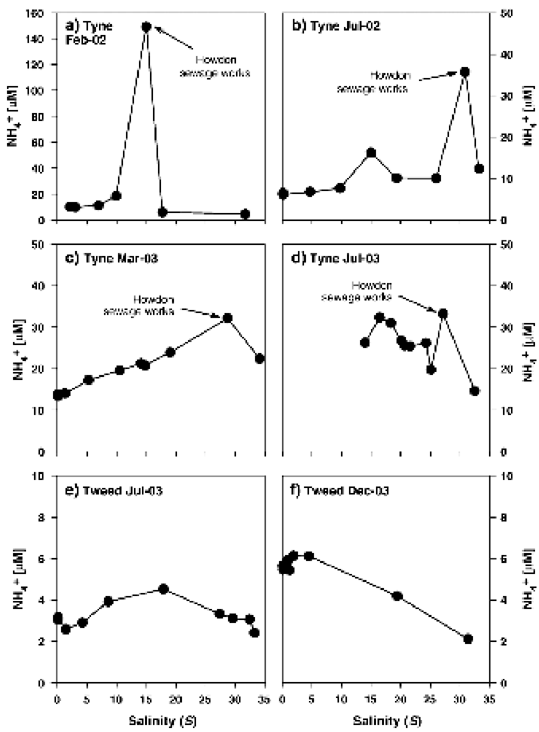

Figure 5 Concentrations [µM] of NH_4 in the Tyne estuary during (a) Feb-02, (b) Jul-02, (c) Mar-03, and (d) Jul-03 and in the Tweed estuary during (e) Jul-03, and (f) Dec-03 plotted versus salinity (S).

4 Conclusions & Wider Implications

In summary, this case study of relatively small temperate zone NE. England estuaries suggests that anthrpogenic DIN is rapidly flushed estuaries undergoes very little in-estuarine processing. This provides a contrast to large European estuaries, where significant N processing through autotrophic assimilation, denitrification and nitrifcation have been reported (e.g. Middelburg et al., 2001). Because of the inefficient operation of the estuarine filter the main impact of high N loading in these well-flushed smaller estuaries will therefore be felt in the coastal zone. One such important consequence documented results from the nitrification anthropogenic NH4+ potential leading to large N2O emissions in the coastal zone. The extent to which DIN is processed in estuaries appears to be influenced by size and fresh water residence time in European estuaries. For instance in large continental estuaries nitrate and ammonia showed removal during estuarine mixing (Middelburg, 2001). In contrast, in the smaller UK estuaries of the Tyne and Tweed rivers very little removal of nitrate and ammonia occurred which is attributed to their low fresh water residence time (Ahad et al, 2006). Therefore alteration of estuarine circulation due to human activities can profoundly influence estuarine capacity to process N.

Whilst the input of organic N and nitrate has declined in many urban estuaries due to sewage treatment, ammonia inputs through treated sewage still occur. Elevated NH4+ inputs may lead to enhanced generation of N2O via nitrification in estuarine and coastal zones (eg. de Wilde and de Bie, 2000). The evidence for intense nitrification in the urban Tyne estuary and adjoining coastal zone (Ahad et al., 2006); therefore, could potentially contribute to increased atmospheric emissions of N2O related to human activity. Such emissions wide-reaching implications for global climate change (Galloway et al., 1995) by further enhancing already significant coastal emissions (Bange et al., 1996, see also Atmospheric Inputs).

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The Potential for Carbon Finance in China's Grasslands
中国草地的碳金融潜力

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Abstract

Global estimates suggest that improved rangeland management has a biophysical potential to sequester 1300-2000 MtCO2e worldwide up to 2030. With a total area of 400 million ha, grasslands cover around 40% of China's land area. Official estimates suggest about 90% of China's grasslands are degraded to some extent, and most scholars agree that overgrazing and improper management are among the main causes. Improved management can reduce GHG emissions and sequester atmospheric carbon. What is the potential for carbon finance mechanisms to support improved grassland management? This paper outlines the key requirements for developing carbon finance projects in grassland areas. Based on analysis of existing data for China's grasslands, as well as practical experience of developing a grassland carbon finance project in China, this paper identifies mitigation options with potential as well as key constraints in linking these options to financing mechanisms.

摘要

全球碳估算表明，截至 2030 年，改善牧场管理能够增加 1300-2000 Mt CO2 固定量。在中国，草地面积为 40 亿公顷，约占中国陆地面积的 40%，官方估算表明，中国约 90%的草地有一定程度的退化，大多数学者认为是不适当的管理和过度放牧造成的。改善管理能减少温室气体排放和促进对大气中的二氧化碳的吸收。在中国，支持草地管理改善的碳贸易机制是什么？本文简述了发展草地碳融资项目的必要性。基于中国草地已有数据分析和中国发展草地融资项目的实际经验，本文指出了减缓碳排放的措施及这些措施的相关限制因子。

1 Introduction

Globally there are more than 120 million pastoralists who are custodians of more than 5000 Mha of rangelands (White et al 2000), a significant proportion of whom live in income poverty. Pastoralist livelihoods are dependant on utilization of natural resources. Traditional resource management practices in many pastoralist societies enable sustainable use of rangeland resources (Barrow et al 2007). Driven by inappropriate rangeland management and development policies, the breakdown of traditional resource management regimes and cessation of beneficial rangeland management practices has often been a key cause of rangeland degradation (IPCC 2000). Nevertheless, pastoralists continue to be blamed in international policy circles for land degradation (e.g. Steinfeld et al. 2006).

Without remedial action, average global temperatures could reach 2ºC higher than pre-industrial levels by 2035-2050 (Stern 2007). Other changes of significance for extensive livestock production include changes in the length and timing of the growing season, and changes in the amount and seasonal pattern of precipitation (Hall et al 1995), all of which can be expected to impact on the productivity of grassland resources and the livelihoods that depend upon them.

Appropriate management of grassland resources can also sequester atmospheric carbon in soils and vegetation. The IPCC estimates that up to 2030, grasslands globally have the technical potential to sequester more than 1400 Mt CO2e per year (IPCC 2007), and concludes also that the cost of implementing improved grazing management would not be prohibitively high. A report by McKinsey's (McKinsey 2009) also suggests that grassland management would be able to supply competitively priced emission reductions compared to many other potential mitigation sources. This is especially pertinent given the development of carbon markets. In 2007, the Kyoto compliance market made transactions worth US$64 billion, while the voluntary market traded at least US$337 million (Capoor and Ambrosi 2008). The value of the carbon market will continue to grow rapidly in the coming years. Could these growing markets be accessed to support sustainable resource management in China's grassland areas while also supporting livelihood development for the impoverished communities in this region?

2 Carbon sequestration in China's grasslands

China's grasslands cover almost 400 million ha, or 40% of China's land area, mainly distributed in the northern China (see Table 1). There are 18 main grassland vegetation types (DAHV & CISNR 1994, cited in Miller 2000), of which 5 types account for more than 60% of the grassland land area. These are: alpine meadow, temperate desert, alpine steppe, temperate steppe and lowland meadow (Miller 2000). Variation in vegetation types reflects the diverse characteristics of their ecosystems, including temperature, precipitation and evapotranspiration, as well as soils and other biophysical parameters. Their productivity – and hence abilities to sequester carbon – reflect a wide range of climatic resources across China, from arid and semi-arid zones, to temperate and alpine zones. Overall, grassland productivity in China has been found to be most sensitive to precipitation (Piao et al 2004).

Table 1 Grassland area by province in China

Province	Total area of Province (million ha)	Provincial Rangeland Resource			
		Rangeland (million ha)	% of Province	% of China's rangeland	Useable range (million ha)
Tibet	122.8	82.05	68.1	20.8	67.2
Inner Mongolia	118.3	78.80	68.8	20.0	68.0
Xinjiang	166.0	57.25	34.7	14.6	48.0
Qinghai	72.1	36.37	51.4	9.3	33.5
Sichuan	56.7	20.96	42.2	5.7	9.7
Gansu	45.4	17.90	42.1	4.6	--
Yunnan	38.3	15.30	24.4	3.9	--
Heilongjiang	45.3	7.50	16.5	1.9	4.8
Ningxia	5.2	3.01	58.2	0.7	2.6
Liaoning	14.6	2.00	13.7	0.5	--
Jilin	18.7	1.90	10.2	0.4	1.3
Other provinces	366.8	68.80		17.6	
Total	960.3	392.80			

Source: Miller (2000)

Average per capita incomes in most of the pastoral counties of northern China are below $2/day. With cash incomes often almost wholly dependent on livestock products, and herders also depending on livestock products for much of their subsistence consumption, herders face economic pressures to increase the size of their herds. Estimates suggest that nationwide, grasslands are on average overgrazed by 33%, and of 66% of China's 266 pastoral counties are overgrazed by 20% or more (Grassland Monitoring Station 2008). Long-term overgrazing is likely to cause shifts in vegetation communities towards less palatable fodder plant types, decreases overall vegetation coverage and leads to a loss of soil nutrients (including carbon) and water retention capacity, eventually causing surface erosion and desertification. Central government reports that about 90% of China's grasslands are degraded to some extent (MEP 2001), and in some regions, more than half of grasslands are considered to be moderately or severely degraded. Trends in degradation vary, with an increasing extent of degradation in some areas such as Qinghai (e.g. Liu Jiyuan et al 2008) and decreasing degradation extent in others, such as Inner Mongolia (Wang 2006). Grassland degradation not only causes loss of vegetation productivity and coverage, but also deterioration in soil properties and provision of other ecosystem services. Xie et al (2007) analyzed trends in soil carbon stocks under different land cover types in China between 1980 and 2004. Their analysis shows that farmland and forest soils contributed a small net sequestration over this period, while grasslands lost 3.5 Pg of carbon due to degradation. From a national perspective, therefore, China's grasslands are of great importance to the stabilization of soil organic carbon stocks in China.

Table 2 Mitigation potential of selected grassland management measures in China (soil carbon sequestration only)

Management practice	mitigation potential (tCO2e/ha.yr)	Notes
Exclosure from grazing	0.22 – 4.44	Range from 11 studies reporting results over more than 10 years
Planting grass	0.11 – 8.98	Range from 6 studies reporting results over more than 5 years
Reducing stocking from heavy to moderate grazing intensity	0.11 – 8.87	Range from 7 studies reporting results over more than 5 years
Cultivating shrubs	0.07 – 5.65	Range from 9 studies reporting results over more than 10 years
Abandoning cultivation of grasslands	0.33 – 10.63	Range from 11 studies reporting results over more than 10 years

Based on Wang, Wilkes and Lang (in preparation)

Methods for increasing the sequestration of carbon in grasslands are generally well-known. Table 2 gives a summary of a small selection of the available data on carbon sequestration of management practices in China's grasslands. With such diverse grassland ecosystems across China, and also considering the impact of site-specific land use histories, the mitigation potential of a given management measure will vary depending on site specific conditions. Some recommended practices (e.g. exclosure from grazing, reducing stocking rates) have been found to decrease soil carbon stocks in certain areas due to the specific response of vegetation to grazing pressure in these locations. Other recommended practices (e.g. planting grass) may also increase emissions if conducted improperly, e.g. if planting is preceded by plowing surface soils. Care should therefore be taken to ensure that adopted measures are suitable for the site.

Implementing the above measures requires financial investments to cover material, labour and other costs. In addition, some management measures will incur opportunity costs for herders. For example, exclosure from grazing requires the erection of fencing, which is costly (currently ca. Euro 1.1 per meter). Where lands have been degraded to such an extent that they are no longer usable, restoration of these lands will only incur direct financial investment costs, with little or no opportunity cost for herders. Other measures, such as reduction in stocking rates, can be cheap to implement but will cause herders to incur high opportunity costs in the form of future income streams that are foregone. Therefore, long-term implementation of improved management measures, and the restoration of degraded grasslands over time, requires a source of finance both to cover initial costs and to provide subsequent rewards or incentives for herders.

Over the last 10 years China has invested huge amounts of public finance in rehabilitation of degraded grasslands, cultivation of forage grasses and other investments targeted at improving production conditions in pastoral areas. Foremost among these has been a programme to retire and restore 66 million ha of grasslands between 2005-2010 across China. This programme funds construction of fencing to exclude grazing on degraded lands, and to facilitate seasonal resting of grasslands under pressure. In return, herders are paid varying amounts (generally around 70 RMB per ha per year) as a compensation. This small amount is often insufficient to make up for herders' opportunity costs, and some reports have noted declines in herder welfare as well as infringements of the programme's implementation regulations.

3 Carbon Market Prospects

Carbon markets have arisen to facilitate trade in GHG emissions. The carbon market exists because of requirements on or voluntary desire of market participants to reduce CO_2 emissions. The carbon market can be classified in three market segments: (i) Kyoto compliance market; (ii) other compliance or pre-compliance carbon markets; (iii) voluntary carbon market.

Compliance markets originate from governmental or intergovernmental regulations determining a cap on emissions of carbon and other greenhouse gases like methane and nitrous oxide. These regulations are the main driver of demand for the rapidly growing carbon market. The Clean Development Mechanism (CDM) established under the Kyoto protocol provides a trading platform for ERs from developing countries. In the Agriculture, Forestry and Other Land Use (AFOLU) sector, only ERs from afforestation and reforestation activities are eligible. Because of concerns that carbon sequestered in terrestrial carbon sinks may be reversed (i.e. emitted at a later date), other land uses were not included in the first commitment period of the Kyoto Protocol, and even forestry emission reductions are not tradable on the EU Trading System (ETS), the largest trading platform. However, there is strong support among some quarters for inclusion of selected land use activities in a post-2012 agreement.

Other compliance markets exist in Australia and the US at the state level, e.g. the New-South Wales Greenhouse Gas Reduction scheme (NSW GGAS) or the Regional Greenhouse Gas Initiative (RIGGI) in Northeastern and Mid-Atlantic states of the US. The Western Climate Initiative, covering 11 US states and Canadian provinces, is currently under design. At federal level, Australia, the US and New Zealand are planning to establish emissions trading systems. The largest carbon market is likely to evolve in the US. Some draft proposals (e.g. the former Lierberman-Warner Bill) consider AFOLU activities, including rangeland activities at the national level, and forestry at both national and international levels, and there is strong support from some quarters (e.g. National Faming Union) for inclusion of rangeland activities in a future national scheme.

The Chinese government has not agreed to a cap on GHG emissions under international agreements, but has been relying on administrative and programme measures to reduce emissions from the domestic energy and industrial sectors. There has been some discussion of future potential carbon trading schemes within China, and among some sectors the general expectation is that some form of cap-and-trade system will eventually be put in place. One proposed scheme, the ‘China Carbon Balance Trade Scheme’ (CECPA 2008), suggests that emission levels be regulated at the provincial level, with provinces exceeding a given amount paying into an ‘ecological compensation fund’, from which provinces with emissions below a given amount can be rewarded. According to the designers of that scheme, the most likely beneficiaries of the scheme are three provinces which are possibly net carbon sinks: Yunnan, Tibet and QInghai. These latter two provinces, in particular, have vast grassland areas with large carbon stocks (Wang Genxu et al 2002), as well as large degraded areas with large potential for sequestering additional carbon through restoration.

Given that emission reductions from China’s grasslands are not currently eligible for any compliance market, the only existing potential lies in trade through the international voluntary market. The voluntary market trades ERs that cannot be used for regulatory compliance. The market also serves as an incubator for innovative ER activities that are not eligible under any compliance market regime. The voluntary market is tiny compared to compliance markets. In 2007, the voluntary carbon market exchanged 65 million tCO_2e (Hamilton, et al 2008), of which 22 million tCO_2e were transacted by the Chicago Climate Exchange (CCX). Since 2007, in close cooperation with US farmer organizations, the CCX has been trading ERs from rangeland management activities. The vast majority of the buyers of voluntary carbon credits are private businesses. The Voluntary Carbon Standards has issued guidance on AFOLU project activities, including grasslands (VCS 2008), but a methodology of grassland carbon sequestration project has yet to be developed.

4 Requirements and Opportunities for Grassland Carbon Projects in China

Box 1 shows the main requirements for designing a carbon finance project. A carbon finance project requires a robust and transparent institutional set-up to generate, aggregate and trade carbon assets. This arrangement should ensure that performance is met because payments are made for measured emissions reductions over a long period. In general terms, this requires a project developer that generates the carbon assets, a standard recognized by the buyer of the carbon assets, and a third party certifier that is accredited by the relevant standard. Specific institutional requirements include extension agencies to promote and support adoption of carbon sequestering management practices; financial agencies to facilitate fund management and carbon payments; and research agencies to support monitoring of carbon stock changes. At the community level, it is most essential that herders have clear tenure over their grasslands so that land use and grazing management can be ensured, and so that the beneficiary of payments is clear. In China, around 60% of all grasslands have already been contracted out by the state, and of these, 68% has been contracted to individual households (Li Xianglin 2007). Even where grasslands have been contracted to communities collectively, this can also be considered a clear tenure right as long as others can be excluded from using the grasslands without permission of the tenure holder. Where tenure rights are not clear or enforceable, this will prove a constraint on the development of carbon finance projects (Tennigkeit & Wilkes 2008).

Box 1: Basic elements of carbon finance project design

- An institutional set-up that considers performance, equity and gender issues.
- An approved methodology detailing the baseline of CO_2 emissions and a carbon monitoring approach.
- A Project Design Document detailing:
  - A baseline description to demonstrate the business-as-usual situation and the with-project scenario
  - Justification of additionality to demonstrate that the project can only be implemented because of the carbon finance component
  - A leakage assessment to avoid the project resulting in extra new carbon emissions outside the project area
  - A permanence or reversibility assessment to avoid the emission of sequestered carbon
  - A carbon monitoring plan detailing the monitoring design and intervals.

Source: Tennigkeit & Wilkes 2008

Carbon finance projects are required to contribute to sustainable development of the host country as defined by the designated national authority (DNA), and DNAs also confirm the legal status of the carbon assets created, which is essential for security of investment by the purchasers of ERs generated by the project. Grassland carbon finance projects would clearly contribute to China's sustainable development goals. For example, grassland management is highlighted as a major sector in China's climate change action plan (NDRC 2007), as well as in China's national plans for environmental protection (State Council 2006)

China has been actively following international discussions on land use, land use change and forestry (LULUCF) in relation to future reforms of the international climate mitigation regime (e.g. Zhang and Hou 2009). At present, however, there has been no formal assessment of the mitigation potential of China's grasslands, and its potential role in China's future portfolio of mitigation actions is still undetermined. While China has strong capacities to undertake research on carbon sequestration and GHG cycles in grasslands, national scientists have mostly not been involved in in-depth consideration of the implications for national mitigation policies. Grassland administrators and the researchers who traditionally have advised them from a production perspective, on the other hand, lack in-depth understanding of carbon cycles and sequestration potential. There is, therefore, a role for international organizations to play in facilitating linkages among national actors, so that the role of grasslands in climate change mitigation can be properly assessed and considered in China's future mitigation plans. In addition to research approaches to raising awareness, early pilot action using the opportunities provided by the international voluntary market is a good way to enable stakeholders to understand the potentials of carbon sequestration in China's grasslands. With this goal in mind, ICRAF-China and the Center for Mountain Ecosystem Studies of the Chinese Academy of Sciences have begun to design a carbon finance project in Qinghai province.

5 Conclusions

1. The basic principles of carbon sequestration in grasslands are well known and documented. Carbon sequestration by management practices has been well documented for a range of grassland ecosystems in China.
2. Given widespread poverty in China's grassland areas, herders have strong incentives to sacrifice longer-term sustainability for short-term income needs.
3. Carbon finance could provide a potential source of incentive payments for sustainable use, but only in areas with suitable biophysical properties and under cost constraints.
4. China has experience of implementing grassland protection programmes across large areas, and institutional arrangements are already in place.
5. There is a need to raise awareness among policy makers and scientists with policy advisory roles, as well as scientists to apply their research.
6. In addition to research, early pilot action can help stakeholders understand the potential for carbon finance in China's grasslands. With this goal in mind, a carbon finance project is being designed for implementation in Qinghai province, China.

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The Use of Urea Fertilizer in Hebei Province: Farmers' Practice and Awareness of Environmental Consequences

河北省尿素的使用状况：农民对环境重要性的认知和实践

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Abstract

Over the last two decades the use of chemical fertilizer became important for China to increase productivity and to reach food self sufficiency. Nitrogenous fertilizer is widely used in the intensified system of winter wheat and summer maize double cropping in Hebei province, one of China's main grain production areas. Former research provides evidence of an over-application of mineral fertilizer and leads to the issue of water and soil degradation due to overuse of fertilizer. The study at hand combines quantitative and qualitative methods to assess the recent fertilization practice, the socio-economic factors influencing fertilizer application and the awareness of the rural population on the relation between over-fertilization and the degradation of environmental resources. Using the unique opportunity to combine long-term panel data with recent qualitative assessments the study reveals that the main factor influencing the amounts of fertilizer applied is the price of fertilizer. The content of chemical fertilizer is found not to be what it should be according to the labels on fertilizer bags. Although there is some awareness about negative environmental effects among farmers, they largely lack sound knowledge about water, soil or fertilizer quality. Therefore it is important to establish a system of agricultural knowledge transfer that is independent of the input supplying industry. Besides, the extension messages regarding fertilizer use should be based on proper results of local soil testing. Finally, regular quality controls should be introduced to guarantee the labeled fertilizer contents to reach a more sustainable level of nitrogenous fertilizer use.

摘要

在过去的二十年中化肥的使用很重要在中国，因为它可以增加产量和促使达到食物自给自足。在中国粮食主产区之一的河北省，氮肥在冬小麦和夏季玉米的轮作中被广泛的使用。以往的研究证明化肥过度使用，这就导致一个问题：非有机化肥的使用如何促使水和土壤的退化。本研究综合定量和定性分析方法以分析近期的化肥使用情况，影响施肥情况的社会经济学因素以及农户对过度施肥和环境资源的退化之间关系的认知程度。综合长期的面板数据和近期的定性分析发现：影响化肥使用量的主要因素是化肥的价格。化肥的实际成分和化肥袋子上面标注的不

完全一致。尽管农户对化肥过度使用对环境的负面影响有一些了解，但是他们很大程度上缺乏关于水、土壤或是化肥质量的可靠的知识。因此建立一个独立于农资供给行业的农业知识传递系统非常重要。同时，关于化肥使用的推广信息应该以当地土壤检测的正确结果为基础。最后，建议实施定期的质量控制以保证标签化肥的成分达到氮肥可持续使用水平。

1 Introduction

The North China Plain (NCP) is characterized by a system of winter wheat and summer maize rotation cropping. According to the World Bank (2001) the production of grain crops is responsible for a big share of chemical fertilizer overuse in China. According to former studies the NCP, including Hebei province, is not an exception from this trend of overuse of chemical fertilizers (Ju et al., 2006; Zhao et al., 2006). The over-application of chemical fertilizers is of major concern for Hebei province considering the negative effects it has on natural resources and especially groundwater (Li et al., 2001). Zhu et al. (2006) state that for 1995-96 the Chinese government considered the level of over-use of fertilizer to be around 35% in Hebei. The use of urea fertilizer is analyzed due to the available secondary data set according to which this type of fertilizer is the mostly applied nitrogenous fertilizer in the villages contained in the data set.

The paper focuses on the assessment of recent fertilization practice in the Hebei province and, explores the awareness of farmers about which impacts the application of chemical fertilizer can have on the environment. Former studies about Hebei assessed land and its allocation, estimated the efficiency of the agricultural production system (Piotrowski, 2009) or analyzed environmental degradation separately from socio-economic variables. Due to our knowledge no study was undertaken that aimed to link fertilizer quality, farming practice and farmers' environmental perception about the use of mineral fertilizer to reveal threats to the sustainability of agricultural production. Therefore this paper contributes to the existing literature about sustainable agriculture in North China by combining quantitative and qualitative economic methods with natural science measurements of fertilizer quality to provide a basis for policy recommendations. The second section briefly reviews studies on environmental degradation due to over-fertilization, associated health problems and social costs. In section three the methodology is explained, four presents the results and five discusses policy implications. Section six concludes and provides an outlook on further research necessary for impact assessment of policies to promote methods of sustainable agriculture in the study region.

2 Water Pollution, Land Degradation and Health Effects of Fertilizer Use in China

There is some debate to how far there is really an over-application of all varieties of chemical fertilizers in China (World Bank, 2001). What seems to be clear is that different kinds of fertilizer are not used in a balanced way and this could reduce the efficiency of uptake by the plants (World Bank, 2001). Also Liew (2004) mentions that chemical nutrients are often not used effective. Especially nitrogen fertilizer is applied in too high doses, too early or with an unbalanced ratio of N to P and K. She (Liew, 2004) highlights that an imbalance in nutrient management contributes to pollution of water sources such as lakes and rivers and that a lot of N in China is lost due to emissions to the atmosphere. There exist several problems with water pollution (Li et al., 2001) which affects peoples living and health via the direct intake or contact with polluted water. For some rural areas in northern China varieties of cancer, which are suspected of being related to e.g. high concentration of nitrites or nitrate in groundwater (Morales-Suarez-Varel et al., 1995) or other pollutants, are higher than in other regions in China (Lu et al., 1986; Zhang, et al. 2000) and also higher than the world averages (World Bank, 2007).

Yang (2006) mentions that Chinese farmers traditionally are aware of the importance of manure use for the amount of agricultural output produced and soil quality. But he also states that the amount of manure declined over the last decades since more chemical fertilizer became available. As a consequence the content of soil organic matter has rapidly declined in most areas of China. Also the use efficiency of N is mostly below 40% (Yang, 2006). So he concludes that extension education is needed to emphasize the importance of organic fertilizer on soil quality and nutrient use efficiency and also to make farmers aware of the environmental and health consequences of chemical fertilizer overuse. Zhen et al. (2005) found in their study in Shandong province, which is neighboring to Hebei, that contacts between farmers and extension workers are rare.

Zhen et al. (2005) also state that the application of chemical fertilizers led to a contamination of soil and groundwater in the NCP and therefore advocate for an agricultural production that should respect the three dimensions of sustainability. It should not overexploit natural resources to provide also for later generations an intact environment; it should be economically profitable for the persons engaged in agricultural production and accepted by the society as contributing to food security and resource conservation.[1]

3 Methodology

Four methods were used and combined to evaluate the recent urea fertilizer application practice and the awareness of farmers considering interdependencies between fertilizer use and water and soil quality.

[1] Some studies calculate the benefits and costs of China's past and recent development with respect to the three pillars of sustainability (Wen and Chen, 2008) and assess economic costs that derive from a polluted environment (World Bank, 2007). Since those studies cover either whole China or sub-regions but not provinces it can only be assumed that the costs to prevent environmental pollution or to recover natural resources increased also in Hebei province over the last two to three decades.

(1) From a secondary panel data set available for the Hebei and provided by the Reseachr Center for the Rural Economy (RCRE) province summary statistics were used to obtain the overall use level of urea fertilizer over the years 1995 to 2002.
(2) These data can also be used to identify determinants of urea fertilizer use via panel data regression models. An unbalanced panel data set containing 4.832 observations over 8 years is analyzed.
Random effects Tobit models as:

$$y_{it} = \alpha + \beta \mathbf{x}_{it} + \upsilon_i + \varepsilon_t ,$$

where i = observation unit (household) index
t = time index
α = constant
β's = coefficients of respective variables to be estimated
x_{it} = vector of explanatory variables
υ_i = individual random disturbance
ε_t = random disturbance related to time

are used for the regression analysis.[1] Different models are estimated with either including or excluding location specific dummy variables and households' allocation of labor time. When interpreting the results one has to consider that no information was available about the amount of fertilizer really applied by the surveyed households. Only data about the purchased amounts are provided. In the survey it is asked in every year for the same kind of fertilizer considering the fertilizer name, e.g. *niaosu* for urea fertilizer, but there exist several different varieties and brands in every category of fertilizer.

Conceptually there are several variables one could think about when analyzing the determinants of fertilizer use. Such variables can be for example the location of fields in plain or mountainous regions or different climatic zones or the irrigation infrastructure of specific villages. Other variables to explain urea fertilizer application are related to farmer's individual either observable characteristics as education level reached, years of schooling or agricultural training received. As Demeke et al. (1998) mention also variables such as farmers' former experience with fertilizer, the availability of plowing animals or machinery, the ratio of fertilizer costs to the price of the major farm product or the competitiveness of fertilizer marketing systems influence the fertilizer application. Stern (2005) lists individual related variables such as environmental predisposition, attitudes about product characteristics (here fertilizer) and the perception of costs and

[1] Since there are households that don't purchase or apply urea fertilizer the data are censored and the left side limit for the dependent variable is 0.

benefits from specific (environmental protection) actions that significantly influence environmentally behavior. Those individual characteristics are generally hidden and one would need to use specific methodologies such as casual models or Bayesian networks approaches (Sanscartier and Neufeld, 2006) or well structured individual level panel data sets to uncover unobservable variables (Hausman and Taylor, 1981).

The variable for the use of urea fertilizer (amount in kg per mu) as dependent variable is an approximation. The variable “purchase value of urea fertilizer” is divided by the variable “amount of urea fertilizer purchased”. The resulting number is divided by the sum of sown area in mu (= 1/15 ha) for grain crops, cash crops and vegetables. Overall there are 3832 observations for urea fertilizer use. Table 1 contains all the variables used in the regressions, their descriptions and summary statistics.

Education is used as explanatory variable because it is expected to reflect the reaction of farmers on price changes of fertilizer (Huffman, 1977). Demeke et al. (1998) consider a positive relationship between fertilizer use and education because a higher level of education is seen as a basis for accessing information about improvements in farming techniques. With respect to the price sensitivity of farmers the education variable is expected to have a negative effect on the amount of urea used. But following the argument of access to improved techniques we would expect to see a positive sign for the education variable.

Most of the households contained in the sample can be seen as subsistence households. Besides producing for markets they rely on their own agricultural production to satisfy nutrition needs. A higher number of household members that could be engaged in working on the household’s available land can be seen as a substitute for fertilizer since more labor would be available for crop production (Croppenstedt and Demeke, 1996; Green and Ng'ong'ola, 1993). Therefore the sign of the variable HH_SIZE is expected to be negative. Also for the LAND variable the subsistence argument would hold. If a household has access to more land than it could meet its production goals or nutrition needs more easily. But if there is less land available than the household would have to use inputs as mineral fertilizer more intensive (Feder et al., 1985). So also for LAND the sign of the coefficient is expected to be negative.

The price of urea fertilizer is expected to have a negative effect on the amount of fertilizer applied as economic theory suggests a decline in demand if the price of a (normal) good rises. Kherallah et al. (2001) show for the case of smallholder farms in Malawi that the effect of fertilizer price on its use can be insignificant.

In general one would expect off-farm income as contributing to lower levels of mineral fertilizer applied because the additional income would reduce the necessity of the household to raise yields and by this the income from agriculture (Feder et al., 1985). So the expected sing for OFF_INC would be negative with respect to the applied amount of urea fertilizer. But as Knepper (2002) points out one has to be aware that it is likely that (off-farm) income is endogenous to a farm household's decision about the applied amount of fertilizer.

A variable for membership in the Communist Party is included to reflect the possibility that party members may be better performing in economic terms in their village due to better access to extension services or credits. The sign of this variable is expected to be negative.

Further variables that are assumed to influence the use of agricultural inputs as gender or age of the household head (e.g. Croppenstedt and Demeke, 1996) are not included in the models because they are not available for the respective time span. Also there is no variable in the data set that would allow estimating the effect of extension on the levels of fertilizer applied (Demeke et al., 1998). With respect to China it would also be interesting to incorporate a variable that reflects tenure insecurity since this could be related to farmers' incentives of investing in long-term site specific land improvements (Otsuka and Place, 2001). Data about land reallocation are not provided in the household data set used here.

Table 1 Variables used in the quantitative analysis and their descriptive statistics

Variable	Description	Mean	Std. Dev	Min	Max
Dependent variable[1]					
CARB_FERT_USE	Logged total amount of urea fertilizer purchased per household (hh) per mu of sown area in kg	11.69	11.010	0	166.7
Independent variables					
EDUC	educational level attained by the main laborer (illiterate = 1, elementary school graduate = 2, secondary school graduate = 3, high school graduate and above = 4)	2.64	0.753	1	4
HH_SIZE	Number of permanent residents in the household	4.21	1.515	1	13
CARB_FERT_PRICE	Logged price for urea fertilizer (Yuan/ kg) as an approximation calculated by dividing the value of urea fertilizer amount purchased per year by the quantity purchased	1.65	0.659	0	24
LAND	Farm size measured by the area of cultivated land of the farm household (at year end) (mu)	6.99	4.734	0	28.3
OFF_INC	Share of off-farm income of the hh per year in Yuan	44.52	28.459	0	100
PARTY	Dummy for hh with party members (yes = 1, no = 0)	0.19	0.392	0	1
V_1	Dummy variable for village 1	0.16	0.371	0	1
V_2	Dummy variable for village 2	0.15	0.356	0	1
V_3	Dummy variable for village 3	0.15	0.353	0	1
V_4	Dummy variable for village 4	0.10	0.299	0	1
V_5	Dummy variable for village 5	0.23	0.420	0	1
V_6	Dummy variable for village 6	0.21	0.409	0	1

[1] For ease of interpretation, summary statistics are given for the unlogged variables.

Source: own calculations based on the RCRE data for the Hebei province for the years 1995-2002.

To gain an insight into the local farming situation some villages of Hebei province were visited in June and July 2008. In these villages as a third method qualitative interviews with farmers, village heads, extension workers and fertilizer sellers have been conducted. One aim of these interviews was to identify sources of farmers' knowledge about their farming practice, input use and their awareness of environmental problems. Farmers that were interviewed have been chosen purposively. During a first interview with the village head, who could be considered as a key informant, he was asked to show us one farm household that performs well in farming and can be considered as better-off in the village and one farm household that is not that successful and worse-off. This was done to widen the range of possible answers from the point of view of people of different social or economic status in the villages.

During a quantitative survey in Hebei in September 2007 farmers often raised mistrust against the quality of fertilizer. So as fourth approach to evaluate the recent use of fertilizer input in rural Hebei, with respect to environmental effects, fertilizer samples were collected and analyzed in a laboratory. The samples where collected in the same villages in which the interviews have been conducted, with one exception where the shops where located in a township close by the village. Due to the local conditions fertilizer shops are mainly allocated along one major road and there are around 2-4 sellers in the village. Either one of the shops was randomly chosen or it was tried to get a sample from every seller. The results of the analysis are then compared with the content ratios of chemical nutrients that were stated at the fertilizer bags.

Even if the results of these four descriptive, quantitative, qualitative and natural science methods can not be combined one to one and completely they provide a conclusive insight in the links between fertilizer use and quality and consequences of miss-application on natural resources especially water and soil.

4 Results

Based on the RCRE data the amount of urea fertilizer purchased per mu had its peak in 2000 with a slight decline in the following two years (Figure 1). The calculations for the years before 1995 and after 2002 confirm this tendency as well as the year of peak in 2000.[1] The amount of urea fertilizer purchased per mu in 2002 is around 16 kg (equals240 kg/ha/year). According to Cui et al. (2007) this is in line with recommendations of nitro-

[1] The results are not presented here since the variables that where used to calculate those numbers are different for the years 1986-1993 and 2003-2006.

gen containing fertilizer for crops like vegetables.[1] Accordingly, if wheat and maize are produced less nitrogen fertilizer should be applied. Also one has to have in mind that in most areas in Hebei province soils are already overloaded with nitrogen (Wang et al., 2007) and nitrogen residuals can be found in groundwater (Li et al., 2001). Considering this and taking into account the high load of nitrogen in irrigation water a total amount of 11-13 kg nitrogen fertilizer per mu is recommended for ensuring stable yields (Feike, 2008).

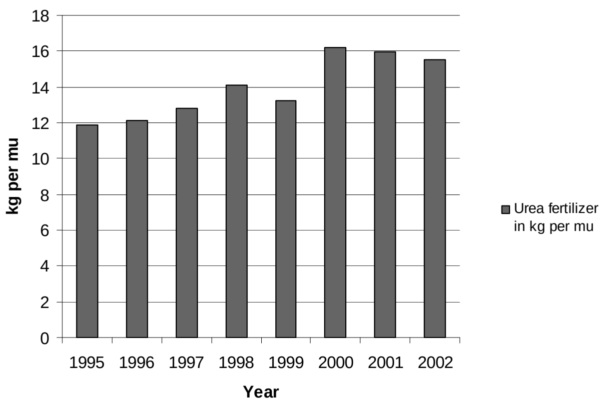

Figure 1 Amount of urea fertilizer purchased per year per mu, 1995-2002
Source: Own calculations based on the RCRE data for the Hebei province for the years 1995-2002.

No direct goodness of fit test can be provided for the underlying random effects Tobit model. The results for "the Wald test statistics reject the null hypothesis that the parameters in the regression equations are jointly equal to zero" (Al-Malkawi, 2007, p. 57) in all model specifications. For all models that contain village level dummies the values for rho are lower then the respective model without the village component. This is a hint that individual effects are less significant then in the models excluding village variables.

The level of education reached by the household head contributes positively as expected to the purchase of urea fertilizer. But the effect is only significant in models (1), (3) and (4). The size of the rural household has the expected negative effect on the amount of nitrogen containing fertilizer purchased. Household labor can be seen as a substitute for mineral fertilizer for the data set analyzed. For the models that include the village dummies this effect is of less importance. The effect of a change in the number of household members on the amount of nitrogen fertilizer used is strong in models (1), (3) and (5). One additional member in the household would contribute to a decline in the use

[1] It has to be considered that in addition to urea other nitrogenous fertilizers are applied such as ammonium bicarbonate and compound fertilizers. So the total levels of N applied reach between 500 and around 800-840 kg/ha/year (Grontmij Nederland bv, 2008) in some areas of Hebei.

of fertilizer by 8.4, 14 and 5.8% respectively. However the inclusion of the village dummies leads the household size to become insignificant. As expected farmers reduce the amount of fertilizer purchased with rising prices. The price variable is significant at the 1% level of error probability for all models and the sign of the coefficient is as expected negative. A 1% price increase would lead to a decrease in fertilizer application of around 0.4% (Table 2). This price elasticity is low but in line with the results from the qualitative interviews that reveal that farmers are in fear to endanger their yields by reducing the use of fertilizer too much. Also other studies (Xiang et al., 2007) revealed a low price elasticity for mineral fertilizer. It is worth to notice that the coefficients for the variable LAND change their sign to minus in models (2), (4) and (6). Even if LAND is only significant at the 10% level of error probability those models are considered more important since they include village location variables. A decline in the amount of fertilizer applied if the farm household farms a bigger area of land is in line with the expectation that the household does not have to use the available land as intensive as in the case of small area of land to reach the consumption needs or expected yields. One additional mu of land available for farming leads to a decline in fertilizer amount in the above models by respective 1.8, 2.3 and 1.8%. That the effect is slightly stronger for full-time households confirms the expectations that they use land and inputs more intensive since their well-being depends stronger on agricultural production then it is the case for part-time households. No clear and significant effect of additional off-farm income on the use of urea fertilizer is found. For the models containing all observations the share of off-farm income has a slightly negative effect on the purchase of mineral fertilizer. But also for this variable the location effect is stronger.

The variable that shows membership in the Communist Party does not have an influence on the use of urea fertilizer. If the sample is separated into households that are engaged full-time in agricultural production and households that stated to be part-time engaged also in other activities, all household and household head related variables become significant.[1] The negative price effect is even stronger for the part-time households. This is plausible since part-time farmers have a more diversified income whereas full-time farmers strongly depend on agricultural outputs and therefore don’t want to risk a decline in yields just because of a “too low” amount of applied fertilizer. The highly significant coefficients of the village dummies indicate that village characteristics are more significant in explaining farmers’ fertilization practice than farm household characteristics. But this result could also reflect differences in farmers’ perception of fertilizer quality or differences in the competitiveness or transparency of the local fertilizer markets.

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[1] The data set contains a variable “Household time allocation”. Households that state that they are allocating their labor time full time to agricultural production are considered as full-time households in the study at hand. Households that mainly devote their time to agricultural or mainly to non-agricultural production are treated as part-time households.

Table 2 Urea fertilizer use, 1995-2002

Dependent variable CARB_FERT_USE	All observations		Only full time farm households		Only part time farm households	
	(1)	(2)	(3)	(4)	(5)	(6)
Village Dummies	No	Yes	No	Yes	No	Yes
EDUC	0.042 **	0.004	0.056 **	0.041 *	0.018	-0.017
	(0.018)	(0.014)	(0.025)	(0.022)	(0.026)	(0.019)
HH_SIZE	-0.084 ***	-0.019 *	-0.140 ***	-0.012	-0.059 ***	-0.018
	(0.013)	(0.011)	(0.020)	(0.019)	(0.016)	(0.014)
CARB_FERT_PRICE	-0.412 ***	-0.407 ***	-0.368 ***	-0.376 ***	-0.398 ***	-0.415 ***
	(0.028)	(0.027)	(0.039)	(0.038)	(0.039)	(0.038)
LAND	0.020 ***	-0.012 **	0.054 ***	-0.014 *	0.004	-0.014 **
	(0.005)	(0.005)	(0.008)	(0.008)	(0.005)	(0.007)
OFF_INC	-0.002 ***	0.001	-0.001 **	0.001	-0.002 ***	0.001
	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
PARTY	-0.066 *	0.023	0.004	0.054	-0.092 *	0.019
	(0.038)	(0.027)	(0.057)	(0.045)	(0.047)	(0.034)
V_1		0.262 ***		0.277 **		0.218 ***
		(0.049)		(0.107)		(0.060)
V_2		0.308 ***		0.365 ***		0.290 ***
		(0.060)		(0.141)		(0.072)
V_3		0.646 ***		0.577 ***		0.655 ***
		(0.045)		(0.102)		(0.054)
V_4		-0.450 ***		-0.635 ***		-0.430 ***
		(0.057)		(0.116)		(0.072)
V_5		1.147 ***		1.108 ***		1.070 ***
		(0.037)		(0.089)		(0.054)
N	3832	3832	1439	1439	2363	2363
rho[a]	0.563 **	0.182 **	0.664 **	0.301 **	0.487 **	0.191 **
Wald Chi-squared[b]	308.47 ***	2267.50 ***	174.79 ***	1018.34 ***	132.91 ***	901.38 ***

z-statistics in parentheses.
***: significant at 1% level of error probability
**: significant at 5% level of error probability
*: significant at 10% level of error probability
[a]:Rho gives the proportion of total variance contributed by panel level variance component (Al-Makawi, 2007).
[b]:The Wald Chi-Square test statistic is the squared ratio of the estimate to the standard error of the respective predictor. The probability that a particular Wald chi-square test statistic is as extreme as, or more so, than what has been observed under the null hypothesis is given by Pr > ChiSq (https://www.ats.ucla.edu/stat/SAS/ output/sas_ ologit_output.htm).
Source: own calculations based on the RCRE data for the Hebei province for the years 1995-2002.

From this part of the analysis it can be concluded that the main factors that affect farmers' fertilization behavior are the number of household members, the price of fertilizer and the available amount of farm land. These results are robust when village dummies are included since the coefficients hardly change.

During (quantitative) interviews in villages in Quzhou county of Hebei in 2007 village heads and farmers said they didn’t trust the quality of fertilizer or the recommendations given by fertilizer companies and merchandisers regarding application rates. The qualitative interviews conducted in 2008 in different villages and counties of Hebei province partly confirm this prevalence of mistrust. Farmers complain about faked fertilizers and that they prefer to buy brands they trust. But even then they expect, that the fertilizer contains less chemical contents than stated on the bag (Village 01_Farmer 01, Village 02_Farmer 01). Surprisingly, the same farmers would still go for the cheaper fertilizer even if they trusted this fertilizer brand less. In contrast to the quantitative results almost all farmers state in the interviews that they would not reduce the amount of fertilizer applied, if the price would rise. From an individual perspective this behavior seems plausible since most of the farmers associate a lower level of fertilizer applied with lower yields. Also farmers believe that fertilizer has no adverse influence on the environment especially ground and surface water because they believe that redundant fertilizer remains in the soil. This is in line with the result of Zhen et al. (2005) that farmers see no link between high levels of nitrate and groundwater pollution.

However, there is evidence that farmers are aware of the interplay between the environment and their farming practice. Farmer01 in Village04 clearly mentions that chemical fertilizer is harmful to the environment and that the use of manure is necessary for maintaining a good soil quality. He says that most of the farmers have to use chemical fertilizers because they don’t have manure. The knowledge about application levels and properties of fertilizer is reported to be transferred from one generation of farmers to the next or stemming from own experience. If plants don’t grow as expected, more fertilizer is applied. So fertilization decisions are taken by the farmers without using information from scientists or extension workers, if provided at all, because they also don’t believe in science (Farmer01 Village05). Some farmers would like to test the soil quality (Farmer02 in Village 05) but there are no simple soil analysis kits available and sending the sample to a laboratory would be too costly. Missing knowledge about fertilizer and its application to specific soils does not only exist among farmers. One fertilizer vendor (close to Village03) asked us if we could tell him if the fertilizer he sells fits to the soil in this region. Also the interviewed shop keepers state that they don’t check the quality of the fertilizer traded. After being asked: “What quality control do you have for fertilizer?” Seller_02 in Village01 answers that he trusts the big national-inspection free companies from where he purchases the fertilizer.

The effectiveness of the extension services differs by regions. In Village01 and Village02 the extension service does not function at all. The head of Village01 states that there have been measurements of soil but he just says that “…somebody came to the village and measured the soil". So even if there are tests the results don't seem to be communicated to the farmers. An explanation for the bad coverage of the region where Village01 and Viallge02 are located is provided by one of the leading extension workers in the county. She says that there was no new personal joining the extension service since 1993. Recently there are 10 extension workers responsible for 342 villages. Since different media (TV and Radio) inform farmers about actual events like pests this is considered to be sufficient for covering the county. Some extension workers are based in so called scientific stations in the villages but they are "hardly more than a person with a telephone" (Extension Worker Village02). So she states that these persons have to run a sideline or even major business as input dealers since there is no funding provided to them by the town or village.

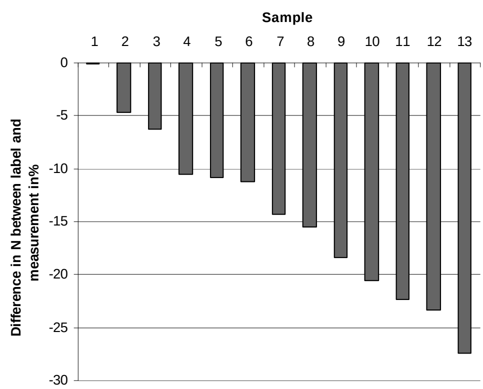
The situation is different in Village03 and Village04 that are located in another region of Hebei and where the system of one technician per village works well (Farmer01_Village03). In addition, these villages are visited by extension workers from the county regularly. Farmers are satisfied with this service and regard the management knowledge provided as important for their fruit tree production (Farmer01_Village04). Also in Village05 the extension service does provide support to the farmers. Recommendations for fertilizer application are given to the farmers but according to the head of Village05 the farmers do not follow the recommendations and apply more because they expect this would increase their output. Farmer01 in this village states that "…the farmers do not attach much importance (to the agricultural extension service), it's their own crops, own experience, they don't believe in science". However, the village head (Village05) states that 60 jin (30 kg) per mu would be an appropriate amount of fertilizer, while he considers 100 jin (50 kg) to be a waste. Two farmers (Famer01 Village01 and Farmer01 Village02) have been asked how they would change their fertilization practice if the land would be privately owned; both did not provide an answer.

As a general result we find that there is more extension service provided in the areas where fruit trees are cultivated (Village03 and 04) than in the areas that are dominated by wheat, maize and cotton production. This could also explain the dominant effect of the village dummies in the quantitative analysis that results in most of the independent variables becoming insignificant. Overall farmers who are visited regularly by extension service staff state that they are satisfied with this service. Farmers who are not visited are unsatisfied with this situation and farmers visited irregularly mention mistrust against the provided recommendations.

Even if the problem of salination of soils is not severe anymore in the Hebei province there are still other factors that lead to the degradation of soils. Yang (2006) considers farmers' practice of using crop residuals and 'organic waste' for plant nutrition and soil improvement as good to keep soil quality high. Over the last years, and especially since the amount of chemical fertilizer available rose, one can see more and more cases where crop residuals are not used in an environmentally sustainable manner. Recently, the burning of wheat ore maize straw became common practice in some parts of Hebei, although this is prohibited. In some cases, the ashes are not even incorporated into the soil properly. The same behavior was observed for plastic film that either stays in the fields or is burned. Asked about environmental influences stemming from farming farmers sometimes do not understand the reason why to ask such kind of questions. Farmer01 in Village05 says that there is no industry in or around the village so there is no source of pollution. Also the Farmer01 in Village04 says that the only source of pollution around was a chemical factory close to the village, but since this factory is closed there is no pollution anymore. The head of Village01 says that farmers are no scientists and therefore do not know if fertilizer has some impact on water quality. Farmer01 in Village03 says that there is no influence between agricultural production and the environment. Consequently most of the interviewed persons consider the environment in and around their villages as good. But for example Farmer02 in Village01 mentions that growing more trees as advocated by the village could lead to more photosynthesis and more rainfall and judged this as a positive effect of environment on agriculture.

As explained in the methodology part it was aimed to assess the fertilizer quality by collecting samples and analyzing the ratio of chemical nutrients. In the five visited villages 14 samples could be collected; mainly N-P-K compound fertilizer. Figure 2 presents the results of the analysis for the content of nitrogen in the 13 samples that should contain N.

Figure 3: N content as labeled vs. content measured, differences in %



Note: Kjeldahl Nitrogen Determination method used for chemical analysis.
Source: own data from collected fertilizer samples in various villages of Hebei province.

Except for one sample all others do not contain the proportion of nitrogen labeled on the bags. Four samples are found to contain more than 20% less nitrogen than they should.

The sample size as such is too small to draw conclusions to how far these results are representative for the recent fertilizer quality in the whole Hebei province. But support for farmers' assumption that the fertilizer has not the chemical contents it should have is found. Since mainly fertilizer that also contained P and K was collected the samples were also analyzed with respect to those elements. Samples are found that contained 40% more P than they should or minus 100% of K. This hints to the fact that the ratios of N to P and K labeled on the bags hardly hold in reality, what makes application of these fertilizers aiming at a balanced use of nutrients difficult. If one considers that farmers are risk averse regarding yields than this findings contribute to the uncertainty about the input quality and farmers are expected to use more fertilizer to safeguard the production, especially if they expect, that the nutrient contents are less then labeled.

5 Discussion

Using summary statistics based on the available data set higher amounts of urea fertilizer are purchased and applied to crops than necessary for sustainable crop yields. However, the results are just approximations because the data doesn't provide detailed information on the amounts applied per mu, the type of fertilizer used and the crops fertilized. Among but also within regions, the types of fertilizers commonly utilized seem to differ greatly. As we can see from the analyzed samples the farmers are to some extent right if they believe that the fertilizer quality is not as what it should be. So even if the farmers are provided with recommendations about the right amount of fertilizer this does not ensure the application of the recommended ratio of nutrients. This is not only a problem that could affect farmers' yields if the applied fertilizer contains to less nutrients. With respect to air, water and soil quality this problem is also severe. At on side it happens that farmers, due to bad experiences with the fertilizer quality, apply too much of fertilizer that maybe is of better quality and by this put too much chemicals to the fields and soil, which than are not taken up by the plants but instead leach to (ground)-water or emit to the atmosphere. On the other side samples also contained more chemicals than expected. Such kind of fertilizer can harm yields, air, soil and water even if it is applied in the recommended dose.

As a result of the econometric analysis one sees that influencing the amount of fertilizer used is most directly possible via fertilizer prices since the estimated coefficients of the price variables are highly significant in all models. So as long as the prices are not too high and allow farmers to produce output profitably higher prices could contribute to lower application rates of fertilizer. According to Zhang (2008) agricultural input use has been reduced by 30% in recent years because of higher input costs. From an economic perspective a price indicates the limited availability of a resource and can be used to account for negative externalities like surface water pollution, contaminated groundwater tables or degenerated soils. Also the increase of the farm size could contribute to lower application rates of mineral fertilizer especially for full-time farm households but since the amount of arable land is limited and a large share of the rural labor force still depends on agricultural production this is hard to achieve. The household size is expected to even decline in the next years. So if there is less household labor available for crop production fertilizer levels are expected not to decrease if not more machineries are used to compensate for human labor or the functioning/ mobility of the rural labor market is improved/ increased.[1]

The qualitative statements reveal that some farmers are aware of the influences that environmental conditions have on agricultural production even if they don't have sufficient natural science knowledge about the concrete links. But such knowledge is not expected to be with farmers. Due to our findings there seem to be some obstacles in knowledge transfer between research and policy institutions and farmers. Studies as by Zou et al. (2005) confirm that this low rate of knowledge transmission is found in general in the agricultural sector in China. Part of this comes from problems in the extension service structure. Either the extension service is understaffed and underpaid or clear organizational or payment and responsibility structures do not exist at all. That extension workers earn a more or less big part of their income from input selling businesses is critical from a normative point of view. There could arise easily a conflict of interest. On the one hand the extension worker should train the farmers in using fertilizer efficient and on the other hand he or she earns more income if more fertilizer is sold.

6 Conclusions

Results from recent research on the links between urea fertilizer use, awareness of environmental problems and the functioning of the systems of knowledge transfer from science or extension service to farmers have been presented and discussed. Qualitative and quantitative proof that the quality of nitrogenous fertilizer is distorted and that farmers are not always provided with recent knowledge to use fertilizer in a sufficient and sustainable way is found. Such sources of uncertainness could be overcome if there are reliable proofs of fertilizer quality and if farmers have the chance to test the quality of fertilizer before application. Such kinds of test are also recommended to be done for soil because not only the type of soil differs regionally but also the level of nutrients already stored in the soil varies.

To overcome the environmental problems stemming from fertilizer input use in rural Hebei instruments that incorporate (negative) externalities of agricultural production in the prices of fertilizer have to be introduced and applied. Also a system for quality controls of fertilizer, which is independent from the respective producers, has to be supported.

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[1] It seems contra intuitive to discuss on the one side a labor surplus in the rural agricultural sector and to mention at the same time that households might become lack of labor force in their crop production. The explanation for this is the (missing) rural labor market. Still most of the farmers in China can be considered more as peasants that farm their own land for subsistence with family labor then as farmers that are entrepreneurs who are able and willing to employ agricultural laborers. So even if there is a overall labor surplus it does not follow that the individual household has access to this labor force.

Since the fertilizer industry would benefit from farmers' trust in their products they should invest in a network of certified fertilizer retailers. It is important to strengthen local extension services that are accepted by the farmers and can provide recommendations and knowledge about environmental consequences of intensive agriculture and to equip them with trained staff and sufficient funding. Future research should focus on the measurement and quantifications of the level of farmers' knowledge related to the cropping systems in different regions because this reveals starting points for agricultural education and training that should be provided more often and situation specific to famers.

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Agricultural Biotechnology and Sustainability: a case study from Shandong province
农业生物技术及其可持续性：山东省案例研究

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Abstract

In this paper, the question of sustainability of biotechnology solution in Chinese agriculture is addressed by means of a case study in five cotton growing villages in Linqing County, Shandong Province, China. Panel data of village and farm characteristics as well and in particular on cotton production were collected from 150 farmers through season-long monitoring in 2002 and 2005. Using a bio economic simulation approach and an econometric difference in difference model it can be shown that agricultural biotechnology requires supportive institutional conditions in order to provide a sustainable solution to biotic stress factors such as insect pests. The paper identifies some gaps in knowledge and some deficiencies in institutional frame conditions that need to be addressed if agricultural biotechnology through genetically modified crop varieties will live up to its promise.

摘要

本文通过以中国山东省临清县的 5 个种植棉花的乡村为实例，提出中国农业可持续性的生物技术解决方案的问题。乡村和农场特点的面板数据，特别是棉花生产的数据是从 2002 年到 2005 年期间对 150 位农民长期监测而收集到的结果。通过运用生物经济模拟的方法以及在不同的模型中使用计量经济差异的方法显示，农业生物技术需要有支撑性的体制条件来为生物压力因素（例如虫

害）提供可持续的解决方案。本文识别了一些知识方面的差距以及体制框架条件的不足。如果要通过基因改良作物的品种使农业生物技术成为可能，就有必要讨论这些差距和不足。

1 Introduction

Some fifty years ago, scientists were enthusiastic about the widespread introduction of synthetic pesticides in agriculture to solve the world's food problem. Since about 25 years scientists and policy makers are voicing optimism about the prospects of pest resistant genetically modified crops. While many negative effects of pesticide use have become known, intriguingly some see biotechnology in crop protection now as a solution to the very problems that pesticide use created (e.g. Naranjo, 2005). However, regulatory decisions about the commercialization of biotechnology products must consider uncertainty over bio-safety issues and consumer resistance and possible constraints on trade. For industrial crops like cotton, China was the first among the developing countries to introduce genetically modified (GM) varieties on a large scale. Since its approval for cultivation in 1997, Bt-cotton experienced double digit growth in terms of area sown until early 2000. On the other hand, Chinese authorities so far have not approved GM rice for commercial use in spite of recommendations to do so on the basis of its estimated potential economic benefits (Huang et al 2008). While numerous studies were conducted to assess the immediate farm-level impact of this technology there is a lack of studies that assesses its long-term performance.

A global review of 47 peer-reviewed economic papers on the farm-level impact of Bt cotton in developing countries was recently conducted by Smale et al. (2006). The authors found that most of the papers focus on China, India and South Africa with economic returns being highly variable over years, farm type, and geographical location. Thus the study concludes that *"the institutional and marketing arrangements for supplying the technology and marketing the product may be the single most important determinant of Bt impact at the farm-level, even when the trait is shown to be effective"*. The authors also note that the most obvious limitation to conclude solid evidence of Bt cotton impact is the short time period considered in the studies. In fact, some economic studies were enthusiastic about the merits of GM cotton for Chinese farmers (see for example Huang et al., 2002a, 2002b, 2002c, 2003, and 2005; Pray et al., 2001, and 2002) while other case studies were more cautious (e.g. Keeley, 2006; Pemsl et al., 2005, and 2007; Fok et al., 2005; Yang et al., 2005a, 2005b, Pemsl et al 2007). Though a considerable number of studies were conducted to assess the farm-level impact of Bt cotton in China, none of the studies has used panel data. However, monitoring the same farms over time, however, is important to assess the long-term performance of the technology. There are factors that can question the sustainability of GM crops. The first one is the possibility of resistance built-up of target pests against the Bt toxin (e.g. Carrière et al., 2001; Tabashnik et al., 2003; Wu et al., 2002), in a similar mechanisms to what has been observed with chemical pesticides. Furthermore, secondary pests can develop as a result of broader ecosystems effects and cause additional yield loss (e.g. Wang et al., 2006). Finally, and based on the experience with other production inputs notably chemical pesticides, the institutional arrangements in the seed delivery systems, with a large number of GM cotton varieties released to the market can lead to a deterioration of the quality of Bt varieties (e.g. Pemsl et al., 2005).

In this paper, we present results from a case study of cotton farmers in five villages in Liquin County in Shandong province. First, a descriptive analysis of panel data from a survey of 150 cotton farmers are presented to provide some indication about the potential impact of Bt cotton varieties on crop management practices. The panel data set is analysed by means of a descriptive analysis using parametric tests. Comparison of the means of variables that describe the performance of cotton production and indicators of the effectiveness of the Bt technology between the two years are carried out. Observed significant differences can be confronted with economic theory and can be taken as indicators of changes in economic and environmental conditions.

Second, results of a bio-economic model that combines the dynamics of cotton-bollworm and major other pests (Gutierrez et al., 2006) is presented. The model is essentially a stochastic budgeting model of bollworm control strategies reflecting the agro-ecosystem conditions in the study area. The model aims to reflect the situation of cotton planting several years after the introduction of Bt cotton varieties in China. It captures a situation of multiple damaging agents and accounts for the prevailing natural resource conditions as reflected by the presence of beneficial organisms. A cotton growth experiment was used to calibrate the biological model. Farm surveys conducted by Pray et al. (2002), Pemsl et al. (2005), and Yang et al. (2005) revealed high levels of insecticide applications by (Bt) cotton farmers in China, indicating probable ecosystem disruption, which may influence the effectiveness of pest control measures.

The term ecosystem disruption in this paper refers to a condition of the cotton ecosystem where the activity of natural enemies is reduced due to slower developmental rates or higher mortality. As a result of pest control interventions such as chemical pesticides and/or Bt varieties.

A specific problem with the use of Bt varieties in China with its rapid seed market development are the insufficient efforts to assure quality control of seeds and hence their efficacy. Evidence of this problem has been documented in India (Morse et al., 2005) and China (Pemsl et al., 2005), countries where regulation of input markets is low and enforcement of intellectual property rights is difficult.

2 The Data

The data used in this study, were collected from farmers growing Bt cotton, in five villages in Linqing County located in the west of Shandong Province, China. The area is a major cotton producing region in the Yellow River Plain and Bt cotton varieties were first approved in 1997. From around the 2000 or 2001 season onwards, all farmers were growing Bt cotton varieties and non-Bt cotton seed was not even available anymore in the market (Pray et al., 2002; Pemsl, 2006). The five villages were chosen based on their proximity to major markets and roads, as well as the share of cotton in the production system. Within each of the villages, 30 cotton-growing farmers where selected who were willing to participate in the monitoring and in a way that the sample is representative for the community as a whole. Farm households were interviewed three times during the 2002 cotton season and all cotton inputs and outputs were monitored using recording forms. The same procedure of data collection was applied for the same set of farmers in 2005. However, seven observations had to be dropped from the analysis because of missing values in some of the variables, resulting in a final sample size of N = 143 in each of the two years.

Leave samples from 150 Bt cotton fields were collected in Shandong Province during 2002 and 2005 to assess the actual concentration of Bt toxin.

3 Descriptive Analysis

The first step in the analysis is to compare the performance of cotton production in the two observation periods. Such comparison would demonstrate adjustment of farmers' management practices to the effects of Bt cotton and it would indicate whether the technology is likely to increase profitability of cotton production over time. In Table 1, selected parameters of the sample farmers and Bt cotton production are presented.

There are several interesting observations when comparing the 2002 and the 2005 crop year. Firstly, farmers significantly decreased the area planted to cotton. This may be largely due to lower cotton prices until early 2005. However, cotton prices had increased by about 40 % at the time the 2005 crop was harvested. Therefore, gross margins were higher in 2005 as compared to 2002 in spite of over 30 % lower cotton yields.

On the input side, the material costs have increased from 2002 to 2005 mainly because of higher costs for fertilizer, while there was no change in labor and seed costs. The most striking difference is the increase in pesticide use both in terms of quantity and number of applications. While the latter showed a significant increase of over 30 % the difference in the quantity of pesticides was less but is still significant. In both years, the major shares of pesticides are insecticides, comprising some 96 % of total pesticides applied. As shown in Table 1, insecticide use against the lygus bug has increased by a factor of 20. This supports observations made in other papers that the use of Bt cotton may induce the augmentation of secondary pests (Hu et al., 2006; Wang et al., 2006). Surprisingly, pesticide use against CBW has increased, too, even though all farmers are using Bt cotton varieties. These points to some problems with the technology under the conditions prevailing in Linqing county.

Table 1: Production indicators for Bt cotton in five villages in Shandong province 2002 and 2005

	2002		2005		Average change in %
	Sample Average	***Stand. Dev.***	**Sample Average**	***Stand. Dev.***	
Landholdings [ha]	0.59	*0.21*	0.53	*0.15*	-9.9***
Cotton area [% of total land]	64.4	*23.1*	41.9	*15.9*	-35.0***
Cotton yield [t per ha]	4.88	*0.82*	3.32	*0.46*	-31.9***
Experience [years of cotton]	20.7	*10.5*	23.7	*10.5*	14.5
Crop rotation [continuous years of cotton]	5.1	*4.3*	6.5	*3.6*	28.5***
Intercropping [area in hectare]	0.2	*0.2*	0.1	*0.1*	-46.0***
Pest pressure [dummy: 1 = higher than normal]	52	-	59	-	-
Number of pesticide applications	10.7	*3.3*	14.2	*3.0*	32.1***
Pesticides[1] [kg per ha]	15.6	*8.9*	18.6	*8.5*	19.2***
Insecticide price[3] [US$ per kg]	3.7	*1.2*	4.4	*1.3*	20.2***
Insecticides targeting CBW [kg per ha]	4.7	*4.4*	6.1	*5.2*	28.5**
Insecticides targeting lygus bug [kg per ha]	0.2	*1.0*	5.1	*3.1*	2392.3***
Insecticides targeting other pests [kg per ha]	8.8	*5.4*	6.5	*3.0*	-26.4***
Herbicides [kg per ha]	2.1	*1.0*	2.5	*1.2*	29.2***
Material costs[2] [US$ per ha]	430	*155*	503	*135*	17.2***
Seed costs [US$ per ha]	41.7	*21.9*	40.7	*21.5*	-2.4
Labor costs [US$ per ha]	499	*160*	492	*79*	-1.4
Fertilizer costs [US$ per ha]	232	*133.4*	405	*129.6*	74.5***
Local cotton output price [US$ per kg]	0.51	*0.03*	0.74	*0.02*	45.0***
Gross margin [US$ per ha]	1565	*438*	1825	*308*	16.6***

Source: own surveys in 2002 and 2005

***, **, and * denote significantly different sample means at α = 0.01, 0.05, and 0.1, respectively.

[1] Pesticides reported here do not include herbicides.

[2] Insecticide prices have been deflated (2002=100%).

[3] Material costs include expenditures for irrigation, fertilizer, mulching, and machinery; but costs for seed and labor (entirely family labor, opportunity costs of US$1.2 per person day (8 hours) were assumed) were not included in material costs. N = 143 per year.

Another proposed benefit of introducing Bt varieties is a reduction in human health costs because of fewer pesticide poisoning cases due to the application of fewer and less poisonous pesticides (Pray et al., 2001). One indicator for human health effects is the toxicity of pesticide products applied. As shown in Table 2, the relative share of extremely hazardous pesticides (WHO classification Ia) has slightly increased. Even though the share of Ib class pesticides applied decreased, the absolute amount of applied pesticides classified as extremely and highly hazardous (Ia and Ib) has remained almost constant considering the larger amounts of pesticides applied. In 2005, the majority of pesticides used are found in class II but the proportion in class III has decreased. However, almost 25 % of the applied products could not be identified as compared to only 15.5 % in 2002, indicating a major and growing problem with the regulatory system of pesticides in China. No information is available about the toxicity of the unidentified pesticides. So overall, it is hard to conclude any improvement in the risk of pesticide hazards from this in-depth case study.

Table 2 Average share of unidentified pesticides and toxicity of identified pesticides used in Bt cotton production in Linqing County, 2002 and 2005 (WHO classification)

WHO toxicity group	2002		2005	
	% of total	Standard Deviation	% of total	Standard Deviation
Unidentified	15.5	13.6	24.1	15.7
Ia – Extremely hazardous	11.2	13.7	13.5	17.3
Ib – Highly hazardous	28.0	18.8	19.0	15.9
II – moderately hazardous	29.0	18.1	54.2	21.6
III – slightly hazardous	26.1	17.4	12.4	13.9
U – unlikely to pose an acute hazard in normal use	0.8	2.6	0.9	3.3
nl – not listed	4.9	7.4	/	/

Source: recall surveys and monitoring in 2002 and 2005

To further explore possible reasons for the increase in pesticide use it will be useful to look at farmers' choice for selecting cotton varieties. Such indicators include: (i) the rate of seed re-use, (ii) the seed price, and (iii) the variety planted by the farmer.

As shown in Figure 1, farmers bought significantly more new seeds in 2005 than in 2002 and tended to rely less on seeds saved from the previous season. One possible explanation for this difference is that while seed costs per hectare have remained constant (Table 1), the average price of Bt cotton seed has dropped significantly in 2005. The average price per kg of Bt cotton seed in the sample was US$4.1 (standard deviation 2.9) in 2002, compared to only US$2.1 (0.8) per kg in 2005. Figure 1 also highlights, that the majority of farmers paid less than US$2 per kg in 2005, while in 2002 this was only the case for very few farmers who purchased Bt cotton seed. If Bt seed can be purchased at a low price, they can save the labor intensive procedure of selecting, harvesting, and cleaning own seeds. The price drop further indicates that the technology fee, which breeders have to pay for the Bt gene is not reflected in the price of seeds with the number of Bt varieties rising in the market.

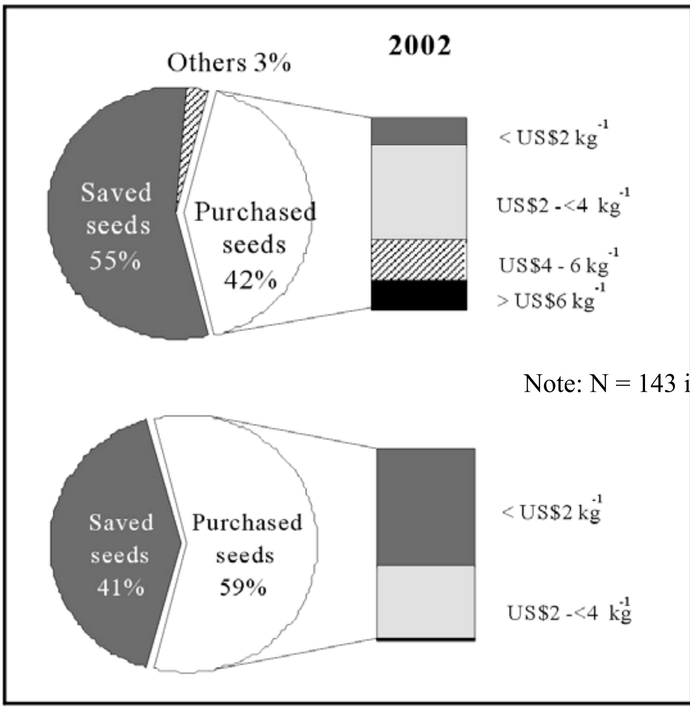

Figure 1 Share of saved seeds and price of purchased seeds in 2002 and 2005
Source:Original surveys in 2002 and 2005

The expansion of the Bt cotton seed market is reflected in the diversity of varieties used. While in 2002 the majority of the farmers (combined 63 %) used either of the two Monsanto varieties 33B or 99B, the latter variety has been largely replaced by domestically bred seeds in 2005 (Table 3). In 2005, three varieties, namely 33B and Lu mian yan 19 and 22, the two latter produced by the Shandong Cotton Research Centre, dominated the Bt cotton seed market in these five villages[1]. All Bt varieties planted in the survey years 2002 and 2005 are of non-hybrid (conventional) type. Seed prices have dropped significantly between the two time periods. This is especially remarkable for the two Monsanto varieties. Unlike in 2002, prices of the Monsanto Bt cotton varieties were no longer significantly different from local varieties by the year 2005. Economic theory suggests that the price of a good is determined by its marginal product, which in the case of seeds is influenced by the different traits of the variety. For Bt the effectiveness of the toxin is an indicator of its quality. To test for the quality of different Bt varieties, laboratory tests of Bt cotton leaf tissue were conducted to quantify the Bt toxin concentration[2]. Comparing the Bt toxin concentration within Bt cotton varieties reveals a highly significant decrease for the two Monsanto varieties (33B and 99B) as well as the unspecified samples. None of the local Bt cotton varieties, which were sold in 2002, were purchased by the farmers in 2005 any longer. Instead, these varieties were replaced by new ones that came into the market. Thus, data was only available from either one of the years due to very short product life cycles, and no comparison could be made across years. The analysis of the toxin content, however, reveals that these new varieties planted in 2005 on average have a lower toxin concentration than the earlier varieties cultivated in 2002. The data show that most farmers were using low price Bt cotton seeds expressing low concentrations of Bt toxin[1].

Also, toxin concentration varies highly among varieties and within the same variety as evident from large standard deviations (Table 3). Interestingly, variation in toxin concentration across the different varieties seems uncorrelated to their price. For example, for both Monsanto varieties, differences in seed prices can also be observed within the same year. At the same time both the average Bt toxin concentration and the average price of the Monsanto varieties decreased significantly between 2002 and 2005. This points to the possibility that counterfeit products have entered the market as it is unlikely that Monsanto would have intentionally decreased the toxin concentration of their seed. Since differences in prices, however, do not seem to reflect differences in seed quality, farmers are faced with input uncertainty. This means that even for relatively high priced varieties, the toxin concentration can turn out low (see Table 3). Hence, farmers may act risk averse and increase the level of pesticide use beyond the economic optimum.

Table 3 Shares of cotton varieties (in % of farmers), average seed price (in Yuan per kg) and average toxin concentration of Bt varieties for 2002 and 2005 respectively

Commercial Name of Variety	Share of Varieties in %	Average Seed Price (Y/kg)	Toxin Content (ng/g)			
	2002	2005	2002	2005	2002	2005
33B	16.1	27.3	3.37	2.05**	490	257 ***
99B	46.2	9.1	3.13	1.32**	484	191 ***
Lu mian ye 18	16.1	1.4	2.76	1.10**	491	-
Zhong mian	1.4	-	1.93	-	794	-
Shu mian/tree cotton	6.3	-	10.12	-	509	-
Lu mian ye 16	1.4	-	2.95	-	381	-
Lu mian yan 19	-	24.5	-	1.68	-	186
Lu mian yan 21	-	9.8	-	2.22	-	186
Lu mian yan 22	-	23.8	-	2.48	-	226
unspecified	11.9	12.6	2.89	1.31 ***	606	229***

Note: N = 143 in each year for shares of cotton varieties. N = 58 in 2002 and N = 91 in 2005 for average prices. 2005 prices deflated using price index for agricultural inputs (available from Ministry of Agriculture).
** and *** denote statistically significant difference between the two survey year means at 5 % and 1 % level, respectively; - denotes that no observations exist.

[1] This is in contrast to protected production (e.g. in glasshouses) where the environment is totally controllable.

4 Modeling Sustainability of GM Crops

Damage control agents such as chemical pesticides, beneficial organisms and resistant varieties depend on the stock of natural resources that govern the productivity of an open[2] agro-ecosystem. Pest control agents may impact on two natural resources, namely: (1) the beneficial organisms that provide natural control of pests, and (2) the susceptibility of pests to the control agent, defined as the absence of resistance at the time of technology introduction. Optimal use of pest control agents thus corresponds with the economic problem of managing exhaustible resources, i.e. how to allocate resource stocks over time (Regev et al., 1976, 1983; Dasgupta and Heal, 1979). Extracting a unit of the resource today implies that there is less of it in the future; hence, user costs exist in addition to the direct costs of the control agent. The extraction costs are the decreasing value of the resource, while user costs are inter-temporal opportunity costs or the option value of the control method available in the future. Furthermore, for common property resources producers do not perceive their actions to influence the stock of these resources and as a result operate in a myopic optimisation framework (Regev et al., 1976). This can lead to an overuse of natural resources that is reflected in a rapidly rising net price of the resources (Hotelling, 1931), so that the price of an alternative technology (choke price) is reached faster. In the case of pesticides, the net price of the natural resources is reflected in a rising marginal product (Lichtenberg and Zilberman, 1986). Therefore, current levels of pesticide use can pre-determine higher use levels in the future (Fleischer, 2000). For example, the high use of pesticides in some cropping systems such as cotton in Chile and California (*sic* worldwide), and in tropical vegetable production (with diamond back moths as a major pest), are typically triggered by prior misguided pest control interventions. Thus leading to what is called the pesticide treadmill (van den Bosch, 1978). Degradation of natural resources in pest control may also "stimulate" the introduction of new pest management technologies such as transgenic varieties. For example, Bt cotton was introduced in China right after a major outbreak of the cotton-bollworm (Wu and Guo, 2005), which may partly explain its rapid diffusion.

Thus, taking account of natural resource processes has consequences for the productivity and benefits assessment of new pest control technologies. The impact of a new damage control agent is influenced by the ecosystem state in which it is introduced. If the technology is introduced in a highly disrupted ecosystem with a reduced capacity of beneficial organism to control pests (Gutierrez and Ponsard, 2006), short-term benefits may be high but the "life span" of the technology and thus total benefits may be low. This is typically the case when the institutional settings that led to the disruption of the ecosystem in the first place are still the same, and hence the technology itself can do nothing to improve these conditions. Thus, a major question is whether Bt crops can really lead the way out of the (pesticide) treadmill and offer a sustainable solution to pest problems or rather steer into yet another (genetic/pesticide) treadmill (Gutierrez et al., 2006)?

[2] Climatic data (minimum and maximum daily temperature) for 2002 and monthly averages for the past 10 years were available from the meteorological station in Linqing County, Shandong Province.

The theory of natural resources and the conclusions that can be drawn from the economic analysis of pesticide use suggest that a bio-economic modelling approach, which takes account of the degree of ecosystem disruption and the institutional conditions governing the use of pest control inputs, can provide additional insights for impact assessment of Bt cotton.

The bio-economic model, developed to address the issues raised above, consists of two major components: i) a biological-ecosystem model that simulates the growth of the cotton plant, as well as the dynamics of major pests and the effects of beneficial organisms and the resulting interactions. The model allows the analysis of various pest control strategies, with the simulated output for each being, among other variables, the cotton yield for each control strategy; ii) a stochastic micro-level profit model that uses the yields generated by the biological model, control costs for each control strategy, and cotton prices to compute the net revenue of the different control strategies.

This section of the paper summarises the general model structure. A physiologically based, biological-ecosystem model for cotton and ten of its major pests (e.g. Gutierrez et al., 1975, 1984) was modified to simulate transgenic Bt cotton (Gutierrez and Ponsard, 2006; Gutierrez et al., 2006). The model was calibrated to the conditions of the study location in Shandong Province, China. To generate the data needed to parameterize the model, a cotton-growth experiment was conducted at the study site in 2002. The experiment provides information on plant growth (weekly dry-weight by subunit and yield) and pest damage as well as counts of pests and predators. The cotton plant model consists of several plant subunit models (i.e. leaf, stem, root, and fruit), which are linked via a metabolic pool from which photosynthate is allocated to the subunits according to biological priorities. The model simulates the mass and number dynamics of the cotton plant subunits, the time varying concentrations of toxin in the subunits, the dynamics of all insect pest populations (pests), and the evolution of resistance in response to toxin levels in each pest. The effects of natural enemies are included as feeding rates per day estimated from field studies. These rates may be reduced by the action of various control factors such as insecticides and natural enemies feeding on Bt intoxicated prey. All of the species in the model are driven by observed weather[1] A detailed description of the model, its assumptions, and the data sets and references used for model validation are found in the above references.

For the simulations, it is assumed that all agronomic factors (such as fertilizer and irrigation) are constant and none limiting. Equation (1) shows the main structure of the cotton plant model. Cotton yield (*Y*) is a function of reproductive and vegetative growth (*GR*), loss due to pests (*L*), and other factors (*Z*) that include plant varieties, control technology and location specific characteristics:

$$Y = f(GR, L, Z, P_n, Bt) \tag{1}$$

The reproductive and vegetative growth (*GR*) is computed as:

$$GR(t) = (\phi * (t)(D(t)\beta - Q_{10})\lambda \tag{2}$$

with the maximum demands (*D*) scaled by the product of all supply-demands ratios of essential resources ($\phi *$) such as light, soil moisture and nitrogen, and then allocated in priority order to wastage (*1-β*), respiration (i.e. Q_{10}), and costs of conversion (*λ*) (see Gutierrez et al. 1984; Gutierrez and Ponsard, 2006). Cotton and its pests are poikilotherms, i.e. body temperature and activity level depends on the surrounding temperature, and hence time and age in the model are in physiological time units (day-degrees). The plant model also captures the varying concentration of Bt toxin over time and for different plant subunits.

Yield loss from pests (*L*) is a function of plant growth (*GR*) and pest populations (*P*) of n = x bollworm, defoliators and plant bugs.

$$L = f(GR, P_n) \tag{3}$$

The similarity of the resource acquisition and allocation biology across plant and animal species allows a generic model structure for analogous processes (Gutierrez and Baumgärtner, 1984). A time invariant model form is used for Bt immune pests (e.g. lygus, whitefly), while a time-varying distributed maturation time model is used for all noctuid species to accommodate time-varying Bt concentrations in their food that increases developmental times, and decreases fecundity and survival. Pest dynamics modules are integrated in the system in a way that there is feedback between pest attack and plant compensation. The model includes pest time-varying preferences for plant subunits. The dynamics of pest population (*Pn*) are modelled for bollworm and other relevant pests. *Pn* depends on climatic conditions (*T*), the reproductive and vegetative growth (*GR*) of cotton subunits (host plant), effect of natural enemies (NE), in- and out-migration (*M*) of insects and the use of pest control technologies (*C*) including Bt varieties and insecticides.

$$P = f(T, GR, NE, C, M) \tag{4}$$

The effects of the natural enemies (i.e. a complex of generalist predators (*Orius sp., Nabis sp., Geocoris sp.* and *Zelus sp.*) that consistently cause 30% mortality per day (Gutierrez et al. 1975)*)* are a function of the level of ecosystem disruption by pesticides and technology factors and interact with pest populations:

$$NE = f(T, P, C, M) \tag{5}$$

Pesticides kill natural enemies immediately and they re-establish in the field over a ten day period as pesticide residues decrease. The effect of the Bt toxin is a 28% reduction in the efficacy of natural enemies for high dosages of Bt (Ponsard et al. 2002) and is assumed to decline with dosage (Bt var or mixtures). Both pesticides and Bt toxin are included in the model (as captured in *C*). Their effects on pest control are complementary as both may negatively affect pests and natural enemies.

Two different types of Bt based control strategies were included in the model, i.e. low quality (= low price) and high quality (= high price) Bt seeds. Low quality was modelled via a change in the scalar of pest susceptibility relative to high quality Bt seeds. Ecosystem disruption was incorporated in the model in three discrete steps, i.e. 0%, 50% and 75% implying corresponding levels of disruption in the control efficacy of natural enemies.

Cotton-bollworm control strategies are described as combination of three different seed choices - high or low quality Bt, conventional varieties - and three intensity levels of insecticide use - no spray, moderate spray, farmers' practice (Table 4).

Table 4 Overview of potential CBW control strategies

Insecticide treatment	Seed choice		
	Bt high quality	Bt low quality	Non Bt
No spray	Strategy 1	Strategy 3	*Baseline*
Moderate spray (3 sprays)	Strategy 2	Strategy 4	Strategy 6
Farmers' practice (6 sprays)	–	Strategy 5	Strategy 7

Source: Pemsl et al 2007

These are compared to natural control (no pesticides and conventional seeds). For each control strategy, simulation runs of the biological model with stochastic climatic conditions were conducted for 20 consecutive years providing yield distributions[1] for the various control strategies. The build-up of pest resistance is not included in the model as it is suggested that the high diversity of the farming systems in the study area provides sufficient refuge for susceptible pests (Jia and Peng, 2002). Fitted normal distributions of yields provide the link with the stochastic micro-level profit model that generates the net revenues of pest control strategies.

The net revenue *(NR)* for each of *j* pest control strategies (NR_j) is the monetary value of the prevented yield loss less control costs. Thus the NR_j is a function of the change in cotton yield (ΔY) of the respective strategy as compared to the baseline of natural control, the cotton price (p_Y), the pest control strategy (C) and their unit costs (p_C), and the interest rate (i) to account for the opportunity costs of capital.

$$NR_j = f(\Delta Y, C, i, p_y, p_c) \tag{6}$$

[1] The software BestFit (Palisade Corporation, integrated into the professional version of @RISK) is used to fit probability distributions to the simulated yield data.

The price of cotton (p_Y) is assumed to be identical for Bt and non-Bt cotton. The costs for the control strategies comprise of costs of insecticides and associated human health costs, labor costs for spraying and the technology premium for Bt varieties. Following Rola and Pingali (1993) and Pingali et al. (1994), human health costs are assumed to equal costs of insecticides.

To account for the stochastic nature of the input variables for the micro-level profit model (yield and prices), the underlying probability distributions are used in Monte Carlo simulation (Hardaker et al., 1997). A cumulative distribution function (CDF) of net revenues for the pest control strategies is then generated from all NRj of each strategy. The CDF or F(X) of a random variable X gives the probability that x takes a value lower or equal to a specified numerical value x_0 so that $F(X = x_0) = P(X \leq x_0)$. The performance of the various pest control strategies are compared by applying the criteria of first-degree stochastic dominance (FSD) and second-degree stochastic dominance (SSD) to the resulting CDFs . The criterion for FSD is that all values of X (net revenues) of a control method (S1) are lower or equal than those of a different method (S2) with at least one strong inequality. The criterion can be applied to compare multiple control strategies S1, S2, … Sj (Equation 7):

$$F_{S1}\left(x\right) \leq F_{S2}\left(x\right) \leq ...F_{Sj}(x) \qquad 7)$$

FSD corresponds to an upward (or left) shift of the probability density function. Hence, all decision-makers would prefer a strategy that is first-degree stochastic dominant irrespective of their risk attitudes (Hardaker et al., 1997). In SSD (Equation 8), a strategy (S1) will be preferable over another (S 2) if the area under F_{S1} is less than the area under F_{S2}, for all values of x (Moschini and Hennessy, 2001):

$$F_{S1} = \int_{-\infty}^{x^*} F_{S1}(x)dx \leq F_{S2} = \int_{-\infty}^{x^*} F_{S2}(x)dx \leq ......F_{Sj} = \int_{-\infty}^{x^*} F_{Sj}(x)dx \qquad (8)$$

SSD refers to a reduction in the variability of outcomes and will only increase utility if the decision-maker is risk averse. Based on these two criteria, the control strategies (Strategy 1 to Strategy 7) are ranked and the probabilities of negative net revenue of control are derived. The method of first and second degree stochastic dominance provides a powerful tool to combine ecological processes with farm level economic decision-making in the absence of empirically verified utility functions and risk aversion coefficients.

5 Model Results

The model shows that yields differ depending on the level of ecosystem disruption, i.e. yields are lowest in a highly disrupted ecosystem for all control strategies (see Figure 2)[1]. Yield variance among disruption levels is highest for the baseline scenario that relies entirely on natural control and generally decreases with a higher degree of control intensity, i.e. more sprays and higher quality Bt. For the modelling it was assumed that resistance to the control technologies is non existent. Low quality Bt seed combined with high levels of insecticide use performed best. Against initial expectations, in the absence of insecticide resistance, insecticide use was more effective than high quality Bt. Technically this can be explained with the multitude of pests against which Bt varieties are ineffective and variation in pest pressure between years. To identify the factors that affect the productivity of control inputs, yields are regressed in a multivariate linear regression on the different control inputs. The sample is separated for the different levels of ecosystem disruption and the explanatory variables are the use of a Bt-variety and insecticides (both as dummy variable), additional dummies for the intensity of the control (high quality Bt-seed and intensive use of insecticides) and an interaction term for Bt toxin and insecticides. All parameters are highly significant ($\alpha = 0.01$) and the overall fit of the regression model was high. The intercept is the yield level that is realized without crop protection intervention under the different levels of ecosystem disruption (see baseline yields in Figure 2).

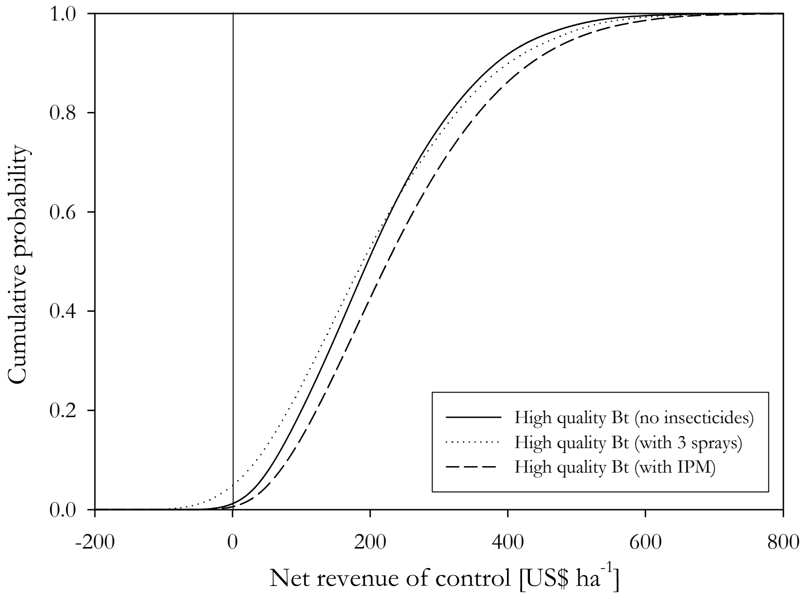

Figure 2 Simulation results of budgeting model (high quality Bt)
Source: Pemsl et al 2007

The most striking result is that the productivity of the control changes dramatically with increasing disruption of the ecosystem. Consider first the case of zero disruption of natural enemies (coefficients displayed row one of Table 5). The use of a Bt-variety yields a meagre 146 kg of additional yield per hectare as compared to the non-Bt baseline.

[1] The economic component of the bio-economic model reflects these technology features as found under farm conditions and includes the product and factor prices prevailing in Shandong in 2002.

The disrupting impact on natural enemies is higher and hence yield increase is even less, if high quality Bt-seed is used. Similarly, the application of insecticides leads to a reduction in yield as the disrupting effect of natural control outweighs the pest control effect of the applications.

Table 5 Estimated coefficients (linear regression) for bollworm control as explanatory variables for cotton yield under different levels of ecosystem disruption

	Ecosystem disruption		
	0	0.5	0.75
Intercept	4,324.72	2,308.72	1,193.47
Bt toxin [dummy]	145.96	1,757.36	2,392.67
Bt quality [dummy]	-33.06	179.40	300.63
Insecticide [dummy]	-274.18	996.67	1,782.63
Insecticide intensity [dummy]	-37.09	369.44	553.03
Insecticide * Bt toxin	216.92	-923.65	-1,384.10
Adj. R^2	0.869	0.974	0.981

Note: Dependent variable: yield in kg per hectare
Source: Estimated from the results of the biological model, Pemsl et al 2007

A high intensity of control (Bt-variety and insecticide use) compensates for part but not all of the disruption caused by the control intervention. These results confirm findings from the literature on pesticide use (see for example Falcon et al., 1968; Ehler et al., 1974; Eveleens et al., 1974) that demonstrated the existence of the pesticide treadmill in cotton. For the two scenarios with disrupted ecosystems, the baseline yield is lower (due to lower activity of natural enemies) and the use of external control is much more rewarding. The use of a Bt-variety adds 1.8 and 2.4 tonnes per hectare compared to the baseline for the 50% and 75% disruption, respectively. In principle, the use of insecticides replaces natural control but the levels assumed for the simulation do not reach the impact provided by the Bt-variety. For these last two scenarios, a higher intensity of control increases the yield level further (positive coefficients for the Bt quality and insecticide intensity variables). A combination of insecticides and Bt-variety results in a relatively smaller return to the separate control measures (the interaction term of Bt-toxin and insecticides is negative). For high ecosystem disruption, bollworm control pays off well with net revenues from US$550 to US$1,150 per hectare at F(x) = 0.5 (Figure 3). In this case, a high level of insecticide use is stochastically dominant over the strategy to plant non-Bt cotton and applied moderate levels of insecticides (S6) because the negative ecosystems effect of low insecticides use exceeds its pest damage abatement effect. For a high degree of ecosystem disruption, the use of low quality Bt seed and moderate insecticides use (S4) is the most economical cotton-bollworm control strategy according to second-degree stochastic dominance.

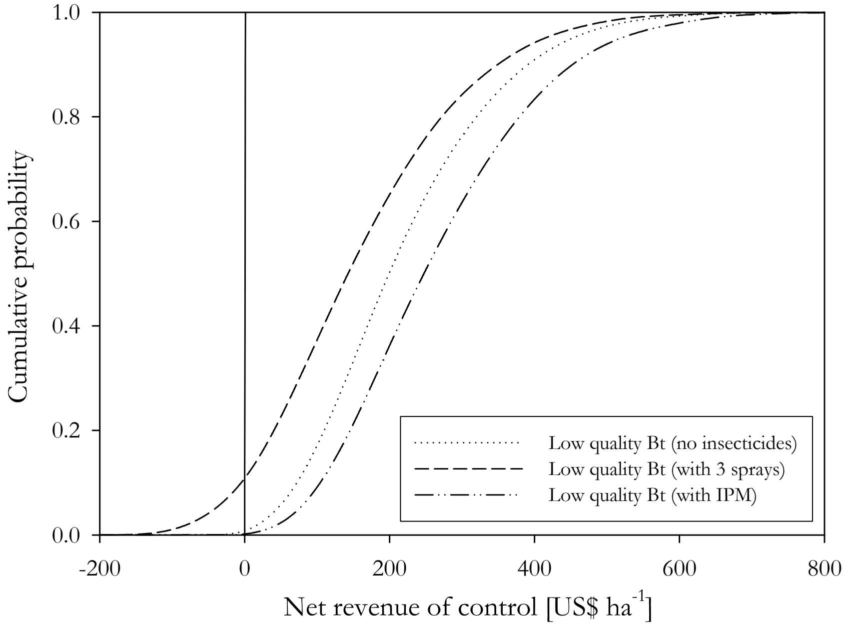

Figure 3 Simulation results of budgeting model (low quality Bt)
Source: Pemsl et al 2007

For a medium disruption level and a risk-averse decision-maker, the low quality Bt seed without insecticide use is the best option. This strategy (S3) dominates strategy 1 (high quality Bt seed without insecticides) applying the criteria of second-degree stochastic dominance. For a 0.5 ecosystem disruption, the modal values of the net revenues are lower and range from US$200 to US$750 per hectare. Finally, for an undisrupted ecosystem (Figure 4), natural control of cotton-bollworm is the most economical strategy (see Falcon et al., 1968; Gutierrez et al., 1975 for bollworm in the Great Central Valley of California). Yet, low-quality Bt-seed without the application of chemical insecticides for bollworm might be an attractive strategy for risk-averse farmers.

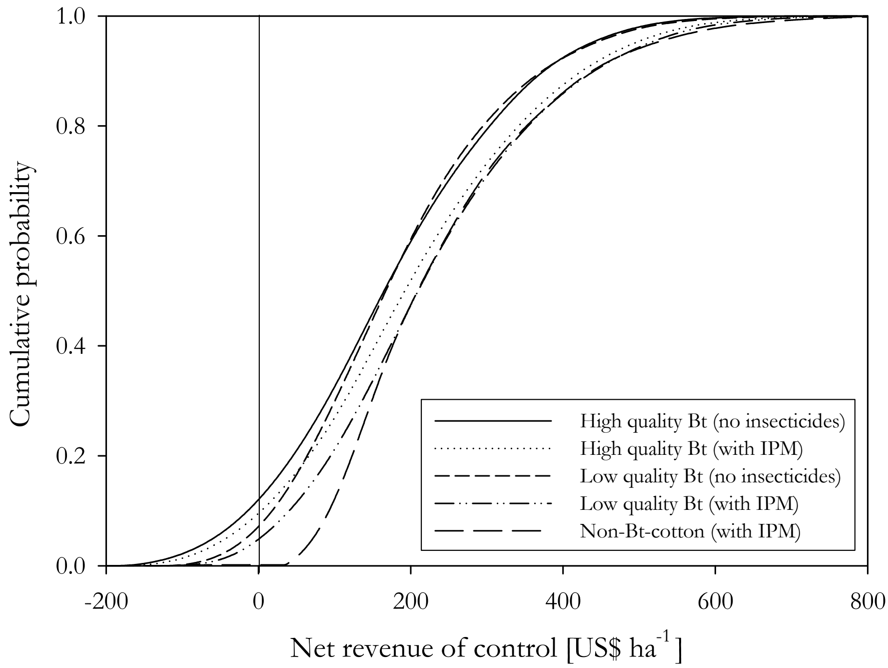

Figure 4: Simulation results of budgeting model (lower CBW pressure)
Source: Pemsl et al 2007

6 Conclusions

In most cotton growing areas, the true status of potential pest species is poorly understood leading to the pesticide treadmill (van den Bosch, 1968). This has also facilitated the rapid adoption of biotechnologies (Gutierrez, 2005). It is not clear to what extent farmers have really benefited from this technology. The empirical data and the bio-economic simulation model presented in this paper helps to explain the observed decision-making behaviour of farmers in Shandong Province, Northern China. Remarkably, they opt for the cheaper and lower quality Bt seeds and continue to spray insecticide against the cotton-bollworm. This result is also in line with the findings of Fok et al (2008) in the Yangtse River Valley who find that the seeds sold under the label of GM seeds may not necessarily comply with such standards and may even be fake.

Our model results also show the importance of the interaction between ecosystem disruption and pest control strategies. If farmers in China operate in agro-ecosystems that have been disrupted by prior pest control interventions, it is not surprising that the Bt technology shows good yield effects as measured against natural control (see also Gutierrez, 2005). On the other hand, since both, insecticide applications and Bt cotton varieties can reduce the population of beneficial organisms[1] and pests readily migrate between (disrupted and undisrupted) fields, cross section comparisons between farmers using Bt cotton with those who use conventional varieties are flawed. The fact that indiscriminate insecticide use has a stronger side effect on beneficial insects than Bt does not validate conclusions drawn from "with and without" comparisons. Whether Bt varieties will actually reduce excessive levels of pesticides in cotton (and other crops) in developing countries, whether they can help to diminish the level of ecosystem disruption and hence generate additional environmental and health benefits can only be found out if the interaction between the state of the ecosystem and human interferences are taken into account. Furthermore, static "with and without" comparisons ignore the possibility of emergence of secondary pests under Bt regimes resulting in additional pesticide use (Gutierrez et al., 2006; Wang et al. 2006). Hence, the choice of the counterfactual (that is the alternative to which the situation resulting from the use of the new technology is compared to) in impact assessment of agricultural biotechnology can pre-determine the results of such comparisons. To measure impact of Bt under on-farm conditions requires the availability of baseline data that allow the use of "difference in difference" models. Such models consider both, "before and after" and "with and without" comparisons. Yang et al. (2005) were able to show that in Bt cotton production, pesticide reduction is related to farmers' understanding of the technology rather than the technology itself.

As this study has shown, reform of the prevailing crop protection policy and investments to improve farmer understanding of the ecosystem in the context of integrated pest management are thus required in order to realize the full benefits of pest control technologies. Thus, what is most needed to shift the pest control and hence the yield frontier is a policy framework that facilitates the implementation of sustainable integrated pest management systems.

Major concerns to be addressed in future studies are enforcement of quality standards in seed markets (Fang et al., 2001) and related intellectual property rights (IPR). It has been argued (Basu and Qaim, 2007) that from a welfare economics point of view zero enforcement and consequently tolerating the existence of "illegal GM markets" can be an optimal strategy because zero IPR enforcement would lower the price of legal Bt seeds. On the other hand, as shown in this case study, the legal GM seed market may actually disappear completely because agents in the seed distribution system do not have any incentive to maintain it. In Linqing County, a large number of breeder and seed organizations generate an array of products with very little information on their performance. Local seed dealers minimize costs by adopting sales strategies that include

[1] Naranjo (2005) compared natural enemy abundance in long run studies of Bt and conventional cotton. The trends in the data show 6% lower natural enemy populations that coupled with effects of feeding on Bt intoxicated prey.

mixing of varieties with different degrees of quality. The rapid introduction of a large number of Bt varieties has lowered the Bt cotton seed price but the technology has become subject to the same kind of market imperfections that have long been observed and reported for chemical pesticides in China (Zhang et al., 2003). Thus, while Bt varieties may be effective to lower the presence of cotton bollworm this not necessarily lead to lower pesticide use. Furthermore, whether Bt cotton varieties in China will live up to their promises will be decided once a major bollworm outbreak occurs.

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Recycling of Organic Residues: A Case Study in Donau-Wald Region, Germany
有机废弃物的循环利用 —德国多瑙-瓦尔德地区个案研究

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Abstract

Recycling of organic residues from municipal and agricultural origins has become an important industry in Germany. This article analyzes a detailed case study about the recycling of organic residues in Donau-Wald region, Germany. The cross-sectoral coordination is the driving force behind the recycling of organic residues in Donau-Wald region. Key actors are linked by information flow, money flow and the enforcement of legislations from European, federal, state and local level.

摘要

市政和农业有机废弃物的循环利用在德国已经成为一项重要的产业。本文对德国多瑙-瓦尔德地区的有机废弃物的循环利用进行详尽的分析研究。跨部门之间的协作是这一地区有机废弃物循环利用背后的驱动力。主要的参与者由信息流、资金流以及欧洲，联邦，国家和当地不同层次的法制联系起来。

1 Introduction

Organic residues have quite big variety, such as liquid manure, agricultural by-products, commercial and industrial organic waste (e.g. food residues and waste fats, market waste, residues from production processes such as beer, sugar, wine, milk, alcohol, juice, meat products, vegetable processing) and source separated organic municipal waste from households.

Instead of landfilling, organic residues as input resources for biogas power plants are becoming a successful industry in Germany. Recycling of organic residues turns locally originated organic residues into energy, organic fertilizer, soil conditioner. It also increases local jobs and the money flow within the region.

Organic residues, especially the biodegradable municipal waste, are mostly treated as waste in landfills or sometimes directly discharged into rivers or other natural environment. The article therefore aims to identify the driving forces for the establishment of a recycling system for organic resides in Germany. This aim was approached through a detailed case study in Donau-Wald Region, Germany.

This case study focuses on the bio-waste from bio-bins (e.g. vegetable and fruit waste, kitchen waste and food leftovers) and the green waste (e.g. grass, tree clippings, mixed plant remainders, mixed garden waste, cemetery waste, mowing waste from road banks and leaves). The Donau-Wald region is located in eastern Bavaria Germany. It consists of the districts of Deggendorf, Freyung-Grafenau, Passau, Regen and the city of Passau, having about 520,283 inhabitants with total area of 4,500 km^2.

2 Recycling of Organic Residues in Donau-Wald

Instead of being disposed of at landfills or by incineration, organic residues in Donau-Wald have been transformed into products. Figure 1 shows the detailed quantity of regional organic residues becoming products in the market for the financial year 2005 in Donau-Wald region. In 2005, there were about 93,267 tons of organic residues collected, which were turned into 37,984 m^3 compost and approximately 10 million kWh of electricity, receiving sales income of 1,560,000€. In the financial year 2005, there were 52,937 tons of bio-waste and 40,330 tons of green waste separately collected in Donau-Wald region. Green waste includes grass, tree clippings, mixed plant remainders, mixed garden waste, cemetery waste, mowing waste from road banks, and leaves; biowaste includes vegetable and fruit waste, kitchen waste and food leftovers.

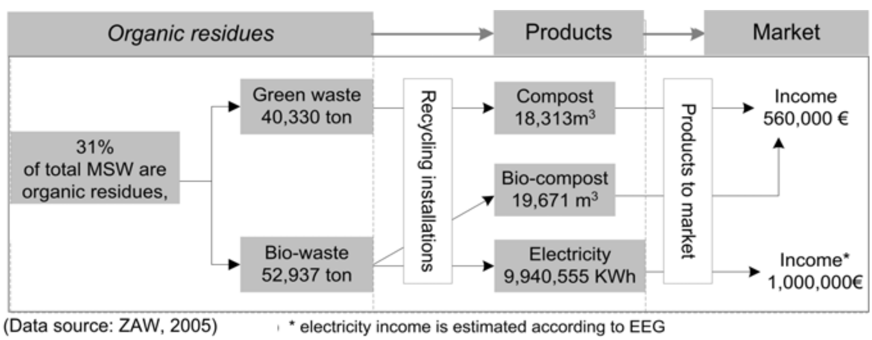

Figure 1 Regional organic residues flow in Donau-Wald in 2005

In the Donau-Wald green waste is used as raw material for producing compost, as soil conditioner or organic fertilizer. In 2005, for example, there were 40,330 tons delivered to green waste collection sites and then recycled at waste composting plants. The compost products include soil conditioner for gardens, vineyards, and lawns, sold as a bagged commodity. Compost products can also be purchased in loose form directly at the composting plant.

The total amount of organic residues was 93,267 tons, which accounted for 31% of total municipal solid waste (MSW[1]) in the Donau-Wald in 2005. Recycling organic residues saves the space and operation costs of landfills and also contributes to the abatement of greenhouse gas emissions from landfills. Recycling of organic residues in Donau-Wald has created integrated goals which combine the economic, ecological and social aspects of the local region. In addition to showing the benefits of recycling organic residues, this case study also identified the driving forces for establishment of recycling system for organic residues.

3 Driving Forces Behind the Recycling System in Donau–Wald

3.1 Coordination among actors

In Donau-Wald, key actors of the recycling system are linked by effective enforcement of legislations, recycling actions, information flow and money flow. Inhabitants, private sectors and public sectors are producers of bio-waste and green waste. In Donau-Wald region, the organizational structure with the participation of local governors (ZAW Donau-Wals) and the involvement of private companies (e.g. BBG Company), compost products distributors, and grid operators are crucial to sustain the existing recycling system. There are 53 distribution sites operated by different local companies in the region to sell the compost products.

Information flow among key actors has been organized in Donau-Wald region through internet, annual reports, citizens and children's awareness campaign, a reacting system for customers' complaints and fulfilling reporting obligations. Effective information flow is a key factor for improving and maintaining the coordination among key actors (e.g. better source separation of biowaste at household and more acceptances of compost products made from local organic residues).

The network of the above key actors and their interactions (shown with the double thick arrows) are represented in Fig.

[1] MSW consists of bio-waste, green waste, other recyclable items (including the fraction of PPK and DSD), bulky waste, reminder waste, construction debris and inert material. The total amount of MSW was 295,753 ton in 2005.

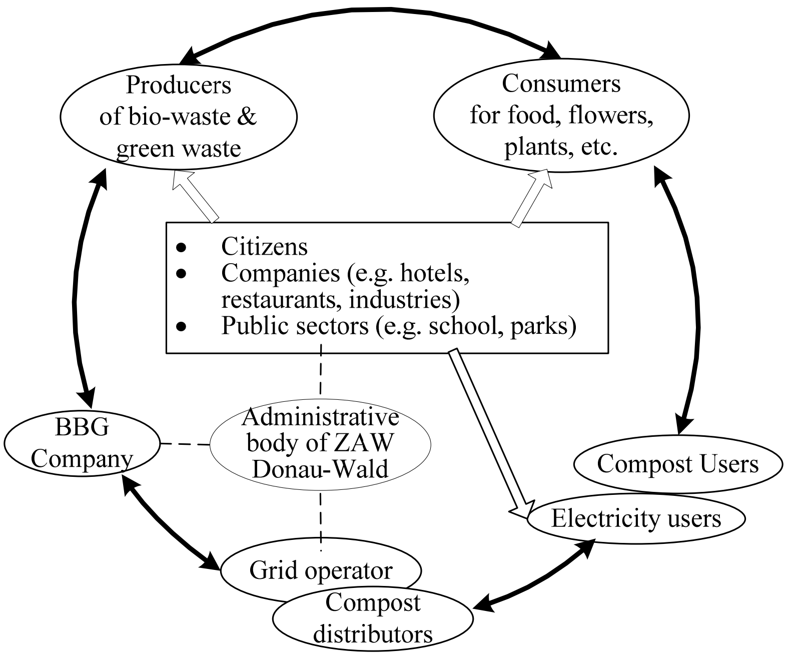

Figure 2 Relations of key actors for recycling system of organic residues in Donau-Wald

3.2 Coordination among actions

In Donau-Wald region, coordinated actions are identified, ranging from source separation of organic residues from other type of waste, collecting and transporting, transforming organic residues into products and selling products into markets. These actions enable the transformation from “organic waste” to “resources” and enhance the regional added value. Actions for recycling of organic residues are dependent on the coordination among facilities, actors, legislations, money flow and information flow.

In Donau-Wald region, over 78% of the total inhabitants have adopted biowaste bins. There are about 117,141 bio-waste bins distributed in the region to collect source-separated biowaste through a kerbside system. BBG Company operated the following facilities by the end of 2005 for the recycling of collected organic residues:

- One biogas (2 × 836 kW_{el}) power plant and attached with a compost plant in Passau with a treatment capacity of 39,000 tons/year of biowaste. The biogas power plant produces approximately 10 million kilowatt-hours of electricity per year, which means about 3,000 households can be supplied with renewable energy.
- Two bio-waste composting plants in the Regen district with a treatment capacity of 12,000 tons/year of biowaste.
- Ten green waste acceptance sites and eight composting plants with treatment capacity

of 200,000 m^3/year of green waste.

3.3 Coordination of money flow

Money flow is a crucial factor for supporting or hindering the performance of the above mentioned facilities. Three major incomes related to the recycling of organic residues in Donau-Wald are identified, namely, receiving a quantity based disposal fee, selling electricity and selling compost products. The sales and supply of compost products range from Lawn conditioner, flower soil, grave soil, plant soil, garden soil and mulch, their prices ranging from 0.18€/L down to 0.05 €/L[1]. Customers of BBG compost products are within and outside of Donau-Wald region. In 2005, the BBG company reached 560,000€ marketing income from selling 19,671m^3 biowaste compost and 18,313m^3 green waste compost. Governmental tax revenue also receives benefits from the circular organic residues flow in Donau-Wald, due to the price of compost products including a value-added tax.

Electricity price to the grid has a large economic impact on the performance of a biogas CHP plant. Thanks to the German "Renewable Energy Sources Act (EEG) ", a favourable electricity price (about 0.109€/kWh)[1] is fixed for 20 years to the biogas power plant (invested about 10 million EUR) in Donau-Wald region, which started operation in November 2004.

The above mentioned three incomes from charging disposal fee, selling compost and electricity have played the key role to maintain the good performance of recycling system in Donau-Wald region.

3.4 Coordination among legislation, action and money flow

Local actions of waste management in Germany are regulated by various types of legislation based on European law, German Federal law, the regional law of the Federal state, and the statutes of the local authority disposal agencies (Jaron, 2005).

The following two federal acts, five federal ordinances and three local statutes are the important legislations related to regulating the actions of organic residues management in Donau-Wald since 1975. Although it is not a completed list of all legislations in this field, they have served to explain an important aspect of this case study, which demonstrated the roles of policies for regulating required actions on the one hand and, on the other hand, generating money flow towards the required actions. Without these policies and legislations, the actions for making a circular organic residues flow in the Donau-Wald would be impossible.

[1] Price as of 01.04.2006, AWG Donau-Wald mbH

1. Waste Disposal Act, was adopted in Germany in 1972

Impacts: Waste Management Joint Board of Donau-Wald (ZAW Donau-Wald) was established on 15 September 1975 and a sanitation landfill was built in 1976. Since 1975, ZAW Donau-Wald has become the administrative body for waste management in Donau-Wald.

2. Ordinance on Waste Recovery and Disposal Records (NachwV) as of 3 April 1990, amended in 1996 and 2006.

Impacts: BBG company in Donau-Wald keeps and transmits documents and record books in order to make them generally available for inspection and maintain proper waste recovery and disposal.

3. Technical Instructions on Waste from Human Settlements (TASi) as of 1 June 1993

Impacts: Bavarian Waste Management Act entered into force on 9 August 1996 (GVBl. S. 396, ber. S. 449) and Donau-Wald is a region of Bavarian state. The business process of AWG Donau-Wald company is regulated by these technical instructions at the national level and the Bavarian Waste Management Act at the local level, requiring that untreated biologically degradable wastes not be disposed of at landfills after 1 June 2005. The biogas CHP plant therefore started in operation at the end of 2004 in Passau, which increased the treatment capacity of the composting plant from 20,000t/yr to 39,000t/yr.

4. German Closed Substance Cycle and Waste Management Act (KrW-/AbfG), as of 1996

Impacts: Under the regulation of the Closed Substance Cycle and Waste Management Act, ZAW Donau-Wald established AWG Donau-Wald company in 1995, BBG Donau-Wald company in 1996 and BRG Donau-Wald company in 1997. They are responsible for avoidance and recovery strategies in a cost-effective and environmentally compatible way for disposal of municipal waste and its like from commercial sources in Donau-Wald region.

5. Ordinance on Specialised Waste Management Companies (EfbV) as of 7 October 1996

Impacts: This Ordinance regulates certain actions of BBG Company pertaining to supervision, certification, organisation, human and technical resources and such things as operations log, insurance, personnel and further training).

6. Ordinance on the Utilisation of Biowaste on Land use for Agricultural, Silvicultural and Horticultural Purposes (Ordinance on Biowaste – BioAbfV) as of 21 September 1998

Impacts: This ordinance regulates the actions of BBG Company in a large range (e.g. the production process, control, products quality test and the obligation of record keeping and providing proof). This ordinance also creates consumer confidence for using compost products in land for agricultural, silvicultural and horticultural purposes. This confidence is important for the marketing success of quality compost products. The ordinance regulates the actions of compost producers on the one hand and generates the market of quality compost products on the other hand. The Donau-Wald has carried out the required treatment of biological wastes actively for the protection of the environment.

7. Act on Granting Priority to Renewable Energy Sources (Renewable Energy Sources Act-EEG) as of 29 March 2000, amended 1 August 2004
Impacts: The Renewable Energy Sources Act made the installation of the new biogas CHP plant economically feasible in Donau-Wald region. The Act provided the fixed condition to buy the electricity generated by the biogas CHP plant. In this regard, it shows that policies could generate the necessary money flow towards expected actions.

8. Federation Statute of ZAW Donau-Wald (Verbandssatzung des Zweckverbandes Abfallwirtschaft Donau-Wald), as of 1 January 1994
Impacts: This Statute provides the legal authority and the duties of ZAW Donau-Wald. It regulates the organization structure, responsibilities, administration resolution and election of the members meeting, business management and account system of ZAW Donau-Wald. Information availability (e.g. public proclamations) is also a required responsibility. According to the cybernetic model of MFM, the statute demonstrates policies regulating actions in a very direct way.

9. Statute of waste avoidance, recycling and disposal in Donau-Wald (Abfallwirts-chaftssatzung - AWS), as of 1 January 2003
Impacts: This statute regulates the legal requirements about the necessary actions of citizens, private and public sectors for establishing a system of waste avoidance, recycling and environmentally compatible disposal. The requirements include what to do and the duty of payment of the disposal fee. This Statute, therefore, provides the legal regulation about the actions of the key actors in the Donau-Wald for reaching the goal of waste avoidance, recycling and safe disposal. It provides the legal regulation for the establishment of circular organic residues flow in Donau-Wald region.

10. Statute of disposal fee for municipal waste disposal by ZAW Donau-Wald (Gebührensatzung) as of 1 January 2003, amended 1 January 2007
Impacts: Disposal fee is one of the key incomes for the BBG company to operate the actions of recycling organic residues. This statute provides the legal guarantee to receive disposal fees at certain levels for a fixed duration. The disposal fee statute thus generates a money flow to promote the actions of BBG.

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[1] Based on "Renewable Energy Sources Act (EEG)

4 Conclusions and Suggestions

Recycling of organic residues has been established through biogas power plant and composting plants in Donau-Wald region, Germany. It accounts for 31% of municipal solid waste in the region. Recycling of organic residues contributes to soil improvement, renewable energy production, climate and environmental protection. Local economic activities and jobs are added as well.

This case study also identified that the driving force behind the recycling of organic residues in Donau-Wald region is the cross-sectoral coordination among the key actors (e.g. organic residues producers, collectors of biowaste, operators of electricity grid and the users of compost products). The cross-sectoral coordination among key actors are sustained by information flow (awareness campaign and companies' annual reports), money flow (e.g. disposal fee, guaranteed electricity tariff to grid and incomes of composting products) and the enforcement of legislations from European, federal, state and local level.

In 2007, about 152 million tons municipal solid waste (MSW) was collected in China from over 660 cities. About 50% of them were disposed of by sanitation landfills, 38% by dumping, 9.4% by incineration and 1.6% by simple composting[1]. Against the growth of urbanization and the scarce of land availability, recycling of biodegradable solid waste (BMW) is a necessity for China. BMW is about 41-65% of MSW in China (World Bank, 2005). According to the case study in Donau-Wald Region, cross-sectoral coordination could be a crucial factor to evaluate and improve the status about recycling of BMW in China.

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Assessing the Potential of Energy Crop Production in China by Remote Sensing
通过遥感技术估算中国能源作物生产潜力

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Abstract

At more than 30% of primary energy supply, biomass undoubtedly plays an important role in developing countries. However, the potential of producing more energy from biomass is limited compared to other sources of energy. Yet some biomass utilization technologies, like biogas can bridge the gap in sustainable energy production, especially while solar energy technology is not sufficiently developed. The focus for sustainable energy production from biomass lies primarily on wastes and energy crops grown on degraded lands.

The impact of producing energy from biomass can be both positive, if there is a significant net climate change mitigation effect, and negative, if that is overcompensated by adverse effects on natural resources and social conditions. Reliable, measurable, and comparable criteria are required to identify potentially negative impacts. Moreover, there is also a need for concise standardized methods by which such criteria can be applied to ensure sustainability compliance for tradable products at a global scale.

Newly developed remote sensing approaches were applied to identify degrading and abandoned agricultural areas that might be potentially suitable to produce biomass for energy in China. Zones of potential conflict with sustainability criteria were then deducted. This concerned areas of high value for maintaining food security, and for conserving nature and biodiversity. The methodology also envisioned exemplary site checks on the ground for comparison with remote sensing approaches and datasets.

Degradation areas that might be suitable for producing energy crops are concentrated in hilly parts of southern China, coinciding roughly with the region where grasses, tubers or woody oil crops are already promoted to increase farm income and contain land degradation. The accuracy of remote prospecting for biomass depends largely on the quality, resolution and up-to-dateness of the data source. In this study, low-resolution internationally available data sources were used, so the results are only vaguely indicative.

摘要

作为超过 30%的主要能源供应，生物质能无疑在发展中国家起了重要的作用。然而，生物质能生产的潜力与其它的能源相比是有限的。一些生物质利用技术，比如沼气，却能够填补可持续能源生产的不足，尤其是在太阳能技术没有得到充分发展的情况下。生物质能的可持续性生产主要依靠废弃物和在退化土地上的种植的能源作物。

生产生物质能的影响可以是积极的，如果其确实起到了减缓气候变化的实际结果；但如果由此对自然资源和社会环境产生的反作用需要过多补偿，超过了其所带来的减缓气候变化的效果，那么它的作用就是消极的。因此需要可靠的，可测的，可比较的标准来识别潜在的负面影响。此外，需要一个简明的标准化方法，通过该方法这些标准能够确保在全球范围内贸易产品的持续遵守。

在中国，新开发的遥感技术被用来识别那些有可能适合生产生物质能的退化的和废弃的农业空地。与可持续发展标准有潜在冲突的区域被排除。这些区域被认为对维持食品安全，保护自然和生物多样性有很高的价值。这种方法也通过比较遥感方法和数据设置使现场示范性检测可视化。

有可能适合生产能源作物的退化土地主要集中在中国南部的山区，大体上与现在已经种植草地、块茎作物和木本油料作物来提高农业收入和抑制土地退化的区域一致。对生物质进行遥感勘测的准确性很大程度上取决于质量、分辨率和数据源的实时性。本研究中利用的是低分辨率的国际现有数据源，所以结果只是大体的表述。

1 Introduction

While mankind has not sufficiently explored the whole bandwidth of technological options for energy production and utilization from renewable sources, in particular solar energy, making use of photosynthesis directly instead of using fossil fuels and thereby releasing great quantities of greenhouse gases, is considered one option to help bridge the current gap in renewable energy, at least for a period of transition. The logic behind is that plants first absorb the CO_2 that is later released during fuel consumption. The provision is that the mitigation effect of the entire production process, including the inputs needed for plant production like nitrogen, which is particularly energy-intensive, is significant and that impacts on carbon stocks by conversion of land use, natural ecosystems, biodiversity, scarce water resources, livelihoods in the production regions, and not least food security remain insignificant.

In 2007, the State Council has excluded the use of grains and green grain crops for biofuel and other forms of bioenergy. Using the current period of moderate industrial growth to increase food production has been declared a priority. This underlines the fact that China is putting great emphasis on sustainable and secure food production. Nevertheless, in view of mitigating climate change, the topic of sustainable biomass for energy production is still on the agenda. Developing practicable approaches that certify sustainable production should be in the interest of China and other signatories to the convention on biodiversity as well as nations for which trade in agricultural commodities is of high importance.

At present, the EU prepares the ratification of a directive on the promotion of the use of energy from renewable sources, ‘which aims to establish an overall binding target of a 20% share of renewable energy sources in energy consumption and a 10% binding minimum target for biofuels in transport to be achieved by each Member State, as well as binding national targets by 2020 in line with the overall EU target of 20% (European Commission 2008). Another aim of the directive is to establish environmental sustainability criteria, which include a 35% minimum greenhouse gas emission savings, the protection of natural forest and areas designated for nature protection, highly biodiverse grassland, and areas with high carbon stocks, like wetlands and continously forested areas. In its preliminary version, the directive is less specific on food security and water resources, but it contains a commitment that such impacts shall be monitored at regular intervals.

The adherence to sustainability criteria is conditional to trade with member states which will have to oblige to the 10% target on biofuels in order to avoid sanctions. ‘While it would technically be possible for the Community to meet its biofuel target solely from domestic production, it is both likely and desirable that the target will in fact be met through a combination of domestic production and imports.’ What follows is not explicitly mentioned in the directive, but the conclusion draws near that instead of trading the physical product, qualified certificates that guarantee the existence of such product and the fact that it has been produced in compliance with sustainability criteria, could be traded instead. The fact that climate change is a global phenomenon and that it does not matter in principle, where the emissions are saved, is also one of the underlying reasons for trading CDM certificates.

So to what extent could China, in as far as it does not need to produce biofuel to meet its own renewable energy commitments, benefit from a biofuel trade with the EU? What is the potential of sustainable energy crop production in China?

2 Methodology

In brief, the steps taken in the methodology are to:

1. Identify GIS data sources and methods
2. Develop a decision logic
3. Prospect for abandoned or degraded land
4. Deduct areas with sustainability concerns
5. Determine the size of potentially suitable areas
6. Find out what crops might be grown there

7. Estimate the crop production potentials
8. Spot check validity of data and methods

The assumption underlying the methodology, is that if energy crops can be grown on land that is subject to degradation or on abandoned agricultural land without causing further degradation, but rather contributing to the rehabilitation of such land, the overall impact should be positive, provided this is of economic interest to the farmers and the local economy, the overall climate change mitigation effect is significant, and conflicts with nature conservation, biodiversity, scarce water resources and food security can be avoided. How then identify degraded or abandoned land in the first place?

The degree to which plants are actively transforming light into plant matter by photosynthesis can be detected from space with remote sensors from the reflectance of incoming radiation in the red and near-infrared light spectra. If much of the near-infrared light is reflected and much of the red light absorbed by plants for their photosynthesis, the NDVI approaches a value of 1. Conversely, if much of the infrared is absorbed by barren areas of rock, sand, or snow, and much of the red light is reflected, the NVDI approaches a value of -1. The NDVI is also referred to as 'greenness' index, since photoactive plants not only absorb red light, but also reflect green light perceptible to human vision.

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

Where:
NDVI = Normalized Difference Vegetation Index
NIR = Near-infrared light
RED = red light

Bai and Dent (2007) devised a methodology on how to discover degrading land (and land improvement) using the NDVI: Fortnightly AVHRR images at 8km-spatial resolution for the period of 1981 – 2003 "were corrected for calibration, view geometry, volcanic aerosols, and other effects not related to vegetation cover." NDVI data were translated approximately to NPP (net primary productivity) using MODIS (moderate-resolution imaging spectro-radiometer) data for the overlapping period 2000-2003. Rainwater use efficiency (the ratio of NPP to rainfall) was taken into account to distinguish the effect, changes in rainfall patterns have on productivity, from the effect of land degradation. The negative trend in RUE-adjusted annual sum NDVI during the period 1981-2003 was taken as indicator of land degradation (Bai and Dent 2007).

In the context of identifying land suitable for sustainable energy crop production, it was assumed that potential conflicts could be minimized, if land that was subject to only slight loss of greenness was excluded. On the other hand, production of energy crops on severely degraded land might not be economic. To define suitable limits, the intensity range was divided into four sections using an equal interval function along the degradation intensity range, classified into slight, moderate, high, and severe, of which moderate and high degradation classes were henceforth exclusively used in the assessment.

For abandoned land (荒地 'huāng dì' in Chinese), an approach described by Field et al. (2007) was used. The authors had determined abandoned land by merging HYDE 3 cultivated land use and grassland for each decade from 1700 – 2000 and subtracting year 2000 cultivated land use from the respective maximum historic land use extent. Since land use intensity is given as a percentage, previously abandoned areas showed as positive percentage land use values, i.e. +1, 2, 3, or 5% of the entire pixel area (of 5' spatial resolution). In a second step, Field et al. (2007) had applied MODIS 2004 data (at 0.5km resolution) to exclude cultivated land, urban land and forest, which exposed the present abandoned land, potentially suitable for energy crop production.

The FAO LADA (Land Degradation in Dry Areas) Program defines land degradation as loss of ecosystem functions over a specified time (Nachtergaele 2008). Such losses comprise losses of biomass (accumulation, yield), soil health, water quantity and quality, biodiversity, and economic as well as social benefits. According to Nachtergaele (2008) "Land Use Systems (LUS) are the most suitable units that capture the status and causes that influence land degradation and sustainable land management interventions". FAO LADA China land use data were recurred on, in order to exclude sustainability concerns. The big advantage of the LADA gridded 8-km resolution data is that they provide spatial information on protected areas for different kinds of land use classes, for example protected pasture, protected wetlands, etc. The dataset includes IUCN sites and those of other international conventions and agreements. e.g. RAMSAR wetlands, World Heritage sites, UNESCO-MAB biosphere reserves, and national sites without IUCN category.

All LADA China protected land use areas that coincided with the potentially suitable areas were excluded. To ensure sustainable use of forestry resources and to avoid potential conflicts with secure food production, forest, intensive agro-pastoral land use, and irrigated areas were excluded. Wetlands were excluded due to biodiversity concerns and carbon richness. Barelands were excluded for their limited productive potential. In the end, the choice of potentially suitable areas was limited to the following 6 land use classes:

7	Herbaceous -no use/not managed
9	Extensive pastoralism
10	Mod. Intensive pastoralism

13 Rainfed agriculture (Subsistance/commercial)
101 Shrub -no use/ not managed (Natural)
103 Shrub – Pastoralism moderate or higher

This was compared to using the following land use classes from the Chinese Special Land Use dataset by the CAS Institute of Geography (scale 1:400,000): 'Bush', 'Non-irrigated-field', 'Sparse-woods' and 'Hill-grassland', excluding 'Cold-desert', 'Desert', 'Economic-forest', 'Glacier-snow', 'Gobi', 'Industrial-mine-land', 'Irrigated-field', 'Lake-reservoir', 'Marshes', 'Paddy', 'Prairie-Grassland', 'Saline-alkali-land', 'Salt-pan', 'Timber-forest', 'Bare-land', and 'City'.

To be economically viable, energy crops require at least moderately intensive management, even if they consist of perennial crops integrated into agroforestry systems. Therefore it was assumed that they should not be established on steep land, which in China are defined as land >25° slope (approximately equivalent to the FAO-90 World Reference Soil Resources landform definition of 30% slope). Excluding steep landforms at the same time accomplished the exclusion of areas under the Grain-for-Green Program in the Yangtze river basin. Areas above 2000 meters were also excluded due to the limited productive potential these areas offer for energy crop production and the comparative sensitivity of the food market in remote areas to changes in crop production patterns.

3 Results and Discussion

The effect of urbanization, masked (= no data) in the results of Bai and Dent (2007) is affecting the results merely at a local scale, as urban land use makes up only 1% of the total degrading area (Bai and Dent 2007). Whether urbanization itself should be considered degradation is arguable, however it usually does infer loss of greenness and ecosystem services. Anyhow, due to the masking, urbanization can be largely excluded as a direct cause of degradation. Yet we think, that indirect effects on land use in the urban-rural continuum and subtle direct effects of urbanization (scattered housing) may well have a greater impact on loss of vegetation than the mere extent of urban land use areas suggests. This argument is nourished by the observation that several clusters of severely degrading areas coincide with urban sprawl, but not with typical signs of soil degradation as shown on maps by Wang and Otsubo (2002). This concerns for example areas close to Guangzhou.

Figure 1 shows the distribution of slightly, moderately, highly, and severely degrading areas. The totals of moderately and highly degrading areas equal 369,415 km² and 44,108 km² respectively. Severely degrading areas are only 5342 km². Most dominant are the slightly degrading areas with 1,774,833 km². Based on the assessment of Bai and Dent (2007) who correlated the negative RUE-adjusted NDVI trend with loss of NPP (net primary productivity) by MODIS image analysis, the moderately and highly degrading lands cover a range of approximately 20 - 60 kg CO_2 loss per ha and year. Excluding areas above 2000 m and 25° slope reduces the potentially suitable area by 13% (Figure 2). The slope factor is largely included in the altitude, as areas above 25° slope are more characteristic of high mountain terrain.

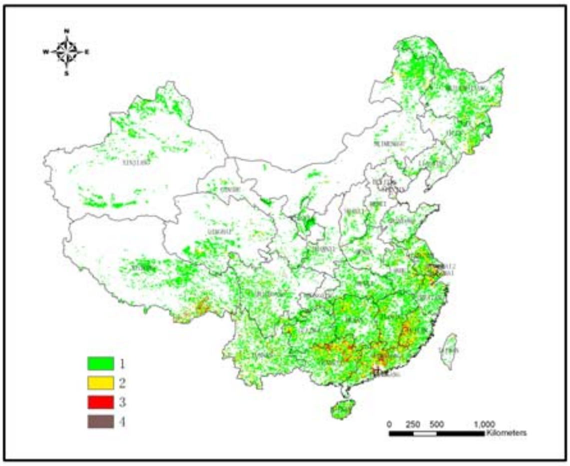

Figure 1 Degradation areas of China according to Bai and Deng (2008) classified into 4 equal classes along the degradation trend intensity range: slightly (1), moderately (2), highly (3), and severely (4)

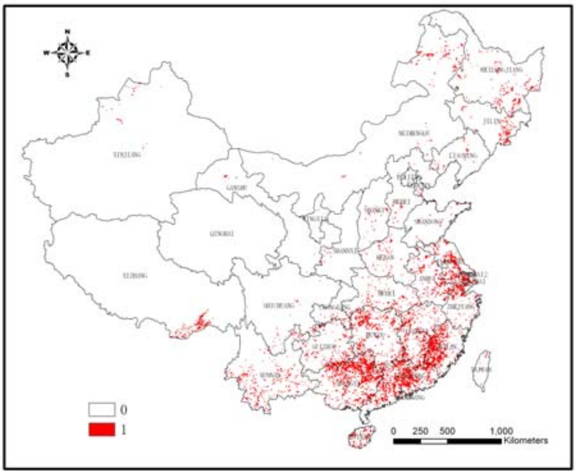

Figure 2 Moderately and highly degrading areas after exclusion of 25° slope and elevations above 2000 meters

For the Chinese dataset, the intercept of the remaining moderately to highly degrading land with the potentially suitable land use (98,048 km²) is composed of the following land use classes: Hill-grassland (29%), non-irrigated fields (29%), sparse-woods (24%), and bush (18%). Deducting 13% for protected land use, equivalent to the share of protected areas in the FAO land use dataset, results in 85,300 km². The intercept of the moderately and highly degrading areas with the 6 potentially suitable land use classes of the FAO dataset is comparatively smaller: 36,288 km². The average between these two datasets, about 60,000 km², is an area equaling 5% of cultivated areas, predominantly found in Southern China.

A comparison of 2000 and 2005 revealed that proportionally much more grassland had been abandoned (15,067 km²) compared to cultivated land, which was negligible during that period (124 km²). The results are shown in Figure 3. Field et al. (2007) estimated the total area of potentially suitable abandoned land as 156216 km² - 233570 km² (2003 cultivated land: 1.234 million km²) with an average biomass production potential of around 38 million tons/yr. According to these authors, that would be sufficient to cover around 1% of China's primary energy demand or 0.75 exajoule /yr (1 EJ = 10^{18} joule). From our first assessment, we find that it would probably be very difficult to achieve this in practice, but one third appears feasible.

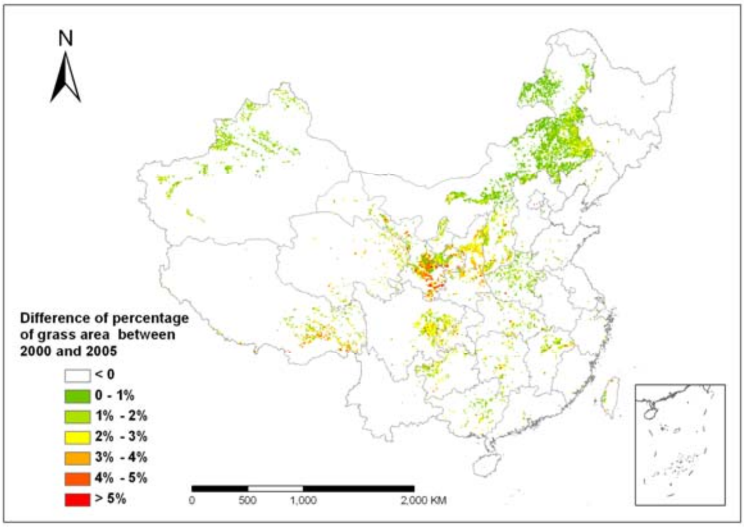

Figure 3 Grassland abandonded between 2000 and 2005
(abandonement is shown as positive percentage of land use for 2000 over 2005)

Based on the low resolution of the datasets used in this study, only an approximate estimate of biomass for energy production is possible. According to field observations made in the south of China, despite the possibility of using degrading or abandoned land, there still seems to be a shortage of land needed for energy development. It requires some degree of aggregation around production facilities, whereas the degrading areas can be comparatively scattered and remote. The possibility of using energy crops in rotation with food crops on other than degraded and abandoned land could to be considered. As China is self-sufficient in its main staples rice, wheat and corn, sweet potato (however the crop play an important role as animal feed for pork) and as there are some fallow areas (e.g. winter fallow that could be used for rapeseed) there should be some potential of using crops like sweet sorghum, rapeseed, sweet potato, cassava, sugar cane, but also less common crops like physic nut (Jatropha), castor, arrowroot, and caper spurge for bioenergy without compromising food security targets. It was also found that there is a significant potential for the development of high-yielding energy crops in subtropical South China. Yet there are many hurdles to overcome, also with regard to process technology development and adaptation.

5 Conclusions

The extent of degrading land available for energy crop production depends largely on the definition and classification of degrading areas. The approach of Bai and Dent (2007) was found to be very useful in that respect and in line with observations made at field level. There is some coincidence between the degradation areas according to Bai and Dent (2007) and soil degradation areas of China (Wang and Otsubo 2002), which have about the same extent of 2.3 million km^2. However, in many parts such coincidence does not exist, especially in those showing the highest loss of greenness. We argue, that if loss of greenness was the result of indiscriminate logging or burning of forests and shrubs in shifting cultivation, there should be more of a coincidence with soil degradation. Possible reasons behind the lack of such coincidence, including possible phenomena like 'desakota' (Gyawali et al. 2008) should be studied in more detail, as loss of carbon is undesirable, even if China is effectively net-sequestering carbon with regard to its biomass development, mainly due to the expansion of forest plantations and measures like the Grain-for-Green Program.

More information is needed also about the abandoned land, the reasons for its abandonment and its coincidence with land degradation. Incorporation of data on land degradation and improvement at the level of prefectures and districts would be helpful to complement existing statistical information for better estimates of potentially suitable areas for energy crops. According to Berry (2003), the cost of land degradation is high in China, at least 4% of GDP. In that respect, sustainable cropping systems using food crops and to a justifiable extent also energy plants could entail ancillary benefits by further reducing or reversing land degradation.

Energy crop development depends largely on the development of fuel prices and other commodities. In the recent past, food prices were found to be also coupled to commodity prices, so subsidies were needed to tip the balance in favor of energy crops. Whether the fact that energy crops are grown on degrading or previously abandoned land, should be taken as trigger to release subsidies, must be looked at with caution. The use of such crops is justifiably seen as a vehicle for potential land improvement. Then if the land is improved, will the reason for subsidizing energy crop production cease to exist? In some areas, especially on slopes above 25%, natural revegetation with least possible human interference is probably the more effective rehabilitation method. Could the prospect of subsidies for energy crops contribute to prevent this?

The concept of sustainable crop production of energy crops is very useful and could be applied also to the production of food crops. Important elements of a standardized assessment are the energy balance and unwanted competition for land and resources to sustain food security. China, due to its land shortage probably not in a position to afford half the level of fossil fuel substitution by biofuel that the EU is aiming at, can still benefit from the development of such concepts to further promote environmentally sustainable agriculture, for trade in biomass as well as food crops.

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Sustainable Land Development and Ecosystem Conservation Through Enhancing Economic Viability of the *Jatropha curcas* Based Biodiesel Production Chain Using a Bio-Refinery Concept

通过提高以生物柴油生产链为基础的、生物炼制概念下麻风树的经济生存能力促进可持续土地开发和生态系统保持

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Abstract

Environmental degradation and depleting oil reserves are matters of great concern round the globe. Developing countries like China depend heavily on oil imports. Jatropha based biodiesel is receiving increasing attention in China because its use is benign to the environment and contributes to enhance energy security by making a country less dependent on fossil fuel imports. In addition, the Jatropha plants can grow on degraded and poor soils and have tremendous potential for enhancing socio-economic conditions, improving microclimate, vegetation and soil quality. Our financial analysis has shown that with the present production level of Jatropha seeds and hence of oil for conversion to biodiesel, planting Jatropha for biodiesel production alone is not economical.Therefore, it is imperative to generate high-valued coproducts using the concept of bio-refinery (a zero waste concept) in which each and every component in the biodiesel production chain is transformed into high valued marketable commodities.

So far, through the BMBF-MoST funded project, we have detoxified the kernel meal that contains 60% protein of high biological value. It has been proven that it is an excellent substitute for soybean meal in the diets of fish and farm animals, and the products obtained are safe for human consumption. Similarly, high valued protein concentrate containing 90% protein with excellent amino acid levels has been obtained from screw-pressed Jatropha cake. The use of by-products such as acid gums, fatty acid distillate, and glycerol (obtained during the process of biodiesel production from oil) as a constituent of livestock feed has also been explored. Other innovations include enhancement of the efficiency of screw-pressed based oil extraction from Jatropha seeds by over 30% compared to the existing screw-pressed based extraction approaches; development of a low cost furnace which uses Jatropha seed shells as a source of energy; and small and large scale Jatropha oil cleaning processes enabling the oil use in cooking stoves. This article presents the salient achievements and ongoing and future studies.

摘要

环境退化和石油储藏量枯竭在全球倍受关注。像中国这样的发展中国家对石油进口的依赖性很大。麻风树生产生物柴油在中国不断受到关注，因为它的使用对环境有益，并且帮助一个国家减少化石燃料进口，从而提高能源安全。另外，麻风树可以在退化的和贫瘠的土地上生长，并且在提高社会经济条件、改善小气候、植被和土壤质量方面有巨大的潜力。我们的财务分析已经显示以现有的为转化为生物柴油而生产的麻风树籽的生产水平，单为生物柴油种植麻风树是不经济的。因此，用生物炼质的概念（零废弃概念）生产高价值的副产品是十分必要的，在生物炼制的概念中，生物柴油产品链中每一个部分都被转化为高价值可买卖的用品。

到目前为止，通过德国联邦教研部和中国科技部资助的项目，我们已经对麻风树种籽进行脱毒处理，麻风树种籽含有 60%的，具有很高的生物值。已经证明在鱼和农场养殖中，它将是大豆饼粕最好的替代品，而且以此获得的产品对人类消费是安全的。同样地，压榨制成的麻风树饼粕浓缩了高价值的蛋白质，含有 90% 的蛋白质全和极高的氨基酸水平。作为家畜饲料要素的副产品也已经被开发，例如：酸脂、脂肪酸精华和甘油（从油到生物柴油产品的生产过程中获得）。其它的创新包括：与现有榨油方法相比，麻风树树籽的榨油效率提高了 30%以上；开发以麻风树种籽壳为能源的低成本炉子；小型和大型的麻风籽油清洁工艺使得这种油。

1 Introduction

Jatropha curcas plantations can be set up on eroded lands under harsh climatic conditions. The seeds contain about 25–35% oil that can be used as fuel directly or as a substitute to diesel in the transesterified form. Many oil importing countries have plans currently to undertake massive cultivation of Jatropha to produce renewable fuel oil locally and reclaim wasteland for food production. In China, *J. curcas* is distributed in Guangdong, Guangxi, Yunnan, Sichuan, Guizhou, Taiwan, Fujian, Hainan provinces (Ye et al. 2009). According to a recent report (Wang, 2006), Guizhou karst to Rehe valley area of China consists of vast barren land, which is not usable for conventional food crops, but is suitable for *J. curcas*. In Guizhou and Sichuan provinces, conditions for Jatropha plantation are most favourable (Ye et al. 2009). Currently, 10 thousand ha of plantation exists in Sichuan province and 35 thousand ha in Yunnan province. It is projected that Jatropha will be cultivated on 700 thousand ha in Southwest China in the coming years (Lan, 2006).

In July 2007, Bundesministerium für Bildung und Forschung (BMBF) and Ministry of Scinec and Technology, Beijing, China (MoST) launched a joint project on 'Feed and Fuel for Tomorrow through *Jatropha curcas*'. The objectives of this project are:

1. Preparation of kernel meal and protein concentrate free of antinutrients and toxic factors and their utilization in fish and livestock diets.
2. Use of by-products such as acid gums, fatty acid distillate, and glycerol (obtained during the process of biodiesel production) as livestock feed.
3. Optimization of screw-pressing technology for extraction of oil and production of seed meal.
4. Development of technology for cleaning of Jatropha crude oil in order to reach the developed standard for use in plant oil stoves.
5. Development of small scale combustion systems (furnace) for using shells as energy source.
6. Economic evaluation of the detoxification process, and its accounting in the overall economic assessment of Jatropha-based small and large scale oil production systems.

2 Salient Findings

This paper reports salient findings from this project in three sections. The work related to: objectives 1 and 2 is presented under 'Animal component'; objectives 3 to 5 under 'Engineering component'; and objective 6 under 'Economic component'.

2.1 Animal component

Demand for protein ingredients is expected to exceed the annual world supply of fish meal (FM) in the next decade, and this increased demand will change the economic and nutritional paradigms that up to now have resulted in high use levels of FM in aquafeeds. The challenge facing the aquaculture industry is to identify economically viable and environmentally friendlier alternatives to fish meal, and the challenge for the livestock industry is to find alternatives to conventional feeds such as soybean meal (SBM), ground nut cake, rapeseed oil meal, maize and wheat. The Jatropha seed cake obtained after oil extraction is an excellent source of nutrients and contains high crude protein. The levels of essential amino acids (except lysine) are higher in Jatroph*a* seed cake than in the FAO reference protein for a growing child. However the presence of high levels of antinutrients such as trypsin inhibitor, lectin and phytate and the major toxic components phorbol esters (PE_S) restrict their use in fish feed (Makkar et al. 2007). In the previous ERSEC paper (Makkar et al. 2008a) it was reported that we have optimized conditions for cracking seeds and for separating shells from kernels; and the detoxification of Jatropha kernel meal, which contains approximately 60% crude protein has been achieved. Here we report dietary utilization of detoxified Jatropha kernel meal (DJKM) in tropical freshwater fish common carp (*Cyprinus carpio*) and temperate region freshwater fish rainbow trout (*Oncorhynchus mykiss*) diets as a protein source. Experiments on carp (*Cyprinus carpio*) were divided into two parts: short term (8 weeks) and long term (16 weeks) feeding trials, whereas on trout one feeding trial for 12 weeks was conducted.

2.1.1 Short term feeding studies on carp

The FM protein in the diet was replaced by 50% and 75% by a range of plant protein resources, including SBM and DJKM. All diets were iso-nitrogenous (crude protein 38%) and isoenergetic (crude lipid 10%). Although the DJKM and SBM used in the present study were deficient in lysine, the prepared diet did not have any deficiency because of the amino acid profile contributed by the FM component and addition of lysine as a supplement.

Fish behaviour, feed intake, growth performance and nutrient utilization: Based on the visual observation during feeding time, palatability or acceptability of feed was good and the behaviour of fish was normal. Growth and nutrient utilization data provided support for the DJKM to be an excellent plant protein for carp feed. Fish fed either of the DJKM diets outperformed those on the SBM supplemented diets (Table 1). Growth performance and nutrient utilization of carp fed J50 diet (50% FM protein replacement by DJKM) were better than of those fed SBM based diets and similar to those fed FM based diets. Slightly lower performance of fish fed the diet where a 75% of FM protein was replaced by DJKM suggested that the capacity of detoxified Jatropha kernel meal to fully sustain growth was slightly lower compared to the diet based on FM only (control diet). The growth data were consistent with the nitrogen retention, protein efficiency and feed conversion data.

The lower growth response of 75% DJKM group could be due to lower protein availability from the DJKM (plant protein structure is much more compact than FM, so digestive enzymes act slowly on plant proteins), poor availability of crystalline lysine added to DJKM groups to equalize lysine content, and/or the presence of antinutrients such as phytate and non-starch polysaccharides (NSP), which are present in high amounts in the kernel meal.

Digestibility: SBM and DJKM in combination with FM protein exhibited excellent dry matter, crude protein, lipid and energy digestibilities. Generally, oil seed meal proteins have digestibility of 80-95% for fish (Jauncey and Ross, 1982). The protein digestibility coefficient is a key factor in the evaluation of the quality of a diet for fish and the potential of the diet for the synthesis of new tissue. Dry matter, protein, lipid and energy digestibilities were 78-85%, 89-92%, 92-97% and 83-88% respectively, which indicate excellent utilization of feed ingredients. Digestibility data supported a markedly higher apparent digestibility for protein from DJKM than from SBM, implying that a greater amount of protein would have been available to the fish from the DJKM diets. The lower lipid digestibility of the fish fed the plant protein based diet may be associated with the increase in the NSP content which reduces fat absorption by disturbing micelle formation in the gastrointestinal tract (Krogdahl et al. 2003).

Digestive enzyme activities and relative intestinal length (RIL): Antinutritional factors such as phytic acid inhibits activity of some digestive enzymes such as pepsin, trypsin and alpha-amylase (Alarcon et al. 1999), or form complexes with minerals and proteins (Moyano et al. 1999); thereby modify digestion processes and impair intestinal absorption. Carp showed a significant decrease in protease, amylase and lipase activities on inclusion of plant proteins in the diet (Table 1). It is known that carnivorous and omnivorous fish require longer time to digest plant protein based diets. In carp, plant protein based diets exhibited higher RIL than the control group. Direct relationship between the amount of dietary plant protein and RIL has also been reported earlier in fish (Kramer and Bryant, 1995). From a physiological view point, a longer RIL could have facilitated an increase in digestibility by allowing enhanced contact time of the digestive enzymes and the feed components, resulting in increase in their digestion and absorption. Omnivorous fish like common carp species showed compensation mechanisms, such as an increase in RIL and as a result increase in digestive activity, to achieve a digestive balance and growth rates similar to those observed for control fed groups.

Haematological and histological parameters: Plant protein in the feed had significant effect on the total red blood cells (RBC) count (Table 1). As the plant protein content increased, an increase in the RBC count was observed. Higher erythrocytes counts were observed in SBM and DJKM fed groups. Plant ingredients may cause early release of immature erythrocytes (Hemre et al. 2005), increasing the erythrocytes count. The white blood cells (WBC) count, haemoglobin content, haematocrit, mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), total bilirubin, blood ions (calcium, phosphorus, sodium and potassium) did not differ significantly among SBM, DJKM and FM fed groups. Hemoglobin (5.0-5.5 g/dL) and hematocrit (27-35%) levels in all groups in our study were within the normal range (Sun et al. 1995). Alkaline phosphatase (ALP) and alanine aminotransferase (ALT) are indicators of liver dysfunction (Soltan et al. 2008). Higher ALP activity was observed in 50% and 75 % SBM groups and in 50% DJKM fed group when compared to the control group. However, ALP activity was similar for 75% DJKM and the control group. No consistent pattern in ALP on increasing the DJKM in diet, similar ALT activities in DJKM, SBM and FM fed groups, and ALT activities in DJKM, SBM and FM fed groups in the optimum range indicate absence of any adverse effect of DJKM feeding on liver function. In histological studies, we did not find any hepatic cell damage. Lower blood glucose level was observed in FM protein fed group i.e. the control group whereas plant fed groups had higher blood glucose levels (Table 1). As plant protein content increased in the diets, blood glucose level also increased. This could be ascribed to higher level of carbohydrates in plant-based diets. The concentration of total protein in blood is used as a basic index for health status of fish. The plant protein based groups had similar albumin levels but these levels were lower compared to the control group. Globulin concentration in blood was higher in the plant protein fed groups compared to the control group, although the levels in SBM and DJKM groups were almost similar and did not follow any trend (Table 1). Lysozyme plays an important role in nonspecific immune response and it has been found in mucus, serum and ova of fish. Innate immunity due to lysozyme is caused by lysis of bacterial cell wall and this stimulates the phagocytosis of bacteria. In our study lysozyme activity did not differ significantly among SBM, DJKM and FM fed groups. The reduction of plasma cholesterol in fish on plant protein based diets may be because of increased dietary fibre in plant protein diets (Table 1). The observed marked hypocholesterolemic effect agrees with the results obtained in a short term trial in gilthead sea bream using the plant protein based diets (Gomez-Requeni et al. 2004). Histological examinations exhibited no significant lesions in intestinal loops, muscosa, liver and muscle morphology in any of the diets. Minor pathological lesions were observed in intestine of the DJKM fed group at 75% replacement of FM protein.

Table 1 Growth performance, nutrient utilization, digestibility measurement, digestive enzymes activity and hematological parameters of common carp (*Cyprinus carpio* L) fed experimental diets for eight weeks

Parameters	Control	Soyabean		Jatropha	
		50% (S_{50})	75% (S_{75})	50% (J_{50})	75% (J_{75})
Initial body mass (g)	3.2 ± 0.1	3.3 ± 0.10	3.2 ± 0.10	3.2 ± 0.10	3.2 ± 0.10
Final body mass (g)	32.0^{a} ± 1.96	30.6^{ab} ± 0.72	27.7^{c} ± 0.57	33.3^{a} ± 0.64	28.3^{bc} ± 1.21
SGR (%)	4.1^{ab} ± 0.11	4.0^{bc} ± 0.05	3.8^{cd} ± 0.08	4.2^{a} ± 0.05	3.9^{cd} ± 0.12
MGR (g $kg^{0.8}$ day^{-1})	21.7^{a} ± 0.5	21.1^{ab} ± 0.20	20.3^{b} ± 0.32	22.0^{a} ± 0.18	20.1^{b} ± 0.99
FCR	1.00^{b} ± 0.05	1.06^{ab} ± 0.02	1.02^{b} ± 0.02	1.01^{b} ± 0.02	1.21^{a} ± 0.24
PER	2.6^{a} ± 0.12	2.5^{ab} ± 0.06	2.6^{a} ± 0.05	2.6^{a} ± 0.04	2.2^{b} ± 0.37
PPV (%)	38.8^{ab} ± 2.41	38.0^{ab} ± 1.87	37.4^{ab} ± 4.06	41.3^{a} ± 0.88	34.4^{b} ± 5.56
ALC (%)	59.0^{ab} ± 1.80	68.4^{ab} ± 10.39	69.7^{ab} ± 5.09	78.2^{a} ± 13.04	72.3^{ab} ± 13.07
ER (%)	30.1^{a} ± 1.91	24.2^{b} ± 2.64	23.2^{b} ± 2.00	29.5^{a} ± 0.93	23.3^{b} ± 4.01
Digestibility measurements, relative intestinal length (RIL), digestive and metabolic enzymes activity					
DMD (%)	84.4^{a} ± 0.40	81.3^{c} ± 0.45	77.9^{d} ± 0.29	82.5^{b} ± 0.25	80.6^{c} ± 0.12
PD (%)	92.3^{a} ± 0.45	91.3^{b} ± 0.31	88.6^{c} ± 0.71	92.2^{a} ± 0.39	90.6^{b} ± 0.07
LD (%)	97.2^{a} ± 0.68	94.0^{b} ± 0.82	92.5^{c} ± 1.11	95.0^{b} ± 0.91	92.1^{c} ± 0.90
ED (%)	87.7^{a} ± 1.33	83.6^{b} ± 0.51	82.8^{b} ± 1.47	87.6^{a} ± 1.11	83.1^{b} ± 0.95
RIL (mm g^{-1})	2.55^{bc} ± 0.13	3.10^{a} ± 0.16	2.75^{b} ± 0.13	3.30^{a} ± 0.18	2.93^{ab} ± 0.10
Amylase (U/g protein)	14.2^{a} ± 1.71	10.5^{b} ± 1.48	10.5^{b} ± 0.83	11.6^{b} ± 1.80	11.0^{b} ± 1.59
Protease (U/g protein)	31.1^{a} ± 5.04	22.7^{b} ± 1.89	19.13^{c} ± 1.32	24.8^{b} ± 1.92	20.1^{c} ± 2.37
Lipase (U/g protein)	4.9^{a} ± 0.74	4.2^{ab} ± 0.61	3.9^{c} ± 0.56	4.4^{ab} ± 0.38	4.2^{bc} ± 0.62
ALP (U/l)	85^{b} ± 55.1	107^{ab} ± 51.8	159^{a} ± 67.5	115^{ab} ± 52.1	75^{b} ± 32.5
ALT (U/l)	92.0^{a} ± 6.63	76.7^{ab} ± 10.3	71.2^{b} ± 3.10	85.7^{ab} ± 4.57	80.2^{ab} ± 10.2
Blood parameters					

RBC (10^6 cells/mm^3)	$1.58^b \pm 0.10$	$1.71^{ab} \pm 0.08$	$1.87^a \pm 0.07$	$1.74^{ab} \pm 0.20$	$1.85^a \pm 0.13$
Albumin (mg/dl)	$1.98^a \pm 0.15$	$1.63^b \pm 0.21$	$1.43^b \pm 0.28$	$1.73^{ab} \pm 0.13$	$1.63^b \pm 0.35$
Globulin (mg/dl)	$0.88^c \pm 0.17$	$1.15^a \pm 0.13$	$1.18^a \pm 0.17$	$1.03^b \pm 0.19$	$1.20^a \pm 0.12$
Lysozyme activity (IU/ml)	$336.4^a \pm 32.0$	$403.7^a \pm 101.9$	$457.5^a \pm 107.3$	$447.7^a \pm 172.9$	$401.8^a \pm 186.7$
Cholesterol (mg/dl)	$144.4^a \pm 16.3$	$129.9^{ab} \pm 31.6$	$93.1^c \pm 15.2$	$136.4^{ab} \pm 9.0$	$103.9^{bc} \pm 26.9$
Glucose (mg/dl)	$72.75^b \pm 4.03$	$91.25^{ab} \pm 8.81$	$99.00^a \pm 2.46$	$87.75^{ab} \pm 4.03$	$97.75^a \pm 5.63$

Values are mean ± standard deviation. Mean values in the same row with different superscript differ significantly ($P < 0.05$).

SGR - specific growth rate, MGR - metabolic growth rate, FCR – feed conversion ratio, PER - protein efficiency ratio, PPV - protein productive value, ALC - apparent lipid conversion and ER - energy retention, DMD – Dry matter digestibility, PD – protein digestibility, LD – lipid digestibility and ED – energy digestibility. Amylase, U- expressed as millimoles of maltose released from starch per minute. Protease, U- Amount of enzyme needed to release acid soluble fragments equivalent to 0.001 A_{280} per minute at 37 ^{0}C and pH 7.8. Lipase, U - Hydrolyze 1.0 microequivalent of fatty acid from a triglyceride in 24 hours at pH 7.7 at 37°C. ALP and ALT, 1 U = 16.66 nKat/l; nKat = Amount of glandular kallikrein which cleaves 0.005 mmol of substrate per minute. Lysozyme activity, IU- The amount of enzyme required to produce a change in the absorbance at 450 nm of 0.001 units per minute at pH 6.24 and 25^{0}C, using a suspension of *Micrococcus lysodeikticus* as the substrate.

Based on the above results we conclude that 50% replacement of FM protein by DJKM protein is as good as FM and better than SBM for carp feed. At this level of FM replacement, the growth and nutrient utilization in carp are as high as in FM containing diet; the blood picture is normal; and the organs are free of lesions.

In our next study we determined energy balance in carps fed DJKM and SBM based diets.

2.1.2 Energy budget

Growth and production can be described in terms of partition of dietary energy yielding components between catabolism as fuels and anabolism as storage in tissues. The energy expenditure can be estimated from the gaseous exchange and the release of nitrogenous compounds. The increase of fish production, especially by improving the metabolic efficiency in feed utilisation, is at the frontier of aquaculture development. Some reports deal with the nutritional energetics related to the effect of diets on energy budgets, but little work has been done to examine the effects of dietary plant proteins on energy allocation in fish (Refstie and Tiestra, 2003). Energy budgets were calculated by feeding iso-nitrogenous (crude protein 38%) and isoenergetic (crude lipid 10%) diets replacing 75% FM protein with SBM and DJKM and the FM based control diet. Growth performance and nutrient utilization of DJKM fed groups were similar to those of the control group and higher than SBM fed group. The PPV, PER, ER and ALC (see foot notes to Table 1 or 2 for full forms) values found in this study are quite satisfactory and signify a good utilization of the diets. The average metabolic rate (mg $kg^{0.8}$ h^{-1}) and oxygen consumption per unit body weight of DJKM, SBM and FM fed groups did not differ significantly. No significant differences were found in each component of energy budgets (except energy retention, %). Jatropha group has higher energy retention than soyabean fed groups (Table 2). Whereas energy expenditure per g dietary protein fed was numerically higher in soybean meal fed group, which concurs with the lower growth performance for soybean meal group. It is generally believed that fibre decreases energy availability by hastening transport through the gut and hence increases nitrogen and fat in the feaces (Hajra et al. 1987). We observed highest energy retention in Jatropha group and it was statistically similar to the control group. Whereas, SBM fed group had lowest energy retention which might be because of higher crude fibre content in this diet that could have led to losses of nitrogen and lipid through faeces. Conclusively, carp fed plant protein (SBM and DJKM) based and FM based diets exhibited equal average metabolic rate.

Table 2 Energy budget of common carp (*Cyprinus carpio* L) fed experimental diets for six weeks

Parameters	**Control**	**Soyabean**	**Jatropha**
Initial body mass (g)	11.2 ± 1.14	10.8 ± 0.97	10.6 ± 0.63
Final body mass (g)	49.0^{ab} ± 7.9	39.1^{b} ± 8.2	48.3^{a} ± 3.0
Energy Budget			
Initial GE content of carcass (kJ)	44.7^{a} ± 4.6	43.3^{a} ± 3.9	41.9^{a} ± 3.0
Final GE content of carcass (kJ)	260.5^{a} ± 32.7	208.1^{a} ±44.1	285.1^{a} ±25.0
Feed GE uptake (kJ)	645^{a} ± 90.7	600^{a} ± 71.0	658^{a} ± 45.2
Energy expenditure (kJ)	289^{a} ± 88.2	270^{a} ± 48.9	273^{a} ± 17.2
Energy expenditure (EE; % of GE fed)	44.3^{a} ± 8.4	45.1^{a} ± 6.2	41.5^{a} ± 0.9
Energy retention (kJ)	216^{ab} ± 29.5	165^{b} ± 43.8	243^{a} ± 26.0
Energy retention (ER; % of GE fed)	33.5^{ab} ± 0.7	27.3^{b} ± 4.9	36.9^{a} ± 1.5
Apparently unmetabolised energy (AUE) (kJ)	140a ± 50.8	164^{a} ± 58.4	142^{a} ± 3.9
Apparently unmetabolised energy (AUE; % of GE fed)	22.2^{a} ± 8.2	27.7^{a} ± 10.1	21.6^{a} ± 1.10
Efficiency of energy retention (ER/EE)	0.77^{a} ± 0.13	0.61^{b}± 0.08	0.89^{a}± 0.05
Average metabolic rate and energy expenditure per g protein fed			
Average metabolic rate ($mgO_2kg^{\wedge 0.8} h^{-1}$)	363^{a} ± 83.3	372^{a} ± 60.6	442^{a} ± 120.9
Energy expenditure (EE)/g protein fed	19.6^{a} ± 3.9	20.0^{a} ± 3.2	18.9^{a} ± 1.1

Values are mean ± standard deviation. Mean values in the same row with different superscript differ significantly ($P < 0.05$).

2.1.3 Long term feeding studies on carp

Carp were fed iso-nitrogenous and iso-energetic diets (crude protein 38%, crude lipid 10%): Control (standard diet, FM based protein), J50 and J62.5 (50% and 62.5% of FM protein replaced by DJKM).

Fish behaviour, feed intake, growth performance and nutrient utilization: The feed behaviour and feed intake of fish in Jatropha fed groups were similar to those in the control group (FM diet).
The growths of common carp fed for long term on J50 and J62.5 diets were comparable with those on the control diet. The growth rate in the present study was relatively lower than that in our previous experiment (Kumar et al. 2008). The growth performance parameters such as BMG, SGR, FCR and MGR (see foot notes to Tables 3 for full forms) were also similar among the experimental groups (Table 3). Similarly, no significant difference was observed in PER, PPV and ALC among the experimental groups. The energy retention was significantly lower in J62.5 group compared to J50 and the control groups as a consequence of lower lipid accretion.

Digestibility measurements: All nutrient digestibilities decreased significantly with increase in the amount of DJKM inclusion (Table 3). The decrease in lipid digestibility is in accordance with studies on salmonids with soybean diets (Øverland et al. 2009). The decrease in protein and lipid digestibilities in Jatropha diets might be due to the presence of heat stable enzyme inhibitors (for example phytate). Despite significantly lower nutrient digestibilities on inclusion of DJKM, the growth response parameters were statistically similar. This statistical insignificance could be attributed to a large variation in growth response parameters. It may be noted that the mean values for all growth performance parameters were lower for the DJKM diets, suggesting that higher inclusion of DJKM in the diet tends to decrease growth performance.

Table 3 Growth performance, nutrient utilization, digestibility measurement, digestive enzymes activity and hematological parameters of rainbow trout (*Oncorhynchus mykiss*) and common carp (*Cyprinus carpio* L) fed experimental diets for 12 and 16 weeks respectively

Parameters	Trout			Carp		
	Control	Jatropha		Control	Jatropha	
		50%	62.5%		50%	62.5%
Initial body mass (g)	4.12 ± 0.26	4.17± 0.49	4.31 ± 0.54	21.5 ± 0.74	21.6 ± 1.04	21.8 ± 1.03
Final body mass (g)	61.0^a ± 9.90	61.8^a ± 6.88	54.6^b ± 5.18	149^a ± 23.0	128^a ± 8.0	104^a ± 31.6
SGR (%)	3.2^a ± 0.12	3.2^a ± 0.15	3.0^b ± 0.24	1.7^a ± 1.71	1.6^a ± 1.59	1.4^a ± 1.36
MGR (gkg$^{0.8}$ day^{-1})	11.4^a ± 0.37	11.4^a ± 0.42	10.8^b ± 0.75	8.5^a ± 0.76	7.9^a ± 0.15	6.8^a ± 1.32
FCR	1.3^a ± 0.10	1.2^a ± 0.10	1.3^a ±0.20	1.7^a ± 0.26	1.8^a ± 0.05	2.2^a ± 0.48
PER	1.6^a ± 0.10	1.7^a ± 0.11	1.6^a ± 0.40	1.6^a ± 0.16	1.4^a ± 0.02	1.2^a ± 0.26
PPV (%)	22.8^a ±1.10	26.3^a ±2.37	25.2^a ± 4.59	26.5^a ± 4.26	26.1^a ± 0.29	21.9^a ± 3.88
ALC (%)	31.0^a ± 2.30	31.9^a ±1.80	27.5^b ±1.89	36.5^a ± 6.34	43.0^a ± 14.99	29.4^a ± 4.04
ER (%)	24.8^a ± 0.45	25.5^a ± 1.49	23.2^a ± 2.18	20.1^a ± 2.56	17.6^{ab} ± 3.04	13.4^b ± 2.69
Digestibility measurements, relative intestine length (RIL), digestive and metabolic enzymes activity						

DMD (%)	$78.6^{a} \pm 0.81$	$79.5^{a} \pm 0.42$	$73.3^{b} \pm 2.11$	$74.9^{a} \pm 0.98$	$71.5^{b} \pm 0.64$	$69.6^{b} \pm 1.32$
PD (%)	$89.8^{a} \pm 0.55$	$89.7^{a} \pm 0.83$	$84^{b} \pm 1.41$	$85.9^{a} \pm 0.98$	$83.2^{b} \pm 0.80$	$78.6^{c} \pm 0.37$
LD (%)	$95.2^{a} \pm 0.43$	$95.2^{a} \pm 0.80$	$89.8^{b} \pm 0.86$	$89.6^{a} \pm 0.51$	$86.2^{b} \pm 0.76$	$80.1^{c} \pm 1.65$
ED (%)	$86.8^{a} \pm 0.83$	$86.1^{a} \pm 0.71$	$81.8^{b} \pm 1.13$	$82.0^{a} \pm 1.62$	$77.7^{b} \pm 1.83$	$73.4^{c} \pm 0.49$
Amylase (U/g protein)	$4.6^{a} \pm 0.40$	$3.2^{b} \pm 0.20$	$2.5^{c} \pm 0.15$	$17.4^{a} \pm 1.32$	$13.6^{b} \pm 0.83$	$11.0^{c} \pm 0.76$
Protease (U/g protein)	$50.3^{a} \pm 3.59$	$41.0^{b} \pm 2.16$	$32.5^{c} \pm 1.29$	$36.5^{a} \pm 1.31$	$28.1^{b} \pm 0.83$	$20.7^{c} \pm 1.24$
Lipase (U/g protein)	$13.9^{a} \pm 1.02$	$10.8^{b} \pm 0.38$	$8.6^{c} \pm 0.48$	$6.8^{a} \pm 0.29$	$5.3^{b} \pm 0.32$	$4.3^{c} \pm 0.22$
RIL (mm g^{-1})	$0.47^{c} \pm 0.02$	$0.56^{b} \pm 0.02$	$0.63^{a} \pm 0.01$	$2.24^{c} \pm 0.07$	$2.78^{b} \pm 0.10$	$3.17^{a} \pm 0.10$
ALP (U/l)	$101^{a} \pm 8.3$	$96^{a} \pm 25.0$	$84^{a} \pm 30.7$	$60.8^{a} \pm 5.6$	$64.8^{a} \pm 29.6$	$84.8^{a} \pm 24.4$
ALT (U/l)	$48.4^{a} \pm 13.1$	$75.2^{a} \pm 41.8$	$71.0^{a} \pm 35.5$	$80.3^{a} \pm 17.2$	$61.0^{a} \pm 6.1$	$64.8^{a} \pm 13.1$
Blood parameters						
RBC (10^{6} cells/mm^{3})	$0.96^{a} \pm 0.05$	$0.97^{a} \pm 0.07$	$1.05^{a} \pm 0.08$	$1.32^{c} \pm 0.02$	$1.41^{b} \pm 0.06$	$1.52^{a} \pm 0.06$
Albumin (mg/dl)	$2.18^{b} \pm 0.28$	$2.66^{a} \pm 0.15$	$2.36^{b} \pm 0.53$	$2.25^{a} \pm 0.48$	$2.05^{a} \pm 0.71$	$2.13^{a} \pm 0.05$
Globulin (mg/dl)	$1.64^{a} \pm 0.30$	$1.40^{a} \pm 0.32$	$1.46^{a} \pm 0.34$	$0.53^{a} \pm 0.10$	$0.78^{a} \pm 0.26$	$0.75^{a} \pm 0.10$
Cholesterol (mg/dl)	$246^{a} \pm 23.9$	$182^{b} \pm 11.2$	$171^{b} \pm 3.4$	$152^{a} \pm 5.4$	$131^{b} \pm 5.9$	$108^{c} \pm 4.7$
Creatinine (mg/dl)	$1.70^{a} \pm 0.86$	$0.98^{ab} \pm 0.22$	$0.34^{b} \pm 0.21$	$1.55^{a} \pm 1.12$	$0.28^{b} \pm 0.15$	$0.20^{b} \pm 0.00$
Glucose (mg/dl)	$117^{a} \pm 10.4$	$90^{b} \pm 6.8$	$86^{b} \pm 2$ 7.5	$115^{a} \pm 14.1$	$118^{a} \pm 30.7$	$127^{a} \pm 33.04$

Values are mean ± standard deviation. For each species, mean values in the same row with different superscript differ significantly ($P < 0.05$).

SGR - specific growth rate, MGR - metabolic growth rate, FCR – feed conversion ratio, PER - protein efficiency ratio, PPV - protein productive value, ALC - apparent lipid conversion and ER - energy retention, DMD – dry matter digestibility, PD – protein digestibility, LD – lipid digestibility and ED – energy digestibility. Amylase, U- expressed as millimoles of maltose released from starch per minute. Protease, U- Amount of enzyme needed to release acid soluble fragments equivalent to 0.001 A_{280} per minute at 37 ^{0}C and pH 7.8. Lipase, U - Hydrolyze 1.0 microequivalent of fatty acid from a triglyceride in 24 hours at pH 7.7 at 37°C. ALP and ALT, 1 U = 16.66 nKat/l; nKat = Amount of glandular kallikrein which cleaves 0.005 mmol of substrate per minute.

RIL, digestive enzymes and hematological study: The RIL index increased in fish fed diets with increasing replacement of FM with DJKM (similar observation as made in the previous experiment; see above) and likewise intestinosomatic index also reflected a gradual numerical increase but this increase was not statistically significant. The extension of intestinal length might be to compensate the poor nutrient digestibility (Table 3) and to increase the surface area for nutrient absorption. Santigosa et al. (2008) also showed increase in RIL in trout and seabream when FM was replaced by plant protein in their diets. Carps are agastric and the nutrient digestion and absorption occurs in intestine. The activities of enzymes were altered significantly on replacing FM by DJKM. The presence of antinutritional factor decreases digestive enzyme activities (Alarcon et al. 1999). Fish in $J_{62.5}$ group had significantly lower protease activity compared to the control and J_{50} groups. The decrease in protease activity at higher inclusion level of DJKM might be caused by the presence of phytate. Santigosa et al. (2008) also reported decrease in activities of digestive enzymes in trout and seabream with increase in replacement of FM by plant protein source. The lower activity of digestive enzymes in DJKM fed groups was correlated with lower nutrient digestibility of nutrients.

Blood parameters did not differ significantly among fish fed the control and DJKM based diets (Table 2). DJKM have hypocholesterolemic effect.

2.1.4 Feeding studies on rainbow trout (Oncorhynchus mykiss)

Trout have been the most extensively studied aquaculture species for nutritional research. The main target of the nutritionists in the field of aquaculture is to replace FM partially or completely in the diet of fish without any negative effect on the growth. This makes the use of DJKM relevant in replacing FM in the diet of rainbow trout. Trout fed iso-nitrogenous and iso-energetic diets (crude protein 45%, crude lipid 25%): control diet (FM based protein), J_{50} and $J_{62.5}$ diets (50% and 75% of FM protein replaced by DJKM).

Fish behaviour, feed intake growth performance and nutrient utilization: Based on the visual observation during feeding time, palatability or acceptability of feed was good and the behaviour of fish was normal.

The J_{50} group had the same BMG, SGR, and MGR as the control diet. The FCR of J_{50} was lowest amongst all the diets. Nutrient utilization parameters such as PER, PPV, ALC and ER of J_{50} groups were statistically similar to those of the control group (Table 3). These results also suggest that 50% of FM protein could be replaced by DJKM without any negative effect on the growth performance and nutrient utilization. The group fed $J_{62.5}$ diet had the least growth and nutrient utilization. It could be that rainbow trout are not able to utilize the nutrients when plant protein is increased beyond 50% replacement of the FM protein. This could be due to higher amount of non-starch polysaccharides beyond a threshold level, affecting adversely the feed utilization.

Digestibility study: Dry matter, protein, lipid, and energy digestibility were in the range of 73-79%, 84.0-89.8%, 89.0-95.2%, 81.0-86.8% respectively which show that all the three diets were well utilized by trout (Table 3). The highest digestibility values were observed in J_{50} group while $J_{62.5}$ group had the least values. The results demonstrate that the trout were efficient in digesting protein, lipid and energy in the DJKM based diets. The reduction in the digestibility on higher inclusion of DJKM in the fish diet could be due to the high intake of non-starch polysaccharides, which might negatively affect nutrient utilization and feed efficiency. The lower lipid digestibility of the fish fed $J_{62.5}$ diet may be associated with the increase in the non-starch polysaccharides content which is known to reduce lipid absorption by disturbing micelle formation in the gastro intestinal tract (Krogdahl et al. 2003). However, the apparent digestibility of DM was generally poor, especially for plant feed ingredients. The low-energy digestibility of DJKM based diets can be attributed to their high-carbohydrate content and their poor digestibility by carnivorous fish (trout).

Digestive enzymes and RIL: The activities of amylase, protease and lipase enzymes were higher in the control group compared in J_{50} and $J_{62.5}$ groups (Table 3). The replacement of FM by the tested plant protein (DJKM) decreased digestive enzyme activities in trout. However, an increase in the RIL was noticed in J_{50} and $J_{62.5}$ with the longest length in the latter. This shows that the diets from plant protein sources were more exposed to the enzymatic activities (as a result of the elongation of the intestinal length) that led to digestive balance and growth rates quite similar to that of the control group). Carnivorous fish like trout takes longer time to digest plant protein based diets (Barrows et al. 2007). In another study, reduction in the activities of protease enzyme was also reported when plant protein was increased in the diet of trout (Santigosa et al. 2008). Possibility for decrease in the enzymatic activity could be the presence of phytate in the DJKM based diets.

Haematology and histological studies: Blood parameters (RBC, WBC, haemoglobin content, haematocrit, MCV, MCH, total bilirubin and blood ions) were statistically similar in all groups. Hemoglobin and hematocrit are taken as indicators of the rate of hemoglobin synthesis to red cell formation and erythrocyte fragility respectively (Barraza, et al. 1991). Hemoglobin (4.3-4.5 g/dL) and hematocrit (37-56%) levels in all groups in our study were within the normal levels (Sun et al. 1995). Compared to the control group, levels of ALP and AST in DJKM fed groups were statistically similar. Cellular damage indicators (ALP and AST) were also statistically similar for all the three groups, which indicate that feeding of DJKM as a protein source did not affect liver function. In histological studies we did not observe lesions in liver of the DJKM fed groups. As for carp, DJKM had significant hypocholesterolemic effects in rainbow trout. While the effects of decreasing the FM level on cholesterolemia may be due to decreased dietary supply of cholesterol and the presence of fibre in higher amounts in the plant based diets.

Our preliminary histological findings demonstrate that trout did not show any abnormal changes in intestine and liver.

In all our above studies, phorbol esters, the main toxic principle for Jatropha toxicity was not detected in fish muscle tissues.

Based on the results from the above studies, it is evident that DJKM can replace 50% FM protein in carp and trout diets, without sacrificing the growth and nutrient utilization of fish. The DJKM can be used as one of the promising FM replacers in the diets of common carp and trout. The fish is safe for human consumption since it is free of phorbol esters.

2.1.5 Preparation of protein concentrate and detoxification

Normally the oil is produced from whole seeds using a screw press. The seed cake left as a by-product after oil extraction by screw press can contain as much as 500 g/kg of shells as the indigestible material, which necessitates removal of shells from the high quality protein. Using the principle of iso-electric precipitation, we have optimized conditions for the protein of protein concentrate from the screw pressed cake. The concentrate so obtained contained a substantial amount of phorbol esters (0.86–1.48 mg/g), trypsin inhibitor, lectins and phytate. The amino acid composition of the protein concentrate mirrored that of the kernel meal and the available lysine was unaffected by the treatment of producing the protein concentrate (Makkar et al. 2008b). As for the kernel meal, in vitro rumen protein digestibility of the protein concentrate was low and protein digestibility using pepsin and pancreatin was high, suggesting high value of protein concentrate for high yielding animals. To make the protein concentrates suitable for use as an ingredient in livestock feed, phorbol esters must be removed, and trypsin inhibior and lectins inactivated by heat treatment. The adverse effects of phytate could be mitigated by addition of phytase in the diet. We have detoxified the Jatropha protein concentrate and feeding studies on carp are being conducted. Seventh week is in progress and there is no sign of toxicity and the growth response of fish fed detoxified protein concentrate diet is excellent.

2.1.6 Use of by-products obtained during the process of biodiesel production as livestock feed

The production of biodiesel from Jatropha oil yields valuable byproducts such as kernel meal, seed cake, acids gums, fatty acid distillate and glycerol. The potential of kernel meal and seed cake has been discussed above. Acid gums, fatty acid distillate, and glycerine have several applications in food and feed industry and the presence of phorbol esters could render them unfit for edible purposes. We follow the flow of phorbol esters during various stages of pre-treatment and biodiesel production from Jatropha oil. During the degumming step a fraction called acid gums is produced. Phorbol esters were present in the acid gums. This implies that the use of these acid gums in animal feed is not possible. On the other hand, phorbol esters were not detected in the fatty acid distillate produced during the stripping or deodorisation process. However, the presence of possibly toxic phorbol ester degradation products in this fraction could not be ruled out. At present no information is available on the nature or toxicity of the possible degradation products.

Phorbol esters were not detected in the glycerine samples in our study, however these were detected in glycerine samples obtained from other industrial plants (Company 1: 0.67–0.97 mg/g; Company 2: 0.13 mg/g). These results suggest that different oil pre-treatment conditions could affect the presence of phorbol esters in glycerine produced from toxic Jatropha oil. The presence of phorbol esters in these fractions could render them unsuitable as a feed ingredient. Further information on this aspect could be obtained from Makkar et al. (2009) and Makkar and Becker (2009).

2.2 Engineering component

2.2.1 Oil extraction using screw press

Mechanical pressing and solvent extraction are the two most commonly used methods for commercial oil extraction (Shahidi, 2005a). Using a screw press, oil recovery from oil seeds could be up to 90 %, while with solvent extraction it could be as high as 99% (Beerens, 2007; Dufaure et al. 1999). For some edible seeds, oil extraction using a screw press followed by solvent extraction is also used.

In small scale oil pressing units, undesirable residues from plant materials are found in the crude oil (Shahidi, 2005b). These impurities lead to depositions during combustion in stoves or engines and reduce lifetime and service intervals significantly. Consequently, the contamination of the crude oil by these unwanted impurities should be avoided during production.

The objectives of this study were:

- Optimization of oil-pressing with respect to oil quality
- Generation of a standard for Jatropha oil for the use in plant oil stoves
- Development of a process for cleaning Jatropha crude oil, enabling its use in cooking stoves

The experiments were carried out with mechanical screw press (German screw press type - Komet D85-1G), which was powered by a 3.0 kW electrical motor (Fig. 1). The maximum capacity of the material input was 25 kg/h

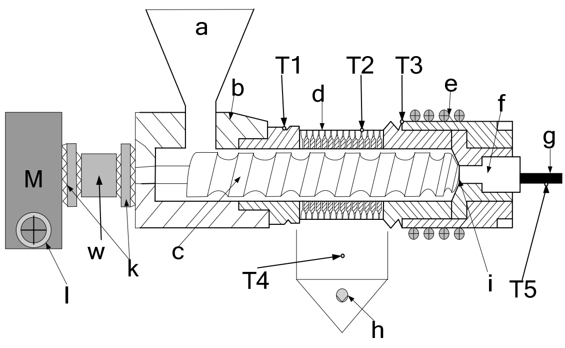

Figure 1 Mechanical screw press for oil extraction and installed sensor, (a) feeding hopper, (b) housing, (c) screw press, (d) oil outlet holes, (e) block heater, (f) nozzle, (g) press cake outlet, (i) cohesion zone, (h) oil collector, (k) coupling, (l) speed alternator, (M) motor, (T1-T4) temperature sensors, (T5) temperature sensor (IR), (ω) rotational speed

Table 4 shows the temperature generated during the pressing process on five different positions while varying the rotational speed and size of the press cylinder holes. The rotational speed (ω) was increased from 220 rpm to 365 rpm in experiment P_1 ω_{220} to P_1 ω_{365} and from 230 rpm to 365 rpm in experiments P_1.5 ω_{230} to P_1.5 ω_{365}. The temperature at the starting point (T1) increased with the increase in the rotational speed for both press cylinders (P_1 and P_1.5; 1 mm and 1.5 mm holes). The press cylinder with 1 mm holes generated higher temperature than that with 1.5 mm holes. This was because of higher friction on the press cylinder with 1 mm holes as a result of greater restriction. The temperature at oil outlet (T2) increased with the increase in the rotational speed

Table 4 Velocity and temperature on the screw press surface, at oil outlet and of press cake

	Temperature sensors				
Press cylinder and rotation speed	**T1 Start point (°C)**	**T2 Oil outlet (°C)**	**T3 Compression zone (°C)**	**T4 Oil recovery point (°C)**	**T5 Press cake (°C)**
P_1 ω_{220}	50.8 ± 1.0	80.6 ± 0.9	106.5 ± 0.9	77.3 ± 6.9	83.3 ± 2.0
P_1 ω_{260}	51.9 ± 3.5	80.2 ± 2.2	115.7 ± 0.7	81 ± 5.8	106.1 ± 2.3
P_1 ω_{365}	54.1 ± 0.7	82.9 ± 0.7	108.8 ± 0.8	81.8 ± 6.1	84.6 ± 3.9
P_1.5 ω_{230}	48.4 ± 0.9	83.8 ± 0.5	108.8 ± 0.5	72 ± 6.2	73.1 ± 9.2
P_1.5 ω_{295}	51.6 ± 0.6	86.2 ± 0.9	111.1 ± 0.9	85.8 ± 4.3	87.9 ± 3.1
P_1.5 ω_{365}	53.7 ± 0.6	87.6 ± 0.9	111.4 ± 0.5	97.2 ± 8.5	85. ± 7.3

* Results are mean values ± SD

* P_1 and P_1.5 press cylinder with 1 and 1.5 mm holes, ω rotational speed of the screw press

At compression zone (T3) (see Fig. 1), highest temperature was recorded in the screw press. The temperature increased with increase in the rotational speed for experiments P_1.5 ω230, P_1.5 ω295 and P_1.5 ω365. For experiments P_1 ω220, P_1 ω260 and P_1 ω365 initially an increase and then a decrease in the temperature was observed.

Oil temperature (T4) on the oil collector (Fig. 1) increased with increase in the rotational speed for both press cylinders, P_1 and P_1.5. The highest temperature was recorded for P_1.5 ω365 (97.2 °C). The standard deviation for oil temperature sensor was higher compared to those for other sensors. This is because that the oil temperature sensor is positioned at ambient temperature and hence gets influenced by environmental changes. The highest press cake temperatures (T5) were recorded for experiment P_1 ω260 (106.1 °C).
The highest oil recovery was obtained for experiment P_1.5 ω230 with 3.2 kg oil per 10 kg of pressed seeds (Table 5). With increase in the rotational speed of the screw press from 220 rpm to 365 rpm for the press cylinder with holes P = 1 mm, the time for pressing 10 kg of Jatropha seeds decreased from 156 min to 90 min, and the oil recovery decreased from 3.2 kg to 3.1 kg/10 kg seeds. The oil content in press cake increased

from 7.9 % to 9.3 %.

Table 5 Effects of various screw press conditions on recovery of oil and press cake, kinematic viscosity and total residues on using Jatropha seeds containing 9 % moisture

Press cylinder and rotation speed	Time (min)	Oil recovered (kg)	Press cake (kg)	Oil content in press cake (%)	Kinematic viscosity (mm^2/s 20°C)	Total contamination (mg/kg)
P_1 ω_{220}	156	3.2	6.58	7.9	82.4 ±0.0	2999 ± 5.2
P_1 ω_{260}	130	3.1	6.66	8.0	47.8 ±0.1	411.6 ± 4.0
P_1 ω_{365}	90	3.1	6.56	9.3	42.2 ±0.0	401.6 ± 1.5
P_1.5 ω_{230}	147	3.2	6.56	8.0	84.2 ±0.1	540 ± 2.0
P_1.5 ω_{295}	115	3.2	6.52	8.3	47.9 ±0.1	655.3 ± 12.0
P_1.5 ω_{365}	95	3.2	6.58	8.9	42.8 ±0.0	1344 ± 10.8

* Results are mean values ± SD (n = 3)

* P_1 and P_1.5 press cylinder with 1 and 1.5 mm holes, ω rotational speed of the screw press

The increase in the rotational speed of screw press for the press cylinder P = 1.5 mm from 230 rpm to 365 rpm, the time necessary for pressing 10 kg seeds decreased from 147 min to 95 min. On the other hand, oil recovery decreased and the oil content in press cake increased from 8.0 % to 8.9 %.

The kinematic viscosity decreased with increase in the rotational speed for press cylinders, P_1.5 mm and P_1 mm (Table 5). The highest kinematic viscosity was recorded in experiment P_1.5 ω_{230} (84.20 mm^2/s) and the lowest in experiment P_1 ω_{365} (42.20 mm^2/s). The content of total residue in oil is of high importance because the presence of larger particles in the oil could cause deterioration of the engines and plug filters. The highest value of total contamination was recorded in experiment P_1 ω_{220} and the lowest in experiment P_1ω_{365}. This suggests that total pollution might be optimized by using different parameters on the screw press.

From these studies on optimization of oil pressing condition, the following conclusions were drawn. Temperature on the screw press depended on rotational speed of the screw press (rpm) and the press cylinder hole size. Oil recovery depended on rotational speed of the screw press and size of the press cylinder holes. The chemical properties of Jatropha oil varied with the changes in the pressing conditions (rotational speed and press cylinder hole size). The optimum operation of the mechanical press could be indentified based on the time required for pressing seeds, oil recovery, oil content of press cake and chemical properties such as; kinematic viscosity and the amount of total contamination. The recommended operational conditions are: (P_1 ω_{260}) i.e. use of the press cylinder with holes P = 1 mm and the rotational speed of the screw press 260 rpm. Studies to improve the oil quality to meet the international standards are in progress.

2.2.2 Jatropha seed shell based combustion furnace

The seed shells of *Jatropha curcas* could be a potential alternative fuel in tropical and subtropical countries. The calorific value of the seed shells is between 16-17 MJ/kg, which is comparable to rice husk and wood. The rice husk and wood are the main energy sources in rural areas in developing countries. The thermal energy of the shells can also be used for many applications in rural areas including drying of Jatropha nuts.
The aim of our work is to develop a furnace for Jatropha seed shell combustion for small scale applications. A systematic analysis of the combustion parameters of Jatropha seed shells was done. In addition, analysis of various combustion technologies available was conducted and a new technology for the combustion of the Jatropha seed shells was developed.

The combustion unit has been developed following the principle of tilting furnace/without grate/bowl burner (Hartmann et al. 2007). Since the combustion unit is meant mainly for use in the field in tropical and subtropical countries, particular attention was paid not to use complex mechanical parts. This enabled easy operation and maintenance of the combustion unit. The burner was started by adding a small amount of Jatropha shells through the dosing screw into the burner bowl. The shells in the burner bowl were ignited manually by using a firelighter. Thereafter the shells and air were added constantly till the desired power was achieved.

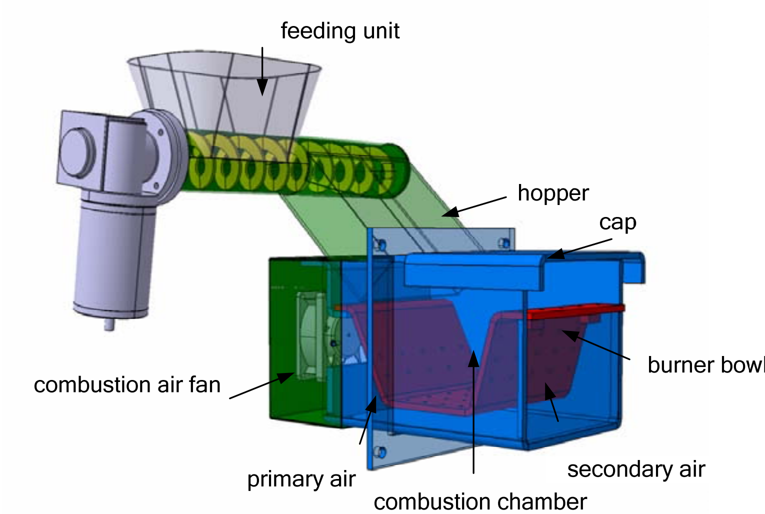

Figure 2 3D-Catia model of combustion unit

Figure 2 shows a 3D model of the combustion unit constructed with the computer-aided design-software CATIA (Computer Aided Three-Dimensional Interactive Application). The combustion unit consisted of an angled stainless steel sheet to which the components: feeding unit with hopper and combustion air fan are attached. The burner bowl acts as a drawer and the cap is removable permitting cleaning of the combustion unit. By lifting the cap, the burner bowl is cleaned by removing combustion residues and ash.

The combustion chamber is inserted in the combustion unit in which the heat of the burnout gases is exchanged. To keep the combustion unit simple in the first step, a control for changing the combustion quality has been left out on purpose. The adjustment of the fuel (shells) mass flow and the combustion air is done empirically with the aid of the exhaust control. The physical properties and the composition of the shells and the ash melting temperatures are given in (Tables 6 and 7).

Figure 3 shows the shells of *Jatropha curcas* nuts. The Jatropha nuts are opened using a husker and afterwards separated in kernels and shells via air separator.

Figure 3 Shells of Jatropha curcas

The shells have high ash content (3.8%). Wood contains about 0.5% ash (Hartmann et al. 2007). The ash content of shells is much higher compared to that of wood. Furthermore, the elements nitrogen, chlorine and sulphur impact the emission of pollutants during the combustion. The contents of nitrogen, chlorine and sulphur in shells are 6, 20 and 6.5 times higher than in wood (Hartmann et al. 2007).

Table 6 Properties of *Jatropha curcas* shells

Parameter	Result	Method
Calorific value, MJ/kg	16.5±0.1	DIN 51 900-2
Water content, %	8.9±0.3	DIN 51 718
Particle density, g/cm³	0.9±0.1	DIN CEN/TS 15150
Bulk density, kg/m³	250.8±0.5	DIN CEN/TS 15103
Angle of repose, °	44.9±0.4	DIN EN 12047
Carbon content, %	50.9	DIN 51 732
Hydrogen content, %	5.8	
Nitrogen content, %	0.8	
Oxygen content, %	39.5	
Chlorine content, %	0.1	DIN 51 577-3
Sulphur content, %	0.1	DIN EN ISO 20884
Ash content, %	3.8	DIN 51 719

The ash melting temperatures are presented in Table 7. These are extremely important for the reliable operation of the combustion unit. At low ash melting temperatures, for example 700°C for grain, slagging in the combustion unit and on the grate can be avoided by special devises for example by using water cooled grate. The ash melting temperature of Jatropha shells is 980°C which is comparable to stramineous fuels (Hartmann et al. 2007). The primary air flow (Fig. 2) cools the burner bowl and prevents reaching the high temperature on the burner bowl. This avoids the slagging and prevents closing of the air intake holes, thus ensuring a continuous supply of the primary air. A prototype of Jatropha seed shell furnace is shown in Fig. 4.

Table 7 Ash melting temperatures

Parameter	Degree Celsius	Method
Ash softening point	980	DIN 51 730
Hemisphere temperature	>1550	
Flow point	>1550	

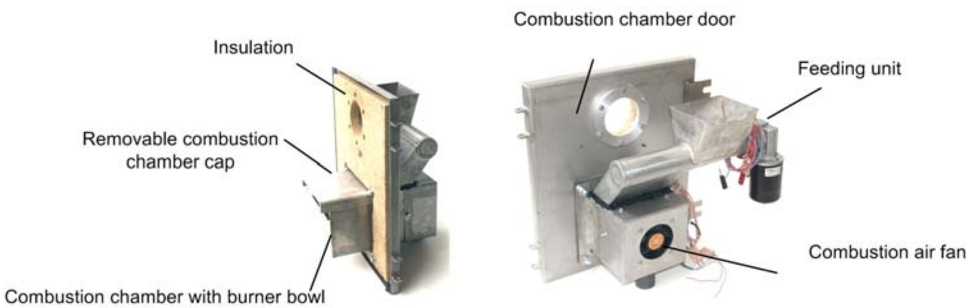

Figure 4 Prototype of Combustion unit

In conclusion, the results show that combustion of Jatropha seed shells is possible without previous processing e.g. pelletizing, and hence the fuel costs can be kept low. However, it is important that the combustion unit is used locally where the shells are produced in order to avoid transportation cost since the shells have low bulk density. During combustion of seed shells a good burnout was achieved and a small amount of unburned shells were discharged out of combustion chamber. This also ensured low emission of burnout carbon monoxide.

2.3 Economic component

This part first describes the setting of the Jatropha value chain in Sichuan province, which is followed by an analysis of the production cost at different stages of the production chain. Data for the analysis were collected from key informant interviews in the Panzhihua prefecture of Sichuan province from April to May 2008.

2.3.1 Settings of the Jatorpha production chain

The interest of the Chinese government in Jatropha can be grouped into three intersecting-areas of energy, environment and agriculture. Large scale investments in Jatropha plantations have been made in southwest China, especially in Yuanan and Sichuan provinces. The National Development and Reform Commission (NDRC) has been the leading institution behind the biofuel development policy and it gives advice and guidance for energy production and consumption in China. Among the players involved in the production chain, government organisations have the biggest role.

In Sichuan province, the Jatropha plantation areas are on former farm land that has been claimed back as forest land. Currently, the government hands out a subsidy of about 230 RMB/mu (67 PPP$/ha) for converting farm land to forest land (Panzhihau Forestry Bureau, personal communication 2008). Plantations in the Panzhihua prefecture are distributed over many districts and counties, including Renhe, Yanbian and Hongge Liangshan (Panzhihau Forestry Bureau, personal communication 2008). The survey conducted in 2008 showed that various levels of the local forest authorities are directly in charge of Jatropha plantations.

The production costs at each stage in the production chain were analyzed using the standard methods in agricultural project appraisal (Gittinger, 1982) and the results are summarized in Table 8.

Table 8a The production cost[1] associated with seeds production

Production scale	Inputs	Output				
	Specific variable cost[1]/kg output	Specific diesel demand (litre) /kg output	Specific electricity demand (kWh)/kg output	Specific water demand (m3)/kg output	Specific total variable cost[1]/production area	Value of gross outputs[1,2]/ha
Seed collector	1.37	0.00	-		6562	11163
Seedling production–nursery	0.06	0.0001	0.01	0.00003	34742	33140
Seed plantation	0.92	59.11	-	0.0001	1238	6326

Table 8b The production[1] cost for oil production, from processing Jatropha seeds

Production scale	**Inputs**				**Output**	
	Production capacity (ton output/day)	Specific variable cost[1] /kg seeds input	Specific electricity demand (kWh)/kg oil filtered	Specific electricity demand/kg co-product[4]	Production cost[1]/kg oil, filtered	Production cost[1]/kg co-product[5]
Oil extraction from seeds						
Small[3]	0.32	2.70	0.58	0.99	5.16	8.85
Medium[3]	1.71	1.37	0.14	0.25	2.62	4.49
Large[3]	45.65	0.94	0.01	0.02	1.81	3.10
Oil extraction from kernels (deshelled seeds)						
Small[3]	0.19	12.72	1.14	1.40	40.41	49.48
Medium[3]	1.03	11.39	0.29	0.35	36.18	44.29
Large[3]	27.53	10.96	0.03	0.03	34.82	42.64

[1] cost is expressed in International US dollar (PPP$) (WDI, 2008)
[2] based on the price prevailing in 2008 when survey was conducted
[3] Operation hours for small, medium, and large scale are 4500, 6000, and 8000 h/year, respectively
[4, 5] Co-product from oil extraction from seeds is press cake; output from oil extraction from kernels (deshelled seeds) is defatted kernel meal

2.3.2 Production cost

Seed collection: Actors involved in this chain include mostly individuals and a few small enterprises. Most seeds are collected by individual farm households who collect Jatropha seeds growing in the wild or along roads in their vicinities. Farm households do not usually go and collect Jatropha seeds on-purpose, rather combine seed gathering with moving out in their vicinity. The investment cost for such seed collectors is therefore zero. There are also a few seed collectors in the area that operate under small private companies. The investment for this chain is relatively small, compared with other parts of the chain. The main investment for the companies is the purchase of a truck, with a usual capacity of between 3 and 5 tons. They buy the seeds at the price of 7-12 RMB/kg (2.03-3.49 PPP$/kg) from Yunnan and Guizhou provinces. The production cost per kg of seed collected is about 1.37 PPP$/kg.

Seedling production: Actors involved in this chain are cooperative farms and local authorities. Seedlings are produced by a cooperative farm that holds a contract from a local forestry authority. The average area under seedlings is about one hectare. The nursery purchases dried seeds from seed collectors at a price of about 7 to 8 RMB/kg (2 PPP$/kg). The farmland of the nursery is usually rented land which is irrigated for about 9 months in a year. The seedlings are raised till a maximum of six months when they meet the requirements of the forestry authorities: 0.4-0.5 m tall and over 0.12 m root long. Seedlings are sold to the forestry bureau for 0.18-0.20 RMB per seedling (0.05-

0.06 PPP$/seedling). The main limiting factor for the nurseries is the availability of irrigation water in the area.

Seed production: Actors involved in this stage of the chain are various levels of the Forestry Bureau, Jatropha cooperatives, village committees, national and international oil companies (The China National Petroleum Corporation (CNPC), The China petroleum and chemical cooperation (SINOPEC), The China National Offshore Oil Corporation (CNOOC)), and academic institutions. Investments into Sichuan plantations were made by Chinese energy firms, including SINOPEC, while plantations are managed by various levels of the forestry authorities. The land for the plantation is former farmland and the barren land. Plantations have a usual size of several hundreds of hectares. The authorities distributed the land to different contractors, most of which are work in the form of a cooperative. These cooperatives then subcontract the plantation work to villagers through a village committee. In some areas, contracts are given to villages not in the immediate vicinity of the plantation but to villages further away that have abundant labour and therefore labour costs are relatively low (Panzhihua forestry bureau, personal communication 2008). Trees are planted in a space of 2 x 3 m (1200 to 1500 trees/ha). The main management costs occur during site preparation and weeding in the first two years while no irrigation is used. The production cost per kg of harvested seed is estimated to be about 0.92 PPP$/kg.

Oil extraction – use of solvent extraction and screw press: Based on key informant interviews, actors involved in this chain are energy firms, government institutions, and cooperatives. None of these actors was available for an interview during the study period and the production cost was therefore estimated from data generated within the project at Hohenheim University and by making several assumptions. The production cost per kilogram of oil output was compared for two extraction methods: chemical (solvent extraction) and mechanical with screw press. The analysis shows that the production cost per kg output for both methods is characterized by economies of scale (see Table 1) as the cost in large scale production is relatively lower when expressed per kilogram of products or co-products (filtered oil and defatted meal or pressed cake). The results also show that the cost per unit output of extracting oil using solvent is more expensive than using the mechanical method.

Oil refinery: Several years ago there were small oil processing and animal feed process factories in Miyi county while in Xichang city there was a small Jatropha seed company and a seedling production company. However, after several attempts to contact these firms, we were told that these firms went bankrupt.

Conclusions, limitations and opportunities: The results estimated the actual production cost of Jatropha seed production and the possible processing cost that are likely to incur in the Chinese context. The seed collection and seedling production are carried out by small private sector companies while the actors for seed processing, oil extraction, and use co-products such as seed cake or kernel meal could not be clearly identified at present. The limitations in this financial assessment reflect the limitations in the domestic markets in the whole Jatorpha production chain, which have not been properly developed. The prices of inputs such as seedling production and seeds do not reflect the real production cost or scarcity value.

According to our another study (Han, 2009), the impact of the emerging jatropha industry on the well-being of farm households in the areas is likely to be limited. By the end of 2009, a change in the forestry law is expected, which is likely to produce more positive impact on rural development through employment and income generation. According to this new law, all forestry land is to be allocated to local farmers. Such farmers will then be obliged to take care of the trees with a condition that they themselves cannot cut the trees but can use the products of the trees, collect the seeds and generate income by selling them (Panzhihua forestry bureau, personal communication 2008). The local government will subsidize households at the rate of 80 RMB/household/year (23 PPP$/household/year) for taking care of the Jatropha plantations.

The national and international oil companies (on behalf of the government) are playing important roles in ensuring the successful introduction and growth of biofuels in the domestic market. The alignment of objectives and incentives of government institutions are critical for ensuring a functional biofuel market in China.

3 Ongoing and Future Studies

Our ongoing and future activities leading to the development of innovative technologies and products include: i) Jatropha plant oil burners of large capacity for drying edibles such as coffee and fruits, ii) a large scale hydraulic and mechanical oil filtering system for making Jatropha oil fit for use in large capacity plant oil burners (meeting EN41214), iii) second generation fuels through pyrolysis of low quality seeds (not suitable for oil pressing or planting), shells, and vegetative biomass, iv) a process, integrated into biodiesel production, for isolation of phorbol esters from Jatropha oil for use as a biopesticide, molluscicide, and tick-killing agents in organic and conventional farming and for use as anti-bacterial, and fungiside agents, v) a 100 ton/annum capacity plant for production of detoxified Jatropha kernel meal, v) bioactive peptides from Jatropha seed cake and their applications in pharmaceutical, food and feed industries, vi) biogas, bioethanol and biohydrogen production from by-products and wastewaters of oil production and from biodiesel production chain, and use of the digester residues as fertilizer and minerals, and vii) industrially usable lignin fractions from Jatropha shells.
The generation of value-added coproducts using the concept of bio-refinery would make

a strong case for extensive planting of Jatropha for reclamation of marginal and degraded lands. This would also decrease investment risk, particularly for small scale farmers.

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Urban Density, Urban Transportation and Energy Performance Urban Planning for Energy Saving and Pollution Reduction
城市密度，城市交通和能源性能——节约能源和减少污染的城市规划

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Abstract

China experienced a lot of progress and changes in the last 30 years of urban planning. During this short time, the requirements to the urban structures changed dramatically. Nowadays, China's cities have to cope with very different challenges. This paper investigates the process of recent urban development in China, and the link between urban planning and energy consumption. The performance of a city under the perspective of energy-consumption and pollution-emission will be a major issue for the coming future. To do so, I will discuss two basic interrelated urban factors, urban density and urban transportation, which are in a planner's field of work, and I will show the influence of these parameters to the energy performance of a city. A number of studies on Chinese Cities do investigate the problems of urban transportation, pollution, density and future urban development, but only few studies draw a connection between land-use, density and energy-efficient performance of a city.

There are many more factors related to urban planning and eco-efficient urban planning, such as ecologic services, heat-island effects, social responsibility and social well-being, waste management, infrastructure, cultural preservation and so on, but to examine the relationships of an efficient balance of urban planning parameters and their influence on energy consumption, I want to use two clearly defined inter-related factors, which are under the control of a planner.

By doing so, I want to show, that within a planner's scope of work, a lot can be done to improve the energy performance of a city.

摘要

过去的三十年，中国在城市规划方面经历了巨大的变化。在这短短的时间内，对城市结构的要求发生了急剧变化。现在，中国的城市不得不应付更多的挑战。本文将研究中国最近城市发展的过程和城市规划与能源消耗之间的关系。城市在应对能源消耗和污染排放这两方面的性能将是未来的一个主要问题。为了解决这个问题，本文将讨论两个基本的与城市相关的规划者考虑

的因素，城市密度和城市交通，并且本文将会给出这些因素对城市能源情况的影响。很多关于中国城市的研究确实分析了关于城市交通、污染、密度和城市未来发展的问题，但几乎没有研究把土地使用，城市密度和能源效率联系起来。

1 Introduction Urban Performance Related to Energy Saving

According to UN Habitat, half of the worlds population is living in cities, by 2030 it will be around 60 of all people on the Earth living in cities. It also is stated, that 80 % of the global carbon dioxide emissions come from the worlds cities. Urban structures are a focus-area for addressing energy-saving and pollution reduction and as an inter-linked system, they should be addressed if it comes to energy consumption, carbon dioxide emissions and climate-control. Growing cities cover larger distances, workspaces and living quarters are growing more apart, people need to commute, more and more energy is needed for urban transportation. Efficient land-use and energy efficient strategies do have immediate effect on energy performance, urban air-pollution and CO2-Emissions.

1.1 Urban development in China and eco−efficiency

Every 24 hours, the worldwide urban development increases by 180 000 people (National Academies Press,2004). Especially in developing countries and Emerging Countries the urban development reaches a point, where the control of the growth becomes a critical factor. Worldwide, cities are growing beyond their capacities and China in its current development is facing the very same challenges. Current urban planning methodologies might not be able, to give answers to new upcoming problems. Right now the urban development in China has a number of critical issues, such as economic, ecologic and social challenges. The negative environmental impact of an urban structure very often reaches a critical point. Urban sprawl increases transportation, which accounts for pollution and green-house gas emissions. Water usage and waste production becomes a problem. At the same time, cities have to be able to offer a vibrant, diverse labour market, within an easy accessible environment, in order to develop economically successful.

Although China has been constructing cities for about 400 years, China had only 86 cities in 1949, when the People's Republic of China was established. At that time, the urbanisation level in China was only 10.6%, compared with the world average of 29% and the average in developed European countries and the United States of more than 60%. China is now in a new stage of urban development. At present, China has some 668 cities, including 32 mega-cities with more than 1 Million residents and 43 metropolises with 0.5 to 1 Million residents. The urbanisation has currently reached around 44 %. By 2025, the average urbanisation in China is predicted to reach well over 60 %.

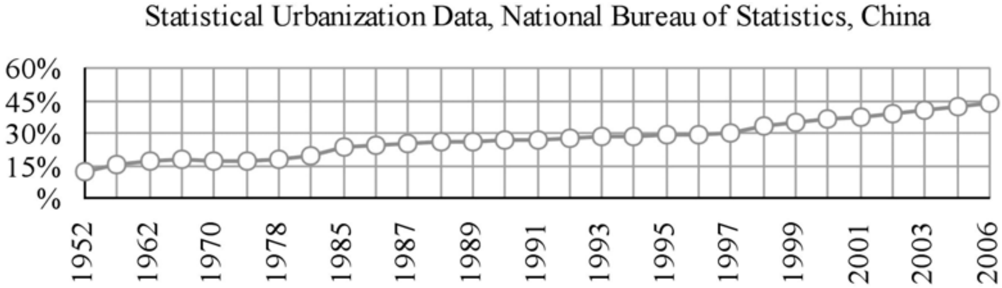

Figure 1 Statistical Urbanisation in China National Bureau of Statistics China, 2007

The improvement of the living conditions of the people requires economic development. But economic growth and the development of *production capacities* very often cause negative impact to the environment, mainly the ecosystem and the urban areas and the people who live in them. The economic performance can easily be out-balanced by the negative impact to the environment and by the growing expenses, for example for natural resources. These additional and avoidable costs right now are estimated to reach 10 % of China's current GDP. To apply eco-efficient strategies means, that there is a balance of maximisation of the economic development and minimisation of the negative impact to the ecosystem: economic growth and conservation of natural resources and improving living-quality at the same time.

*Eco-efficiency is defined as maximising efficiency of production processes while minimising impact on the environment. Eco-efficiency can be achieved by using new technology, using fewer inputs per unit of product such as energy and water, recycling more and reducing toxic emissions. In summary doing more with less. (*GTZ*, German Association for Technological Co-operation, Introductory Brochure: Partnership for Sustainable Development, Stuttgart 2002)*

2 The Relation of Density and Transportation

2.1 Inter-related objectives

Urban planning methods can, among others, control two major urban factors: density and transportation. These two factors are inter-related and have an effect on the energy performance of a city.

A city is a complex entity of many inter-linked systems. To evaluate and describe it's economic performance, it's energy use, the resulting pollution and the environmental impact, one has to look at the interrelated items, such as city shape, transit use, motorisation, ecologic services and resulting energy consumption and air pollution. Beijing, for example, is a dense, highly urbanised mainly mono-centric city (Bertraud 2006), which, with it's ring roads and radial corridors, in theory favours urban transit.

This mono-centric layout ideally reduces inner-city travel distances - most urban activities are close to the centre, whereas most of the housing is located in a certain diameter around the centre. Everybody, in theory, can travel from home to workplace within an hour. But, on the other hand, this urban model easily suffers from chronic congestion, if individual transportation and private car-ownership gets too high, if the public transportation network is not dense enough, and if the traffic control is not capable of dealing with the demand. The inner-city land prices tend to get too high, which in turn forces many working class people to move to more affordable, which means more distant housing areas.

2.2 Threshold of density and transportation

Density is Good - This seems to be true for a certain degree of density. Trips are shorter in trip length in cities with higher density than in cities with lower density (Bertraud, 2004). Above a certain degree of density, traffic can not flow freely, living quality may decline, pollution becomes a problem. But below a certain density, public transportation can not operate efficiently. If people can not rely on public transportation, they become dependant on private transportation, recently in China mainly cars. Commuting time from home to work increases at the same rate as energy-consumption. It seems, that two inter-related objectives can contradict to each other. To maximise the efficiency, we have to find a balance between density and the physical distances to travel inside the city.

The effects of this relationship have a direct influence on the economic performance and of the energy consumption of a city. The energy consumption becomes an indicator for an efficient balance of density and the amount of urban transportation.

2.3 Examples of different models

A study from the Institute of Urban and Regional Development University of California Berkeley conducted by Alain Bertaud (2004), compared two international cities, Atlanta / USA and Barcelona / Spain, to evaluate the performance of a city under the aspects of the cities' spatial layout, and transportation. In principle, two different city-models are existing, with a number of variations: the mono-centric model and the poly-centric model. In reality, most cities are representing a mix of these patterns.

1. The mono-centric model with mostly radial urban traffic. Most traffic occurs in a radial pattern from residential areas to the work-places at the Central Business District:

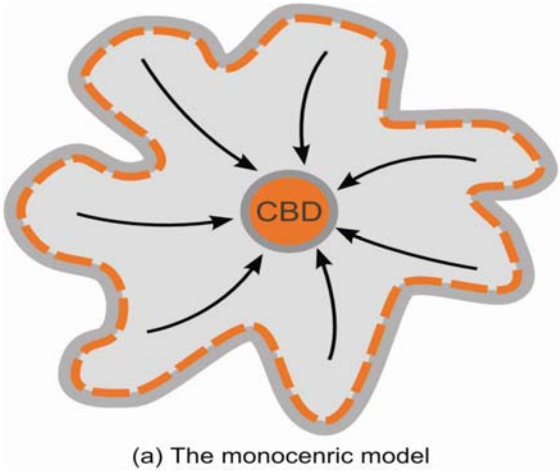

Figure 2 The monocentric model (Bertaud, 2004)

2. The poly-centric model. Most traffic occurs in a random pattern between the hot-spots of the city:

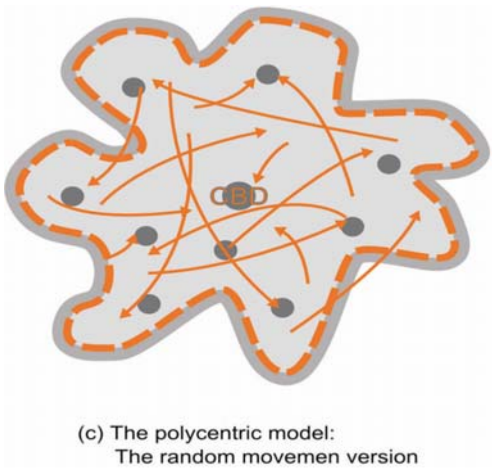

Figure 3 The polocentric model (Bertaud, 2004)

The report compared Atlanta and Barcelona as two cities representing these models. Both cities are similar in size, with about 2.5 Million people in Atlanta and 2.8 Million people in Barcelona (1990 Census). Both cities have very different numbers in the built-up area and in density:

Atlanta Built-up area: 4,280 sqm

Barcelona Built-up area: 162 skm (see Fig4: In-scale comparison of built-up area)

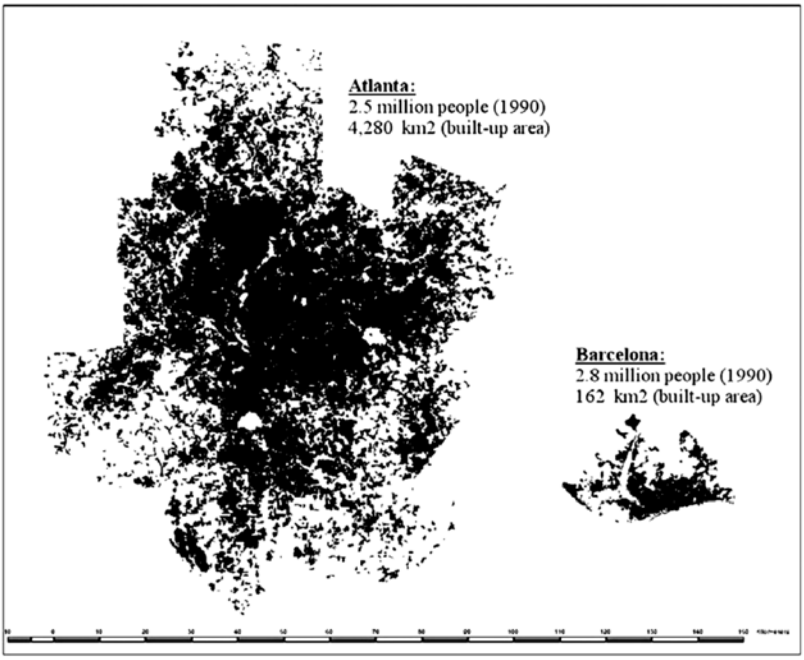

Figure 4 In-scale comparison of built-up area (Bertaud, 2004)

The maximum trip length in Atlanta is about 137 km, whereas the maximum trip length in Barcelona is only about 37 km. In Barcelona it was recorded, that around 20 % of all urban trips can been done by walking. In Atlanta, the number is so insignificant, that there is no record of walking trips within the municipality.

The urban transportation patterns in the examples are including private and public means of transportation. Experience shows, that most people accept to walk maximum of 10 Minutes to reach a traffic hub. Projected to the built-up area, that means, that in Barcelona 60 % of the population lives within a radius of 600 meters to a public transportation hub, whereas in Atlanta only 4 % can reach a hub within a reasonable time (800 m). People in Atlanta are mostly using private cars.

2.4 Energy−saving through urban transportation

US example: A car, occupied by one person produces an average of 3.3 grams/passenger kilometre of Nitrogen Oxides for inner-city work trips. A fully occupied bus would produce 2.5 g/km, while a train would only produce 0.75 g/km emissions for the same distance. A fully occupied bus is 6-times more efficient that a private average car. A fully occupied rail car is 15-times more efficient than a car. A 10% US nation-wide increase in public transport would result in a 506 million litres gasoline saving (Corson, n.d.).

These short examples clearly indicate the apparent relationship between land-use, urban transportation networks and transportation related energy consumption. Commuting is a major source for urban transportation. The wide use of public transportation as opposed to private cars, would reduce fuel consumption for urban transportation. An efficient urban transportation system will reduce fuel-based energy consumption. The combination of urban shape and land-use patterns can influence several aspects of urban transportation, such as trip-length and attractivity to certain transportation modes. Different urban models favour different modes of transportation.

2.5 Energy–saving through efficient land–use

There is an apparent direct relation of urban density and transportation behaviour. But there is also another serious relation, about the individual use of cars within a city, and it's relation on efficient land-use. Road networks and parking have negative effect on inner-city density. A private car to move around and park within a city needs around 40 square meters (Bertaud 2004). Average inner-city density in Beijing is about 24 727 people per square kilometres (Table 1, 2000 National Bureau of Statistics, Data from the 4 inner-city districts).

Table 1 Density of four Beijing inner-districts

District	Population (2000 census)	Area (km²)	Density (per km²)
Dongcheng District	536000	24,7	21700
Xicheng District	707000	30,0	23567
Chongwen District	346000	15,9	21761
Xuanwu District	526000	16,5	31879

The average density of these 4 districts account to the available area of roughly 40 square meters per person - which equals the required area for a single car moving and parking. This area is taken away from pedestrian areas, from commercial spaces, offices and shops, from parks and amenities - it is expensive area. The result is, in order to accommodate more cars in the city, we have to take that area from important, valuable urban area, and at the same time, we decrease density. If the density as shown above, falls below a certain threshold, public transportation can not operate effectively. Planners need to draw conclusions out of this circle, and evaluate the practicability and necessity of individual driving within the city centres.

2.6 Cases of development objectives in China

China in general seems to focus on massive road building in tandem with improving street-based public transport services and construction of rapid transit systems in larger

cities[1]. Big cities are rapidly sub-urbanising, with large residential complexes and new towns in the outskirts, together with a focus on often newly build Central Business Districts. Beijing experiences a trend, which policies are recently favours private car ownership. This has certain reasons, the car industry is a driving motor for economic development, the society has more disposable income, the cities are getting bigger. Big cities, such as Beijing therefore focus their urban transport initiatives mainly on road-based traffic, cars, buses and BRT. In Beijing however, there has been substantial investment into extended subway system. (See Figure 5 Beijing Subway 2012 Forecast) Nevertheless, these measures would be even more efficient in investment and in outcome, if they would be backed up with consistent policy in urban development and thorough urban transport strategies, supporting multi-modal urban transportation. Alternative means of transportation, bicycles, for example, which have been a primary mode of transportation within China's cities are getting more and more replaced by private cars and road-based public transportation. A lot of bicycle lanes recently have been changed and need to share the same space with an additional car lane or parking cars. In central Beijing, due to the amount of road-based traffic the average travel speed on major arteries dropped from 45 kph in 1994 to 12 kph in 2003 (Cervero, 2004).

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[1] From 2000 to 2003, China's roads absorbed nearly 14 million additional vehicles – an average of almost 13,000 new cars and trucks per day! (Residential Relocation and Commuting Behavior in Shanghai, China: The Case for Transit Oriented Development Robert Cervero and Jennifer Day)

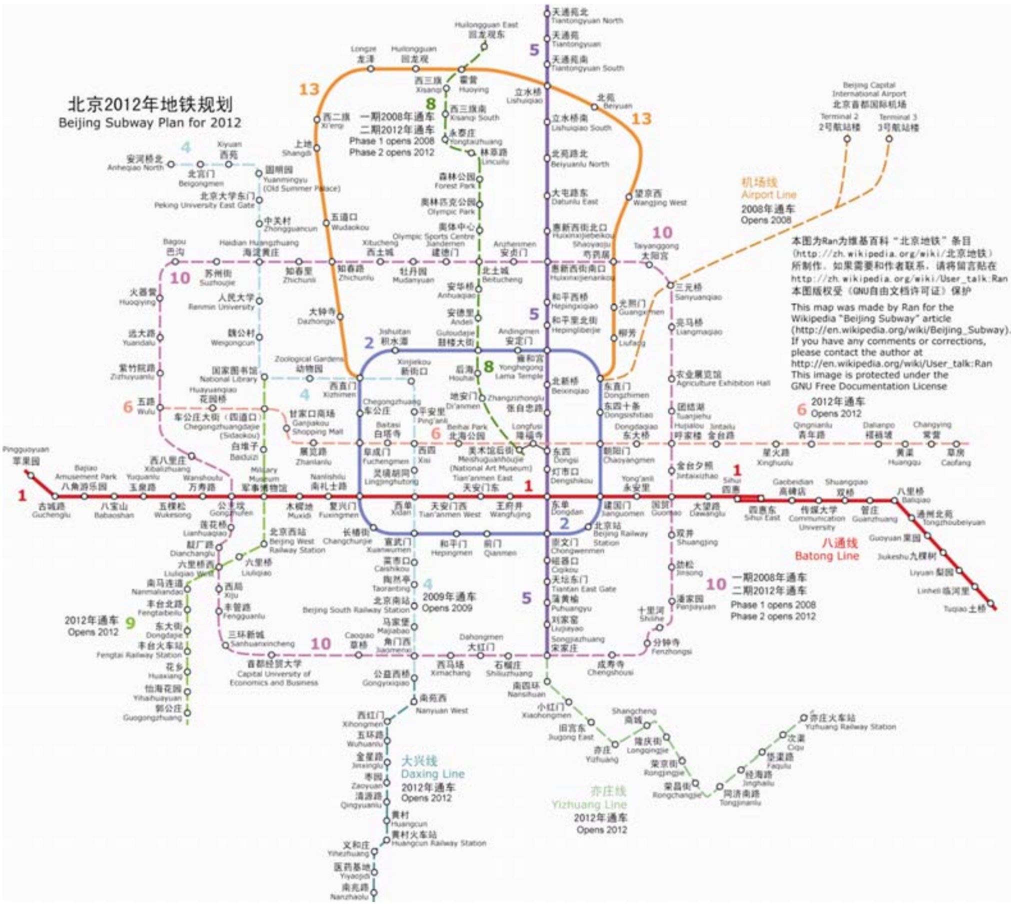

Figure 5 Beijing subway plan for 2012

Hong Kong follows a principle, to develop MTR-Hubs first (Cervero and Murakami, 2008), and then allow and attract commercial and residential development, which a successful integration of rail transit investments and urban development. Hong Kong is a good example of a city, where private car ownership is possible, but not necessary. Most people in Hong Kong are using the Mass Transit Railway to commute.

3 Conclusion

There is not a single answer to solve the problems, and there is not a single perfect city shape, which is able to satisfy all requirements. But previous studies show, that with a careful understanding of all parameters, and the balance of planners involvement in accordance with long-term policies, the energy-efficient performance of a city can be greatly improved. Given China's unprecedented development during the last 3 decades since the economic reforms in 1978, it is evident, that China needs country-specific solutions.

The study shows, that dependency on private car as the major urban transportation mode might not be the most efficient solution in terms of land-use and energy-consumption. Although, private transportation is an important part of a modern society, the use of private cars within a metropolitan area should be considered with care. Instead of favouring private car ownership, authorities and planners should focus on a multi-modal urban transportation system, combined with an integrated urban development strategy, which makes the use of private cars within the city unnecessary.

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Rainwater Harvesting: A Sustainable Urban Flood and Water Resources Management that China Could Learn from Germany
雨水收集：中国可以从德国借鉴的一种可持续的城市防洪和水资源管理措施

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Abstract

Rational exploitation and utilization of rainwater resources is a sustainable urban flood and water resources management measure, which could maintain the health of hydrological cycle in urban area. It can also reduce urban flood disaster, conserve groundwater, improve water quality, and increase water supply. In North China, the distribution of annual rainfall is generally centralized between May and August, and percentage of the amount can reach 70% of the annual precipitation. Many cities in North China face the problem of serious water shortage in one hand. On the other hand, most of rainwater flows into the drainage pipelines as waste water, and sometimes results in flood disaster. To utilize rainwater rationally and effectively will be not only a way to increase water resources, but also a good way to deduce urban flood disaster, and hence is a significant sustainable measure to alleviate the shortage of water resource, improve and protect ecological environment and reduce flood disasters in urban area. Since the 1960s, the investigation and practices in integrated rainwater utilization has been initiated in Germany. A great deal of good experiences on the harvesting and utilization of rainwater have been achieved. This paper, based on a project financed by UNESCO Beijing Office, systematically gives a state-of-the-art review on the harvesting and utilization of rainwater in Germany. It involves not only technologies including collection, storage, transfer, treatment, and utilization, but also related legislations and laws. From the 1980s, rainwater harvesting in China has been paid much attention and practices in several cities have initiated. Review on similar fields has also been presented for China. The gaps between two countries and the challenge that China faces in the harvesting and utilization of rainwater are investigated and analyzed in this paper as well.

摘要

合理开发利用雨水资源是一种可持续的城市防洪和水资源管理措施，这可以保持城市地区健康的水文循环。它也可以减少城市洪涝灾害，涵养地下水，改善水质，以及增加水供应。与海水淡化和远距离跨流域调水相比，利用雨水资源是最经济，简便，有效的途径。在华北地区，降雨量一般集中在 5 月到 8 月，可以达到年降水量的 70%。许多华北地区的城市面临严重缺水问题。另一方面，大部分的雨水流入下水道的污水管道，有时导致洪涝灾害。合理而有效地利用雨水不仅仅能增加水资源，也能减少城市洪涝灾害，因此在城市地区是一个重要的可持续措施，可以缓解水资源短缺的问题，改善和保护生态环境，以及减少洪涝灾害。利用雨水包括各种不同的措施来保护和利用雨水，如收集，储存和净化后直接利用；还包括使用各种人工或自然湖泊，池塘，湿地和低地来管理、存储和利用雨水，以改善城市地区的水环境和生态环境。

在过去几十年中，随着人口增长，持续的干旱，地表水污染以及地下水的过度开采，世界各地都很重视开发利用雨水资源。自 1960 年代以来，德国就开始了雨水综合利用的调查和实践研究。在雨水收集和利用方面已经取得了丰富的经验。本文基于联合国教科文组织北京办公室资助的一个项目结果，系统地综述了德国目前在雨水收集和利用方面最先进的结果。不仅包括技术方面，如收集收集、贮存、转移、处理和利用，而且还包括相关的法律法规。从上世纪 80 年代起，中国也开始重视雨水收集，并在一些城市中开始实践。本综述中也介绍了中国在类似领域中的工作。中德之间在这个领域的差距，以及中国在雨水收集及利用方面面临的挑战本文也作了分析。

1 Introduction

The history of rainwater harvesting can be traced back to about the 9^{th} or 10^{th} Century in Asia. It has traditionally been viewed as a potential water supply source in rural areas where the supply of water through pipeline networks is uneconomic or not technically feasible. Recently, rainwater harvesting in urban areas has gained much attention due to the recognition that the utilization of rainwater has both economic and ecological advantages (Zaizen *et al*, 1999; Che, 2004; Ghisi, 2006). During the past decades, with the development of economics and rapid urbanization in China, the growing demand for water resources in urban areas has resulted in overexploitation of groundwater in many cities, and urbanization tremendously increased the urban impermeable area which makes rainwater flowing away from drainage channels in urban areas. Consequently, urban groundwater cannot be timely recharged and conserved. It not only led to geological problems such as land subsidence but also increased the urban flood threat. Therefore, the utilization of urban rainwater plays a significant role in mitigating the shortage of urban water resources, and reducing the menace of urban flood disaster (Liu and Shao, 2006; Xue, 2006). It can also conserve groundwater, increase water quantity and improve water quality. Rational exploitation and utilization of rainwater resources could also maintain the health of hydrological cycle. Compared with the seawater desalination and long-distance inter-basin water transfer, the utilization of rainwater resources is the most economical, simple and effective way (Villarreal and Dixon, 2005). Therefore, the scientific utilization of rainwater resources is a sustainable measure for not only taping new sources of water supply but also reducing urban flood disaster. It has strategic significance to relieve shortage of water resources, improve and protect eco-environment, reduce the disaster of both floods and droughts.

Rainwater utilization includes the ways to protect and use rainwater by adopting different kinds of measures such as collection, storage, and direct utilization after purification. It also includes measures by using all kinds of artificial or natural lakes, ponds, wet lands and lowland to regulate, store, and utilize rainwater, improve water environment and ecological environment in urban areas (Zhang and Wang, 2006). Since the 1960s, the investigation and practices in integrated rainwater utilization has been initiated in Germany. A great deal of good experiences on the harvesting and utilization of rainwater have been achieved. This paper, based on a project financed by UNESCO Beijing Office, will give a systematic state-of-the-art review on the harvesting and utilization of rainwater in Germany. It involves not only technologies including collection, storage, transfer, treatment, and utilization of rainwater, but also related legislations and laws. From the 1980s, rainwater harvesting in China has been paid much attention and practices in several cities have initiated. Review on similar fields will be also presented for China. The gap between two countries, and the challenge that China faces in the harvesting and utilization of rainwater, will be analyzed in this paper as well.

2 Practices and Experiences on Harvesting and Utilization of Rainwater in Germany

Germany is located in a pleasantly cool favonian zone of the eastern Atlantic and the continental climate. Temperature is stable and moderate. The spatial distribution of rainfall is uneven, but the temporal distribution is even. There are a great number of rivers and lakes. The topography in Germany is featured that south is higher and north is lower, which results in most rivers flowing from south to north. It just offsets the rainfall discrepancy that south is more while north is less. Therefore, Germany is a country where spatial and temporal distribution of water resources is even and water resources are abundant. However, for the purposes to maintain a good water environment, the government doesn't only constitute strict laws and legislation to collect and utilize rainwater, but also makes a deep and wide investigation on rainwater utilization (Herrmann and Schmida, 1999). Presently, Germany has become one of the most developed countries in the harvesting and utilization of rainwater resources.

3 Technologies on the Harvesting and Utilization of Rainwater

3.1 General information on rainwater harvesting and utilization technologies

3.1.1 Collection of rainwater

The quality of rainwater from different areas is usually different. For instance, rainwater from roofs is generally lightly polluted at the beginning and has good quality later; while the rainwater from highway areas usually contains a lot of pollutants such as metal, rubber and fuel, etc. Therefore, rainwater from different areas is usually collected separately in Germany. For the rainwater from roofs, with slight treatment or without treatment it can be used for toilet flushing or greenbelt irrigation (Mentens *et al*., 2006). For the rainwater from highway areas, it can be released only after being treated up to a specified standard. Then, the cost of waste water treatment is decreased significantly and the amount of the tap water supply is reduced considerably.

3.1.2 Transfer and storage of rainwater

Because rainfall is a random event and is not consistent with water uses, it is necessary to store rainwater from different areas by some transfer and deposit facilities. In Germany, rainwater is usually transferred by using two kinds of major facilities, underground pipelines and open channels. In Germany, the rainwater pipelines are not only used to convey water, but also as a reservoir to store water to mitigate the peak flow. Open channel used for rainwater transfer become one of the landscapes in German cities. The designer pays much attention on the function of urban landscapes. The channel is usually designed to simulate the trace of sinuous natural rivers or constructed as some kinds of sculpts, as shown in Figure 1. Many kinds of facilities are used to store rainwater in Germany. Plastic cistern is usually used to store rainwater in domestic purposes, while water landscape structures or artificial lakes are usually used to store rainwater in communities. In addition, greenbelts and gardens are usually structured in an undulate shape, and artificial wetland is also usually adopted to increase infiltration of rainwater. In a word, Germany engineers integrate the facilities of transfer and storage for rainwater, urban landscape, and environment improvement structures. Not only the rainwater resources are used effectively, but also the cost of sewage treatment is decreased significantly.

Figure 1 Open channel used for rainwater transfer in Germany

3.1.3 Filtration, control and treatment of rainwater

Rainwater from different ground surface usually contains different kinds of impurities such as leaves, woods, sand grains, etc. In order to dispose these litters, Germany engineers have developed different kinds of filters. According to the filtration capacity, they may be divided into two types: decentralized and centralized. Decentralized filter is usually small, equipped with leakage pipes at the bottom, while the centralized filter is usually big, which collects rainwater from different areas and then filtrates together. Both of two filters can filter out the impurities that are more than 0.25 mm in diameter.

Because the polluted rainwater must be treated before use or release, and the variation of rainwater harvested is great and changes randomly, therefore, control equipment for the release of rainwater has been developed in Germany. The equipment is used with the combination of storage facilities. Rainwater is firstly discharged into storage facilities, and then released with constant flow through the control equipment, then flow into the sewage treatment plant, and finally treated with desired high efficiency.

3.1.4 Utilization of rainwater

In Germany, rainwater is mostly used in urban water landscape, artificial wetland, greenbelt irrigation, groundwater recharge, toilet flushing and laundry, and ecological environment improvement. For example, rainwater is used for water landscape in large commercial areas, and infiltration and toilet flushing in small residential areas. In addition, rainwater from roads and streets can be used in groundwater recharge. Rainwater has been widely used in various purposes in Germany.

3.2 Technologies of rainwater utilization in different development areas

3.2.1 Rainwater utilization in large commercial development areas

In Germany, related laws prescribe that polluted rainwater must be purified to satisfy a specified standard before drainage, and the rainwater utilization system must be built in new building or redeveloped areas. Drainage of rainwater will be free of charge if treatment system is constructed. Rainwater utilization, therefore, is an important facility for the planning and construction of development areas, especially for the construction of large commercial development areas. Several typical buildings include, for example, the Potsdamer Platz Square, Munich International Exhibition Center, and the new airport in Munich (Chilton *et al.*, 1999).

3.2.2 Rainwater utilization in small residential areas

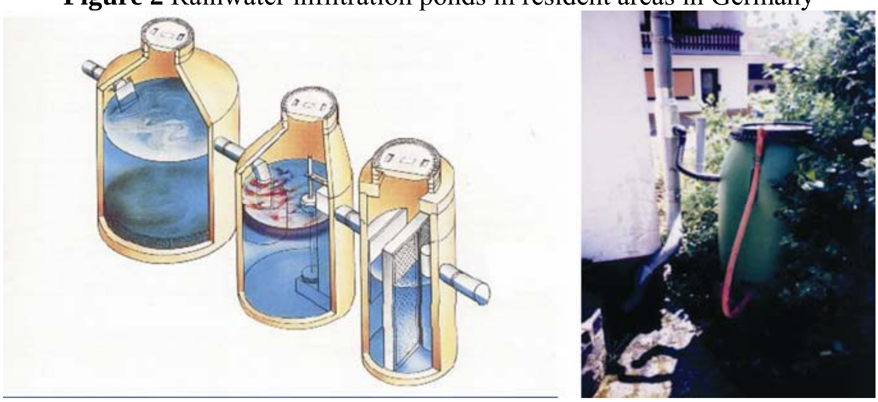
In Germany, rainwater utilization technology is adopted not only in large commercial development areas, but also in the residential areas. The roof rainwater will be firstly discharged into the surrounding green space through rainwater leakage pipelines, then infiltrated into the natural underground soil. If precipitation intensity is greater than infiltration capacity of soil, rainwater will be drained into the infiltration channels or depressions. Rainwater on roads and parks will be directly drained into the infiltration channels or depressions in small resident areas. The infiltration channels or depressions can be designed according to the tolerance of green land on flood. Within the tolerance level all the rainwater will be infiltrated. When rainwater exceeds this level, it will be drained into the pipeline system or small rainwater ponds through municipal overflow system. Besides green land, infiltration channels, and depression, the permeable sidewalk has also been widely paved. Figure 2 shows the rainwater ponds in a residential district in Germany.

3.2.3 Rainwater utilization in a single household

Germany is one of the developed countries and people's living standards are higher. One family usually lives in a single house. The rainwater utilization technology is also very developed. Common pattern of rainwater utilization in the household is that the rainwater on roof is collected directly through rainwater leakage pipelines, impurities will be filtrated through decentralized or centralized filtration, then flows into the reservoir. Rainwater is finally conveyed to water use unit through pumping. This kind of rainwater is generally used in green land irrigation, toilet flushing, etc. Figure 3 shows an example of rainwater storage system in German family.

(a) (b)

Figure 2 Rainwater infiltration ponds in resident areas in Germany



(a) (b)

Figure 3 Rainwater storage system in a German home

3.2.4 Rainwater utilization in road areas

Rainwater on the motor vehicle roads contains pollutants of high concentration and must be treated before drainage. There are equipments for runoff collection along motor vehicle road in Germany. Runoff collected from the motor vehicle road in urban areas is directly drained to the sewage treatment plant for disposal, and the runoff collected from highway is treated in the treatment system along the highway before drainage. Generally, in the treatment process, polluted water is firstly deposited, then treated through the oxidation ditches, and finally infiltrated into the ground.

3.3 Laws and legislations on rainwater utilization

Because the technology of rainwater utilization is already advanced in Germany, the government encourages publics to use the rainwater utilization technology through a variety of market mechanisms. For example, if residents have made use of the rainwater utilization technology, the state will no longer charge them for rainwater drainage fee. The rainwater drainage fee is equal to sewage treatment fee, which is usually about 1.5 times of tap water charges. Because the average annual rainfall is up to 800 mm in Germany, a substantial amount of fees, therefore, can be saved for a single family.

In the legal aspects, German government has constituted strict legal regulations. For any new or re-developed areas, the runoff should not exceed the runoff before development. It obliges developers to adopt rainwater utilization facilities. Hamburg was the first city (1988) to take the subsidy policy for rainwater utilization, and more than 1,500 residential rainwater utilization systems have been funded by the government during the following seven years. In 1992, Hessen started to levy groundwater use taxes, and subsidize water-saving projects including rainwater utilization. In the same year, new construction laws were enacted, which gave municipal authorities or local communities the right to promote rainwater utilization. Following that, the Baden State, Saar State, Bremen City, and Hamburg City all revised legislations on rainwater utilization. This is a beginning of new epoch for urban planning and construction. In the late 1990s, several other states and cities issued the new policy to finance and encourage the utilization of rainwater resources. All these measures have greatly improved the utilization and development of rainwater technology in Germany.

4 Development and Utilization of Rainwater in China

In North China, distribution of annual rainwater is uneven and the interannual change is significant. The precipitation within one year mostly occurs from June to October, during which the runoff during five months usually accounts for more than 70% of the annual total. There are serious shortages of water resources in many cities, but most of rainwater resources flow into the drainage pipelines as waste water in many urban areas. The present utilization ratio of rainwater is under 10%.

Rainwater utilization in China had a long history. The ancient project of rainwater utilization in the Beihai Park is a good example of rainwater utilization in the ancient times. Significant research and practices on urban rainwater utilization initiated in the 1980s, and greatly developed in the 1990s. Demonstration projects have been constructed in Beijing, Shanghai, Dalian, Harbin, Xi'an, etc. The Ministry of Water Resources has authorized "Tenth Five-Year Plan of National Rainfall Collection and Storage and 2010 Plan" in 2000. Special Committee on Rainwater Utilization had been launched in Lanzhou in July 2001. Department of Irrigation, Drainage and Rural Water Supply in the Ministry of Water Resources held a national rainwater harvesting and utilization meetings in Baise City, Guangxi. The 29th meeting of the Standing Committee of the Ninth National People's Congress adopted "Water Law of the People's Republic of China". The law clearly stated that the state encourages collection, development, and utilization of brackish water and rainwater (Wang, 2006). The practices show that the rainwater resource has been paid much attention by both government and publics, and a new epoch of rainwater utilization in China already started.

4.1 History of rainwater utilization in China

The utilization of rainwater has a long history in China. A typical example of ancient projects can be found in the Beihai Park. Located in the Beihai Park, the Inland City was a soil island, constructed 800 years ago. The besieged fortress was built after the Yuan Dynasty, which has the height of 4-5 meters and the area of 6,000 square meters, as shown in Figure 4. The Inland City is 4.6 m higher than surrounding ground and was paved with bricks on the ground. The big and strong old trees have grown more than 800 years. Both collection system and utilization system of rainwater, built in the beginning of 15 century AD, has played great role during the past near 1000 years.

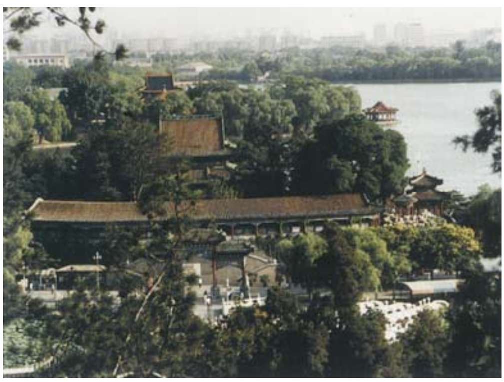


Figure 4 Inland City in the Beihai

The Inland City is a closed, isolated structure. The ground is higher 5.64 m than water surface in the Beihai sea, and the replenishment from groundwater is hard for the growth of old trees, and which only relies on the recharge from natural rainfall. The Inland City was paved with bricks that formed a series of 10cm×2cm triangular small channels, which can receive and transfer water. Below the channels, an underground water culvert was constructed. The culvert was dug around the city and made of bricks. When rain occurs, rainwater is transferred through the channels and flows into the culvert where it is stored. At the same times, the rainfall also infiltrates into surrounding soil through the permeable bricks. When soil moisture is saturated, an underground river is gradually formed. The trees do not rot in rainy seasons and not wilt during dry seasons.

The way to pave the trapezoidal bricks at the ground and construct underground drainage culvert could make full use of natural rainwater, which further created a suitable growth conditions for trees in the Inland City. Some big and old trees have grown more than 800 years in the park. It is, nevertheless, a successful experience on the harvesting and utilization of rainwater in ancient China.

Practices of urban rainwater utilization initiated in China 20 to 30 years ago. At the end of 1980s and early of 1990s, Beijing, Shanghai, Dalian, Harbin, Xi'an and other cities began to launch rainwater utilization investigations. Since 2000, Beijing started to take practices in the harvesting and utilization of rainwater with the combination of demonstration projects, and to explore the integration, legalization and standardization of rainwater utilization cooperated with Germany scientists, and preliminary experiences have been achieved.

4.2 Rainwater utilization in Beijing

The annual average rainfall is only 585 mm in Beijing, available water resources per capita is less than 300 m^3, far below the international standard. The shortage of water will inevitably become more and more serious due to the decrease of water resources and the increase of water consumption per capita. Among the annual average precipitation of 585 mm, 486.8 mm falls in flood season, and most of the amount is in urban area. The amount of runoff lost in urban area is about 0.28 billion m^3. Therefore, Beijing government highly emphasizes the harvesting and utilization of rainwater. Since the 1980s, Beijing has done a great deal of work on the construction of demonstration projects, technology of collection and utilization, and policy constitution. All of these activities have made Beijing the leading city in China on the utilization of rainwater (Zuo *et al*., 2008).

4.2.1 Demonstration projects of rainwater utilization in Beijing

In 2000, with the support from the Ministry of Science and Technology in China and Germany government, financed by the Beijing Committee of Development and Reform, Beijing Committee of Science and Technology and Beijing Bureau of Water Affairs, the research project "Research and demonstration project of rainwater control and utilization technology in Beijing" was initiated and carried out. From 2000 to 2004, six demonstration projects of rainwater utilization classified into five types have been constructed, that are located in the old urban area, newly-constructed urban area, area to be constructed, park greenbelt, and school campus with the total area of 60 hm^2.

As one of the six projects, the demonstration project for rainwater utilization in campus was constructed in the Beijing College of Water Resources and Hydropower with the total area of 4 hm^2. Roof rainwater is collected by pipeline system to irrigate the campus greenbelt and wash lavatory after treated. Infiltration and ring ditches are used for collecting rainwater from the stadium. After filtration and removing of the early rainwater, it can be used to sprinkle playground and irrigate greenbelt. The sidewalks and part of the playground were paved using permeable pavement. Greenbelt is paved using concave herbaceous field.

After removal of the initial runoff, rainwater from the roof of teaching and experiment buildings with the area of 5494 m^2 is collected and then drained into the reservoir located in southwest of the playground with the volume of 500 m^3. The rainwater on the plastic runway with the area of 2360 m^2 is collected through the ring ditches. A series of small initial interception pools are dug along the ring ditches. The rainwater flows into the percolation pool after removing the initial runoff, and finally pumps into the sluice reservoir. Figure 5 shows the plastic runway and ring ditches.

4.2.2 Technology of rainwater harvesting and utilization in Beijing

With the combination of practical needs on rainwater utilization, an in-depth study on the collection, storage, disposal and reuse of rainwater, infiltration and recharge to groundwater, technology of pervious bricks and ground pavement have been carried out in Beijing. Great achievements have been obtained with the construction of demonstration projects.

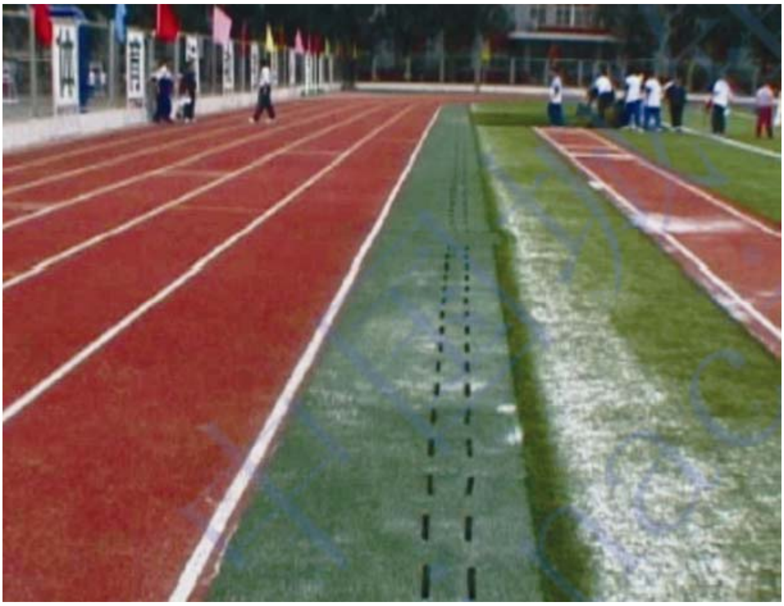


Figure 5 Plastic runway and ring ditches in the Beijing College of Water Resources and Hydropower

(1) *Technology of rainwater treatment*

Technology on the treatment of rainwater with different quality and the uses of rainwater for different purposes has been investigated. Technology has been developed in response to water quality characteristics according to different requirements for various uses. Priority flow treatment, interception and infiltration technology, automatic rotated runoff ponds, and sediment filtration pond with the function of storage are developed. The technique for disposal of the floating oil on the water surface has been invented.

(2) *Permeable pavement and related technologies*

The contradiction among permeability, strength and frost resistance was solved, and the technology for using permeable ground to infiltrate rainwater and reduce runoff was developed (Wang et al., 2001). Production technology for pervious bricks with fast high permeability and strength, freeze-thaw resistance has been proposed, and the quality monitoring method for pervious bricks and pavement methods have been put forward. The infiltration coefficient for the pervious bricks developed is greater than 1.0 mm/s, and compressive strength reached 35 Mpa, the intensity against freeze-thaw is 5.85%, the permeable pavement surface can infiltrate 50-100 mm rainfall per day without generation of runoff.

Through observational results in the Shuangzi Garden for four years, and the experiment during the rainstorm occurred in July 20, 2004, it was proved that the ground covered by brick pavements showed a good performance for the decreasing of surface water and runoff. Figure 6 shows the pavement bricks in the heavy rain.

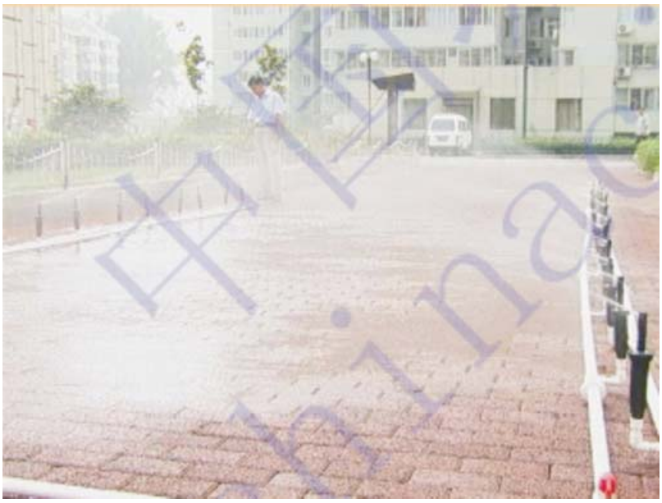


Figure 6 Pavement bricks in the heavy rain

4.2.3 Policies on rainwater utilization in Beijing

Beijing has constituted related policy to support the demonstration and popularization of rainwater utilization technology. “The Interim Provisions on Strengthening the Rainwater Utilization in the Development of Construction Land” was promulgated in March 2003, “Water Law of the People’s Republic of China” was promulgated in October 2004, “Comprehensive Planning in Beijing City (2004-2005)” was promulgated in January 2005, “Water-saving Measures in Beijing” was promulgated in May 2005.

The recognition on rainwater utilization has been continuously strengthened in Beijing. On May 31, 2005, Mr. Wang Qishan, the mayor of Beijing City, has changed the word from "Flood prevention" to "Coexist with flood". It greatly increased the recognition of rainwater utilization. Seven organizations including Beijing Bureau of Water Affairs jointly issued “Rainwater Utilization Proposals” in April 2006, to promote the utilization of rainwater. In November, same seven organizations jointly issued “Announcement on Strengthening Rainwater Utilization in Construction Projects” again. This shows that the policy on rainwater utilization in Beijing has reached a new stage.

4.3 Progresses on urban rainwater utilization in China

During the past 20 to 30 years, urban rainwater utilization practices in China have achieved significant progresses in aspects of construction, technology, and constitution of law and regulations.

4.3.1 Demonstration projects

In China, many demonstration projects on rainwater utilization have been constructed in Beijing, Shenzhen and other cities, from that valuable experiences on the construction and utilization of rainwater have been achieved. These experiences have been promoted in several cities.

Beijing has promoted the utilization technology of rainwater in Zhongguancun Environment Protection S/T Demonstration Park, 2008 Olympic Park Center, Yongshun New City, Huangcun Industrial Park, Zhujiang International City, Yizhuang Satellite City, Wukesong Cultural and Sports Centre, etc. The total area reached more than 7,000 hm^2. Besides the Qiaoxiang Village in Shenzhen city, several demonstration projects including Xinghedan Weir, Haiyun Building, Meishanyuan District and Liguang Corporation, etc. have been constructed for the treatment and utilization of rainwater. Furthermore, demonstration projects on the utilization of rainwater resources will be constructed in Lianhua Mountain, Civil Central Area, Olympic Sports Center, Longhua Second-line Expansion District, Senior Technology School, etc. The experiences in Beijing and Shenzhen have been promoted in Shanghai, Tianjin and other cities. The municipal water supply system in Shanghai 2010 World Expo will adopt “Double-water sources”, i.e., the rainwater from roofs and water resources from the Huangpu River. When the utilization system on roof rainwater is completed in a large area, only the quantity of roof rainwater will reach 0.1097 million cubic meters within one year.

4.3.2 Technologies of rainwater utilization

China has primarily formed its own technology system on rainwater utilization through technology transfer, and independent study and development. On the basis of the rainwater utilization technology learnt from Germany, Beijing Institute of Water Resources has carried out a systematic investigation on the mechanism of water quantity and quality for urban rainwater and flood resources. It also includes the technology for the mitigation, collection, transfer, treatment, recycling and infiltration of rainwater, the recharge to groundwater, infiltration bricks and ground surface paving technology. These technologies have been tested and practiced in demonstration projects.

Furthermore, China Institute of Water Resources and Hydropower Research, Nanjing Institute of Water Resources and Hydropower Research, and other scientific research institutions have made great efforts on the collection, storage, regulation, and control of rainwater, risk and benefit assessment on rainwater utilization, etc. A significant progress has been achieved.

4.3.3 Policy on urban rainwater utilization

In China, the government has paid much attention on rainwater utilization. This may be reflected in related provisions in policies and regulations. Besides the “Water Law of the People's Republic of China” clearly constituted that collection, development and utilization of rainwater are encouraged in the region where water is in shortage, and the “Technical Criterion for Rainwater Utilization in Architecture and Domestic Districts” was initiated in April 1, 2007, in which construction and use of rainwater utilization facilities are stipulated as a mandatory requirement and it must be strictly enforced. Beijing, Shanghai, Shenzhen and other cities also constituted local policies and regulations, such as "Water-saving Measures in Beijing City", "Standardized Action Plan on Resources Saving and Comprehensive Utilization in Shanghai" and "Implementation Plan for Comprehensively Promoting Development of Cyclic Economics in Shenzhen for the Near Future".

5 Challenges that China is Facing and Strategies that China Should Take in Urban Rainwater Utilization

5.1 Challenges that China is facing in urban rainwater utilization

With the development of urbanization, water shortage is becoming serious in China. According to the statistics from the Ministry of Water Resources, water supplies in 400 of 669 cities in China are inadequate, and 110 of them are facing serious water shortage. In 32 mega-cities, 30 of them are facing long-term water shortage problems. In 46 major cities, 45.6% of them are in poor water quality. In 14 coastal cities, 9 of them are facing serious water shortage. Beijing, Tianjin, Qingdao, Dalian and so on, are especially serious in shortage of water. In 2006, urban population in China was 577.6 million. It is expected that the population will reach to 1.46 billion in 2020, and the urbanization rate will probably reach to 55-60%. In other words, urban population in China will reach 8-900 million in 2020. There will be additional 200 to 300 million of people who will move into the city. The expansion of urban area will give a great challenge for the urban water supply. In those cities that the water shortage has already become serious, rainwater resources will become an important supplement for conventional urban water supply in China.

Urbanization in China has resulted in the increase of built area, and changed the relationship between storm and runoff in urban areas. With same rainfall, flood peak will occur earlier, peak volume will become greater, and flood risk in urban area will increase. Since 2000, serious flood disasters occurred in Beijing, Shenzhen, and other cities. Figure 7 shows the waterlogging under the Lianhua Bridge in Beijing on July 10, 2004. With the accelerated urbanization, this phenomenon has become increasing serious. The needs to construct rainwater utilization projects that can decrease runoff generated from storm and reduce flood peak flow, become more and more urgent. In a word, rapid urbanization in China raises urgent needs on urban rainwater utilization. Rainwater utilization is also faced with unprecedented challenges and opportunities.

5.2 Strategy on urban rainwater utilization in China

Considering the fact that urbanization is speeding up, the following strategies are proposed on the basis of experiences obtained from both domestic and foreign countries on the utilization of rainwater resources.

5.2.1 Integrated technical system for rainwater utilization

Integrated technology system on design, construction and management of rainwater utilization facilities should be established. This system mainly include hydrological model to estimate corresponding design and the scale of related structure; techno-economic analysis on the basis of water balance, to determine allocation measures on the storage, infiltration, control and drainage of rainwater, to achieve the target of "zero drainage" for the precipitation with specified return period, and the technology to control water supply. The rainwater will be regarded as a backup water resource and can be allocated with treated wastewater, tap water, and other water sources.

Figure 7 Waterlogging at Lianhua Bridge in Beijing on July 10, 2004

5.2.2 Technical standard for rainwater utilization

The technical standard for the utilization of rainwater includes all aspects such as design, construction, management and operation of facilities, filtering, storage, control and monitor for rainwater utilization. The constraints such as scale of construction, functions and people who are served should be fully considered when the standards are made. At the present stage, the first thing is to encourage the city in which rainwater is utilized maturely to establish urban standard. When the demonstration achieves a good result, measures should be taken to develop national standards.

5.2.3 Industrialization of rainwater utilization

Presently, rainwater utilization is generally regarded as a kind of public affair managed by government. Market mechanism should be promoted. Government should establish relevant economic policies to encourage high-tech enterprises to develop technologies of rainwater utilization, and encourage private capital to participate in the collection of rainwater. At the same time, enthusiasm of developers and enterprises should be motivated through various preferential policies and mechanisms of profit.

5.2.4 Policies and regulations on utilization of rainwater

Firstly, policies should be constituted through the people's congress to encourage and reward communities that have made specific regulations on rainwater utilization, under that investors can have economic benefits directly. Secondly, permission formalities on the construction of projects that are used for urban rainwater utilization should be improved, and specialized institutions to audit projects of rainwater utilization should be established. Implementation and the final evaluation of the project on rainwater utilization should be strengthened. Finally, administrative system should be established to achieve coordination and joint promotion between different sections, and responsibilities should be cleanly specified among urban planning, water affairs, municipal services, garden, and other related departments. Through this way the planning, feasibility investigations, project assessment, design permission, supervision of construction and management of rainwater utilization can be improved greatly.

6 Conclusions

The state-of-the-art on rainwater utilization including the rainwater resource utilization techniques in China, a typical example city for rainwater utilization in Beijing, the gap between China and Germany on rainwater resources utilization are summarized in this paper. Several developed countries including Japan, United States, and Germany have achieved very good experiences on rainwater utilization including techniques, policy and regulation constitution. All of these advanced techniques and good experiences are worthy to be learnt by Chinese sides. This field, together with other related fields of research on water sciences, will provide a good opportunity and great challenge for the scientific cooperation between China and Germany, between Chinese scientists and German colleagues.

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Overall-Effective Measures for Sustainable Water Resources Management in the Coastal Area of Shandong Province, Huangshui River Basin

山东省滨海地区水资源可持续管理的有效措施：以黄水河流域为例

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Abstract

Water scarcity and water pollution are severe problems in the north part of China, seriously affecting socio-economic development and standards of living and environment. In the coastal catchments of the Shandong province the situation is even more stressed due to salt water intrusion. The positive results of previous projects on rainwater harvesting in a salt water intrusion area at Jiangsu coast in 1995 and on flood control and groundwater recharge in Beijing from 2000 to 2005 encouraged to apply a holistic IWRM approach to the complex water and socio-economic problems in Shandong, in particular for the Huangshui River Basin and the Longkou district. With good water management there is a realistic opportunity to relieve the water scarcity situation, to abate salt water intrusion and with this to stop the already ongoing socio-economic depression. The project is funded by BMBF on the German and MOST on the Chinese side, started in June 2008 and will last until Mai 2011. On the German side, totally seven partners are involved in the project; all of them are experienced in solving water related problems. The overall project contains two phases – a planning phase and an implementation phase. On the one hand Integrated Water Resources Management indicates that all single relevant physical processes should be treated as a part of a complete and interactive system. In the project it will be focused on the interaction of groundwater recharge, surface and groundwater, both from the quality and the quantity point of view. In practice, this means that a detailed integrated hydrological model for the Huangshui River

Basin will be developed using the specific experiences and software provided by the different partners. On the other hand, IWRM means that decisions should be made, taking into account the different stakeholders in the project area as well as future social and economical developments. For this reason, a GIS supported DSS system will be developed. In the first stage of the project a detailed simulation-model independent analyses of all possible measures to reduce the water stress in the region will be made. From this, a so-called measures catalogue will be generated that will consider ecological, political as well as social aspects and will provide a cost benefit analysis for each of these. This catalogue will be the main input for the DSS, which will use the hydrological model to analyze the different selected measures packages in detail. On the basis of technical, economic and social criteria and in close cooperation with the regional decision makers, a final strategy can then be selected. For this purpose the use of multi-criteria analyses is intended, which allows multiple attributes, both tangibles and intangibles, imprecise and uncertain probabilities, dependency and feedback and is interactive and learning based. Finally a short overview on the implementation phase focusing on water saving, greywater recycling and waste water reuse will be given.

摘要

在中国华北地区，水资源短缺与水污染正严重制约着当地社会经济发展、人民生活水平提高和环境质量的改善。在山东省滨海地区，由于存在海(咸)水入侵问题使得这一现象更加突出。1995年在江苏省滨海海水入侵区采用了雨水收集利用措施，2002−2005 年在北京进行了防洪与地下水回灌技术研究。在以上两个项目成功经验的基础上，本项目决定利用水资源综合管理(IWRM)技术来解决山东省特别是黄水河流域及龙口市存在的日益严峻水资源与社会经济问题。利用该项管理技术可以有效的缓解水资源短缺及海水入侵问题，减缓由于缺水引起的日益严重的社会经济问题。该项目由德国教研部(BMBF)和中国科技部(MOST)共同资助，实施期限为 2008 年 6 月至 2011 年 5 月。德方共有 7 个单位参加，每个参加单位在解决水问题方面都有着丰富的经验。该项目包含两个阶段—规划阶段和执行阶段，本文主要针对第一阶段。一方面，IWRM 意味着所有单一的物理过程都将是整个交互式系统的一部分，本项目中重点从水质水量两个方面来关注地下水补给、地表水与地下水之间的相互作用，实际操作过程中，在黄水河流域将利用不同参加单位提供的经验和软件来完成一个整合的水文模型；另一方面，IWRM 意味着必须在考虑项目区不同用水户利益及未来社会经济发展指标的基础上做出正确的决策，为此，必须开发基于 GIS 的决策支持系统(DSS)。在项目实施第一阶段，在对该地区可以缓解水资源紧张状况的各种可能措施分析的基础上将开发出详尽的模拟模型，因此形成的措施方案集将考虑生态、管理及社会等方面，同时可以为不同方案提供成本效益分析。这一方案集将作为 DSS 的主要输入部分，并利用其中的水文模型对所选择的不同的措施方案集进行详细分析。基于技术、经济和社会的准则，再加上当地政府决策部门的密切合作，即可找出解决问题的最终策略。为此需要进行多准则分析，它允许多种属性，包括具体和抽象的，不精确和不确定性的，依赖和反馈的以及互动和学习为基础的。最后，对于项目实施第二阶段中的节水、中水循环与废水再利用等方面进行了简要说明。

1 Project Outline

The Shandong Province, especially the Huangshui River Basin (Longkou county), is an out-standing example for water conflicts arising from piece meal action as well as fast growing population, industry and agriculture. In the coastal catchments of the Shandong province the water scarcity is even increased due to salt water intrusion, reducing the usability of available water resources. Furthermore, social status and income of farmers in the Shandong province is significantly below a level that would allow them to keep up with the technology development in irrigation and farming. The socio-economic problems can only be tackled by truly integrated water management approaches. In the following table the salt water intrusion development in Longkou City is shown. In the 90's already many measures against the saltwater intrusion have been implemented. In 1995 for example an underground dam was finished in the downstream part of the Huangshui River, 1.2 km from the seaside, with a total length of approximately 6 km (LIU, 2003). The average depth of the dam is 26.7 m. On the one hand, the dam prevents the ground water from flowing into the sea. On the other hand, it can stop the sea water intrusion. The table shows that even after this project was finished, the area affected by salt water intrusion continued to increase. It is part of the project to investigate the influence of this dam and to analyze whether its effectiveness can be increased.

Table 1 History of Sea Water Intrusion in Longkou City (Guo, 2004)

Year	Annual Intrusion Rate (km^2/year)	Cumulative Area of Sea Water Intrusion (km^2)	Highest Intrusion Distance over Land (km)
1984	5.1	45.8	3.1
1988	4.6	64.3	4.6
1989	19.4	83.7	---
1990	-5.0	78.7	---
1991	10.3	89.0	---
1992	1.8	90.8	---
1993	5.6	96.4	5.3
1998	1.7	105.0	5.9

The general objective of the project however is to bring together German expertise in water management and newer developments in context with the European Water Framework Directive with the research efforts in the coastal area of Shandong province to relieve the desperate water scarcity situation. The total water consumption within the project area amounts in average to about 162 million m^3/a. It is composed by approximately: agriculture (irrigation) 69%, rural domestic 6%, urban domestic 3%, industry 21% and environment 1%. Although water saving techniques in irrigation after many years of research and international cooperation are introduced, agricultural water demand still increases. With a usable runoff of about 120 million m^3, the water demand of 162 million m^3/a clearly exceeds the water resources, in average by about 25%. This problem is even more severe considering the monthly and annual distribution of water resources and water demand (Kutzner, 2006). After further assessment of the present situation and the many abatement measures tried with, especially to stop salt water intrusion, it was found that there is a tremendous potential to improve the situation by appropriate integrated water management. If a solution for this extremely complicated problem can be developed and implemented the methods and technologies used may be generalized and applied to the whole Shandong province or even to other parts of China. The project area is shown in the following figure.

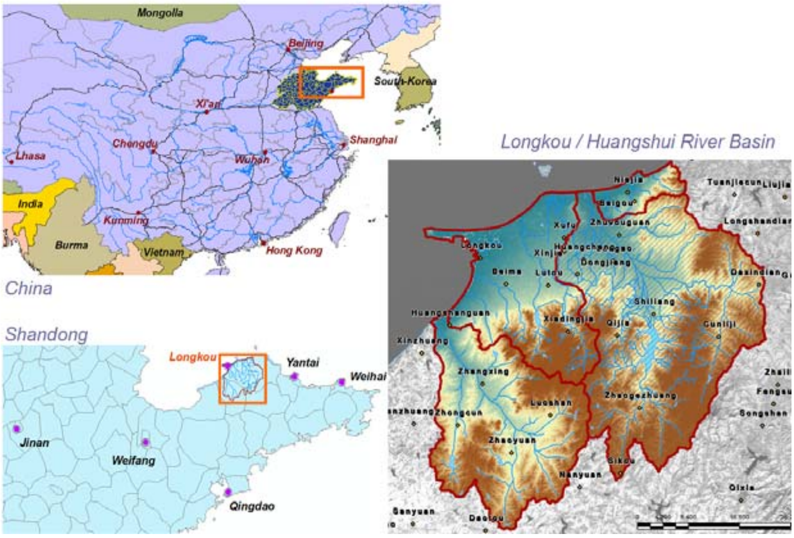

Figure 1 Study area Huangshui River Basin / Longkou

The figure below gives an overview of the structure of the ongoing Chinese-German project. It is divided into a planning and an implementation phase. The project is funded by the German Ministry of Education and Science BMBF and the Chinese Ministry of Science and Technology MoST.

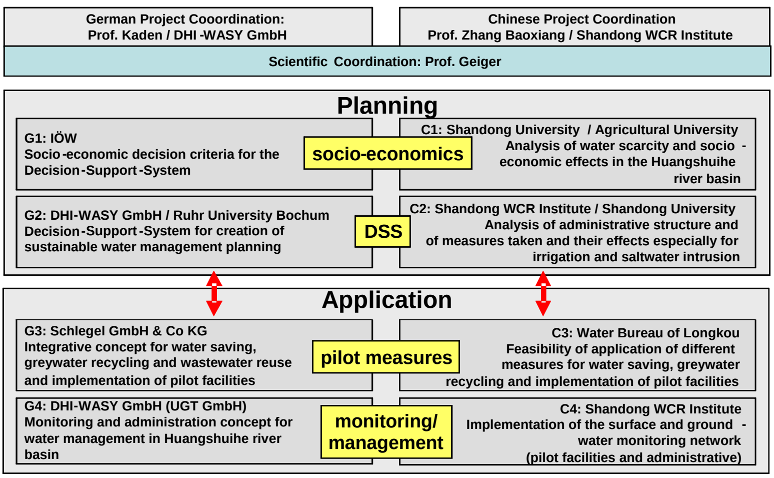

Figure 2 Project structure

2 Planned Results

In the following the basic methodology and planned major project results and solutions are shortly explained. In the course of the project this list might be modified and extended.

2.1 Methodology for IWRM

The problems and conflicts in the coastal regions of Shandong province and in the Huangshui River Basin are tightly merged. Individual measures have no effect, as the past has shown, especially, because social-economic consequences result from a variety of influences. This becomes obvious when looking at the problem of salt water intrusion. This could be stopped, if no further ground water would be extracted for irrigation. This would lead to tremendous social problems. But the problem of salt water intrusion can't be solved with technical measures alone. A solution can be only achieved with an integrated water resource management (IWRM).

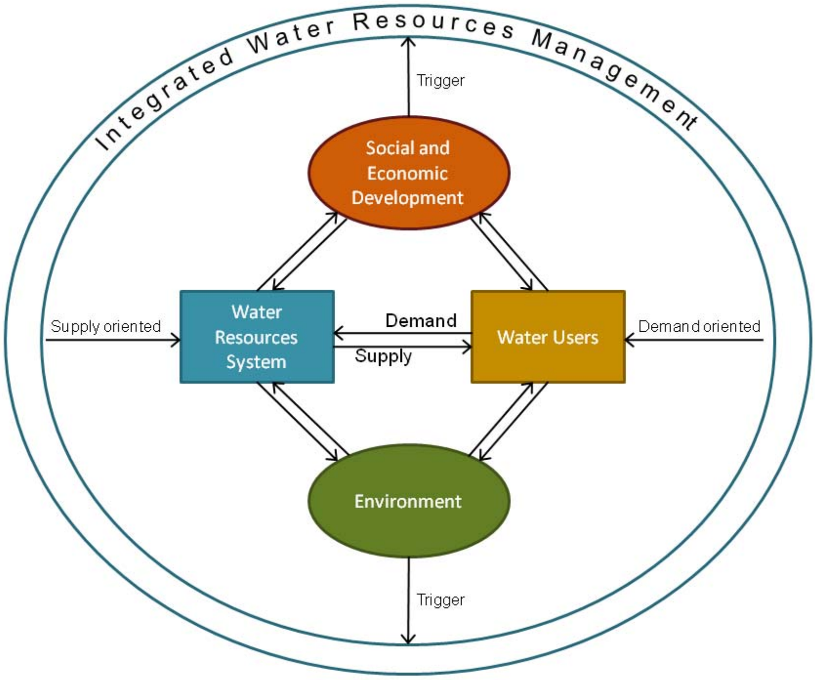

Figure 3 IWRM after Koudstaal et al., 1992

Figure 3 clearly displays pathways that have led to the current water resources problem in Shandong. A predominantly demand oriented water management, with a main focus on the water users displaying an ever increasing demand, has led to an over-taxation of the water resources system, causing serious limitations to the social and economic development of the region triggering a call for an integrated water management. Additionally, a disruption in ecosystem functioning impacts water quality and water users' health and threatens to further decrease available fresh water resources.

Following the principle of an integrated water resource management, water is an essential element of the ecosystem. It is a natural resource and a social and economic commodity. Water demand should be calibrated to be in equilibrium with water supply, thus safeguarding the ecological and socio-economical services this resource supports. According to this complexity, a variety of aspects have to be considered, in order to take into account the multitude of water related interactions in the society. In addition, a variety of stakeholders has to be involved. The coordination of interests between these groups might be very complicated. Decision-Support-Systems support this complicated planning and decision process. In general, the possibilities for a sustainable IWRM are versatile. The applicability depends on local and regional conditions, as well as socio economic states and requirements. It is almost impossible to analyze all of the effects of a possible measure in detail. Therefore, the concept of a two-stage DSS is recommended, after a detailed analysis of the catchment area. The methodological approach is characterized by the phases; problem identification, pre-selection of cost effective measures (Stage 1) and verification and selection of a final strategy (Stage 2). This approach guarantees that on the one hand, no possible measure is left out, and on the other hand the effort for the planning procedure is reduced to the necessary.

In Stage 1 all available measures especially in the field of water saving, ground water recharge, water recycling, structural measures against salt water intrusion and institutional measures are considered. In the first step of the decision process, all applicable measures for the project area and the considered water-related issues are collected, sorted and combined in a logical and functional measures catalogue. Every measure will be appraised according to a number of criteria, relevant for determining a sustainable integrated solution. Sustainability is considered in their economic, social and environmental aspects. Important criteria considered here are construction and operation costs, durability, effectiveness in reducing water consumption or increasing water availability, water quality aspects, risk assessment and such social and political criteria as political acceptance, impacts on employment rates in several branches, redistribution of incomes and fairness. All relevant items in the measures catalogue will be typecast according to these hierarchically structured criteria.

In the next step in this stage, scenarios for socio-economic developments are defined which are used to evaluate the measures of this catalogue by resulting political and social and economic aspects. This sort of sensitivity analysis ensures that unknown future conditions are considered. Finally a small amount of the best scenarios are selected upon environmental- and recourse costs. At this point it should be certain, how this measure can be put into practice. Guidelines for the dimensioning need to be available.

In the following final planning (Stage 2) only a small selection of bundles of measures can be analyzed in detail. On the basis of technical, economic and social criteria and in close cooperation with the regional decision makers, a final strategy will be selected. For this purpose the use of multi-criteria analyses is intended. In this phase a detailed analysis of the linkage of individual measures, if relevant, is carried out to find an optimal combination of measures. At this point the relevant processes are modelled in the natural system and the efficiency of the individual measures is calculated while considering the social economic aspects.

2.2 Socio-economic analysis and catalogue of measures

Chinas water resources are relatively small and uneven distributed. In average, China's water resources per capita are only one quarter of the world average (Yang, 2001). Especially the North of the country, where Shandong is located, is affected by water scarcity (Varis, 2001). The amount of the available annual water resources in Shandong is only about 340 m^3 per capita, which is classified as absolute water scarcity (Falkenmark, 1992). Currently, water management practice is not sustainable in Shandong. Groundwater is used at an amount, which leads to dropping groundwater level (Varis, 2006). Overexploitation and water pollution results in considerable environmental, social and economical costs. Due to population and industrial growth as well as ongoing urbanisation, water demand will even increase in the future. Therefore, measures are to be taken for achieving a more efficient and sustainable water use.

Ecological targets such as sustainable water use can usually be achieved in various ways at heavily differing financial costs and ecological side effects. Water saving can be achieved by applying a variety of alternative measures. To identify the best alternative, it is necessary to incorporate not only the financial impacts but also the ecological and social side effects. Therefore, these impacts have to be quantified and in a second step weighted against each other as well as against the financial costs and benefits. Potential measures and management alternatives are evaluated from the perspective of economic efficiency. For sustainability, the social acceptability and the distributional effects of a decision (i.e. unequal costs and benefits for different stakeholders) are taken equally into account. However, weighting ecological and social effects' contribution to social welfare does typically create substantial difficulties for political decision makers. It is simply difficult for policy makers to estimate the importance of various effects on ecosystem goods at the same time. Environmental economic valuation offers a systematic and traceable procedure for translating impacts on ESS into economic terms and thereby making them far more accessible to the public and policy makers. In addition, a comprehensive qualitative assessment of the preferences, values and believes of the local stakeholders and of the distributional effects of alternative measures can explain existing oppositions and implementation problems. Acceptance and chances of implementing innovative land use options depend on the (positive and negative) consequences for the relevant stakeholders and on their perceptions regarding their participation in the decision making process.

After identifying desirable measures for achieving sustainable water use, policies for implantation are to be developed. Additionally, to the direct and opportunity cost calculations, the institutional conditions for the implementation of the developed management alternatives; administrative structures, legal, political and socio-cultural conditions are of great importance. Institutional analysis facilitates the development of feasible and consensual management plans. Proposals for cooperation structures and financing instruments (including fresh and wastewater pricing options) take the availability of public budgets and the social acceptance into account, which is closely connected with the share of household income that could be affected by alternative water management options.

The planned results are as below

- Detailed socio-economic assessment of the alternative management options as an input for the decision support system
- Methodology for an applied socio-economic assessment that is transferable to other planning regions and water management problems
- Catalogue of potential measures for IWRM, characterized according to the following major topics:
    - General function of the measures
    - Advantages and disadvantages
    - Boundary conditions for usage
    - Cost for realizing and maintaining the measure
    - Social effects of the measure.

2.3 Decision support system for IWRM

The overall objective of the project is to establish an integrated water resources management plan for the river basin management which adequately incorporates water management and socio-economic objectives, constraints and consequences. In general, the alternatives for sustainable water management are manifold and possible solutions are most likely a combination of technical strategies (water saving, water recycling, groundwater increase, waste water treatment, water supply) and institutional policies (Water Rights, river basin commissions with participatory approaches, water councils, etc.). It is impossible to analyze the effects of all alternatives in the measures catalogue in detail and, as shown above, the study and implementation of isolated, non integrated measures also proved to be insufficiently effective. This holistic approach can be achieved by analysing the multitude of technical and institutional measures and their combinations in a very general decision support system, aimed at determining the most effective measures and combinations for the study area in question (Stage 1). This preliminary selection of measures can then be analysed in detail using hydrologic, hydraulic, groundwater and socio-economic modelling. The modelling results can then be analysed in a more specific DSS (Stage 2), aimed at fine tuning the interactions between different technical measures and between technical and institutional measures in order to define the most effective integrated water management solution.

In Stage 1, to analyse the effectiveness and interactions of all items of the measures catalogue, the predicted effectiveness and impact of all measures have to be estimated according to every relevant criterion. For instance, for a very specific irrigation technique criteria like construction and operation costs, durability, potential water saving ability, required space, potential risks, employment opportunities, necessary training, effects on water quality and groundwater enrichment, etc. will be estimated by a team of German and Chinese experts. This results in a fuzzy estimate of performance of this measure for each criterion.

Using algorithms based on the *Fuzzy - Analytic Hierarchy Process (F-AHP)* and *Dynamic Programming*, a finite amount of optimal combinations of measures will be generated based on the aforementioned fuzzy expert opinions. F-AHP (Vahidnia, 2008) uses matrices and linear algebra for the formalization of a decision process. It allows structuring of the complex decision problem of an IWRM in a hierarchical order, thus exhibiting the relationship between the decision alternatives, objectives and evaluation criteria. F-AHP facilitates analysis by transforming a complex evaluation into a hierarchy of smaller more manageable sub-evaluations (Kaden, 2009). A complex dataset is thus decomposed into smaller constituent elements between which pair-wise comparison is elicited, enabling well-founded expert-assessments of performance for each measure according to each criterion. Not all measures are equally efficient for all criteria, F-AHP is a compensatory decision methodology as alternatives that are deficient with respect to certain criteria can compensate by their performance with respect to other criteria (MERZ ET BUCK, 1999). Additionally, some measures might show an overlapping for some criteria. Dynamic Programming is a method of solving problems that exhibit these properties of overlapping sub-problems by means of recursion.

Stage 2 comprises a more detailed analysis of the selected scenarios. This stage combines modelling of the relevant processes, impacts and measures under study as well as their socio-economic evaluation. With the help of technical, economic and social criteria and in close interaction with the regional stakeholders the final strategy can be selected. In this Phase an additional multi-criteria optimization module will be developed, which uses the results of Stage 1 of decision support as well as the information provided by the GIS-based simulation system. For this purpose a multi-criteria visualization based decision and negotiation support technique, named the

Reasonable Goal Method / Interactive Decision Map (RGM/IDM) technique, will be applied. This tool provides excellent options to explore new ways to balance competing interests. The trade-off between different criteria is based on a dialogue defining a "reasonable goal", a target, located at a convex hull of the criterion points. The user explores Pareto frontiers which helps him to understand tradeoffs between criteria. After a selection of the preferential goal the method identifies different alternatives which are close to this goal. This selection of alternatives offers new ways to differentiate among planning results at an early stage under consideration of the uncertainties of planning. Efficient measures can be estimated without an explicit formulation of preferences of decision makers or stakeholders in an interactive and collaborative decision process within a dynamic decision environment. The RGM/IDM technique belongs to the group of multi-attribute decision making (MADM) methods, in which the scenarios can also have a spatial reference.

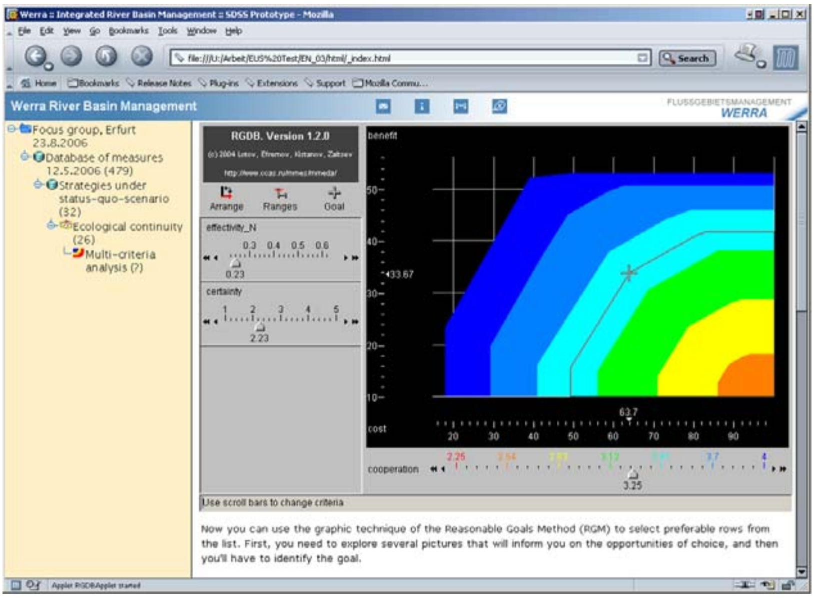

Figure 4 Example of the RGM/IDM technique used in an IWRM-project (Dietrich, 2004)

In a GIS-based system the data base for the modeling and the integrated water resource management is stored. The basis is a system developed in Germany for the implementation of the EU-water framework directive called WISYS. It offers a detailed object model, evaluation and process tools for water management related subjects. WISYS is based on ESRI's ArcGIS and covers both rural and urban topics. The evaluation and presentation tools WISYS offers can be used within the project. It is also intended (and already partly realized) that the software will be adapted to Chinese needs (i.e. water quality standards and language). Within the project, the object model will be adapted in order to be able to calculate the indicator values used by the MADM module efficiently for the scenarios to be evaluated. Further adaptations will be necessary in order to store and extract the information calculated by the simulation systems (ground and surface water levels and salinity values for example). It is also intended to extend the data model to provide the changes within the simulation models which have to be made according the scenario which has to be evaluated. Additional tools will then be needed to automatically adapt the simulation model parameters according to the selected scenario.

The models used describe most of the hydrological circle, including interception, infiltration, evapotranspiration, overland flow, unsaturated flow, groundwater recharge, groundwater flow and surface water flow. Each of the components offers also the possibility to describe mass transport processes. The groundwater component even takes into account the effects of density dependent flow processes. Especially for this project this is very important. The basic concept of the simulation part of Stage 2 of the DSS includes two different model approaches; a relatively coarse and a detailed model. The coarse model is used to verify the general feasibility of the water usage proposed in the selected scenario. For this, the groundwater flow processes are of secondary importance. This model consists of the simulation packages MIKESHE (for example in Sahoo, 2006) and WBalMo (for example in Kaltofen, 2008). MIKESHE dynamically couples all major hydrologic flow processes, including 2-D overland flow, 1-D channel flow, 3-D saturated zone flow, 1-D (Richard's based) unsaturated zone flow, snowmelt and evapotranspiration. The latter can be calculated by using the Kristensen and Jensen method (1975), by which the actual evapotranspiration and the actual soil moisture status in the root zone is calculated from the potential evaporation rate, along with maximum root depth and leaf area index for the plants. Overland flow is calculated by a diffusion wave approximation using a finite difference scheme. MIKESHE is also capable of simulating integrated advective-dispersive transport, sorption, biodegradation, geochemistry, and macropore flow and is generally applicable for most hydrologic, water resources and contaminant transport applications. In contrast to similar codes, MIKESHE utilizes rigorous physical flow equations for all major flow processes, but also permits more simplified descriptions (NIVA, 2007). The 3D finite difference groundwater component can be exchanged by a simplified cascade model for example. This option will be used for the coarse model.

WBalMo (Water Balance Model) is an interactive simulation system for river basin management. WaBalMo has been used to identify management guidelines for river basins, design reservoir systems and their operating policies, and perform environmental-impact studies for development projects. Using an ArcView (ESRI) user interface, a representation of the river basin is derived from an existing digital stream network. The natural processes of runoff and precipitation can be stochastically (Monte –Carlo) simulated and the respective time series are balanced with monthly water use requirements and reservoir storage changes. By recording of relevant system characteristics during the simulation, probability estimates can be provided for water deficits, maintaining minimum runoff or reservoir levels. Simulations can be performed both for stationary and transient (e.g. climate changes) conditions (Loucks, 2007). If the resulting deficits of a coupled WbalMo and MIKESHE simulation are within the limits set by the user, the suggested water usage from the evaluated scenario can be accepted and some of results can be automatically transferred to the detailed model (groundwater recharge, extraction rates, direct rainfall runoff in the streams by overland flow).

The detailed model also consists of two software packages; FEFLOW (Diersch & Kolditz, 2002, Zheng, 2007) and MIKE11 (Szylkarski, 2002). The groundwater model FEFLOW is one of the most sophisticated groundwater modeling packages available. The program provides an advanced 2D and 3D graphically based modeling environment for performing complex groundwater flow, contaminant transport, and heat transport modeling. Both saturated and unsaturated flow regimes can be modeled, in either case steady or transient. New features even include the representation of multi-species reactive transport modeling. FEFLOW uses a Galerkin-based finite element numerical analysis approach with a selection of different numerical solvers and tools for controlling and optimizing the solution process. Both confined and unconfined problems can be simulated. Most important though for this project is the possibility to take into account density dependent flow processes.

MIKE11 is a powerful numerical surface water model developed by Danish Hydraulic Institute (DHI) to simulate 1D flow problems. The software offers to simulate unsteady flow in river networks as well as looped networks using an implicit finite difference scheme. Both sub- and supercritical flow conditions can be calculated by solving the full Saint-Venant (1871) equations. These equations are especially accurate for simulations in flat areas like the downstream part of the Huangshui River Basin. MIKE11 offers the possibility to represent several types of structures in the model, of which some can be automatically operated according the results of the running simulation. Furthermore, MIKE11 is able to simulate mass transport processes as well as sedimentation and erosion processes. MIKE11 and FEFLOW can be coupled using the module IfmMIKE11 (Monninkhoff, 2007). The module will be extended for this project in order to be able to take into account also mass exchange processes between the ground- and surface water bodies. This detailed model will give detailed information about the impact of the proposed measures on the groundwater levels, the salinity of the rivers and the groundwater, as well as the effectiveness of the artificial recharge along the rivers. Furthermore, the locations of the extraction wells can be optimized to minimize the salt water intrusion. Here, a second module is intended to be used. This module uses grid technology to speed up model design as well as operational tasks like model-based optimization (Arndt, 2008).

The results of the detailed model will be compared with the results of the coarse model; in particular the exchange rates between the surface and groundwater bodies. In case of large differences, the coarse model has to be adapted to verify the availability of the proposed extractions. The results of both models will be stored in the database, in order to compare different scenario packages using the DSS module mentioned above.

In Figure 5 the basic concept of GIS-based and model-supported DSS System, Stage 2 is displayed.

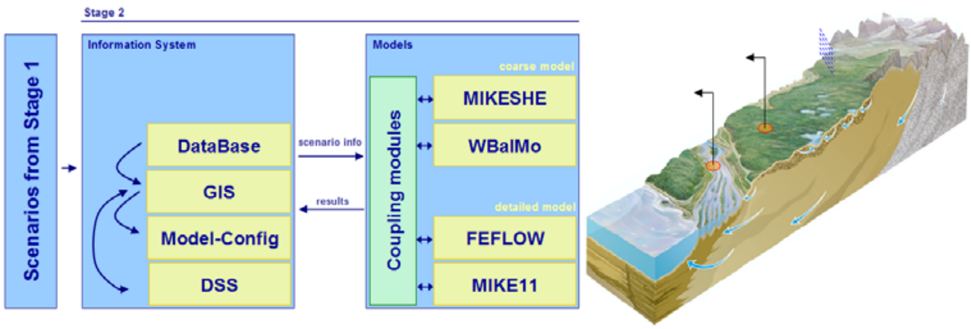

Figure 5 Concept of the proposed GIS-based and model supported DSS system (from Winter, 1998)

Planned results:

● Implementation of the developed tools and methods for sustainable water resources management for the Huangshui River Basin as an example for the Shandong Province

● Generalization of the results in the Huangshui River Basin in form of comprehensive scenarios to applied on the regional (province) level

● generalized methods and information and decision support system for application under different natural and socio-economic conditions

2.4 Concept for water saving and pilot facilities

The simulation models integrated in the DSS system will mainly support to quantify the water availability distribution and the possibilities to improve or stabilize the quality of the water resources. Another important aspect of the project will be to suggest enhanced solutions to reduce the water demand in the region. For this the possibilities of the application of the following German techniques will be verified and, if applicable, tested in practice:

● Water saving measures in private households and industry

● Rainwater using for private and agricultural purposes

● Water reuse in private households

● Water circulation in industry

● Recycling of domestic and industrial wastewater for use in agricultural irrigation

● These measures are applied within an integrated concept which is shown in Figure 6. The development of this concept and the realization of fitting measures is the aim of this project.

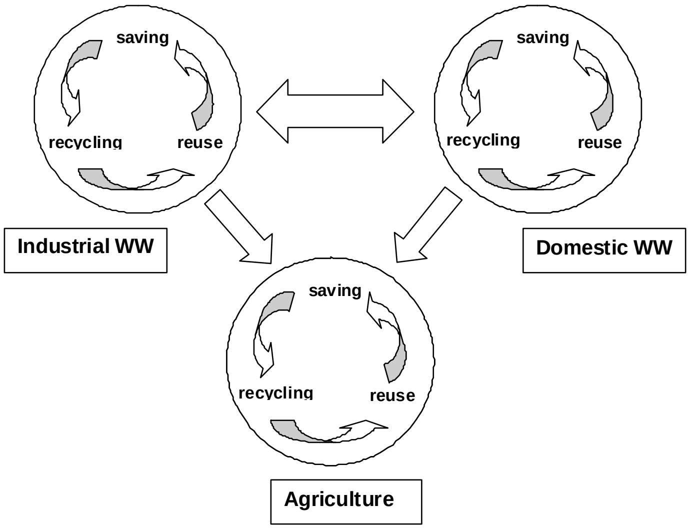

Figure 6 Integrated water saving and wastewater reuse concept

2.5 Monitoring concept

In the pilot region Huangshui River Basin a monitoring system satisfying the needs for integrated management is missing. Although in some amount monitoring of groundwater is being done (including water quality monitoring and monitoring of salt water intrusion), the density of the network of gauges is too low to be able to set up a regional ground- and surface water modelling and DSS system. Furthermore, compared to the groundwater monitoring network, surface water quantity and quality observations are rare both in space and time. The objective of this sub-project is to develop a monitoring concept for the pilot region fitting to the requirements of IWRM including soft- and hardware.

A thorough survey and evaluation on the existing installations and standards concerning various monitoring purposes will be performed. Based on that, the monitoring concept will be developed in a step-wise approach. In the first stage of the project, the concept will concentrate on the fast improvement of the existing system in order to support the data collection for the implementation of the presented IWRM approach. In the second stage the monitoring concept will be refined based on the tools and results of the project. The groundwater model will be used to optimize the monitoring system for salt water intrusion abatement. Groundwater monitoring equipment produced in Germany will be tested for use under the given local conditions.

This monitoring system will be designed above all for:

- Monitoring and evaluating the influence of salt water intrusion abatement measures
- Analyzing the characters of groundwater quantity and quality and its variations
- Investigating water quality variation of infiltrated water during the infiltration process in the soils
- Investigating the elimination efficiency of pollutants in the reclaimed water

Planned results:
- Monitoring concept for the pilot region according to the requirements of IWRM
- Test reports for monitoring equipment
- Prototypes of automatic monitoring techniques for observation of saltwater intrusion.
- Information system for storing and processing the monitoring data

2.6 Potential for application/duplication for environmental and WRM improvement in China

As the overview above indicates it is the intention of the project to generalize the methods, tools etc. developed within the project in order to apply those for other regions as well. According to the characteristics of the project area along the coastal zone, this generalization takes special consideration to similar coastal areas.

Acknowledgements

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Water Scarcity and Water Pollution in Agriculture in the North China Plain: Strategies to Ensure Agricultural Sustainability
中国华北平原农业水污染和水紧缺：农业可持续发展策略

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Abstract

Water pollution and water scarcity are major threats for the sustainability of agriculture in Northern China. The current demand for water in China's Northern agricultural regions surpasses the supply significantly. Furthermore, agricultural practices as improper use of fertilizer, irrigation management and pesticide application pollute the diminishing water resources. The North China Plain (NCP) is dominated by grain production and represents one of China's most important agricultural regions. The study at hand surveys the options to reduce pressure from agriculture on the water systems in the NCP. Based on one quantitative and one qualitative survey in the Hebei province and on the review of secondary data, strategies and research recommendations to reduce water pollution and scarcity in the NCP are worked out. Missing awareness of farmers towards agricultural sources of water pollution is found. Also, the farmers in the NCP rely on a scientifically insufficient information basis to decide about the applied amounts of water in crop production. The regional water use methods do not incorporate external effects sufficiently. So an institutional system has to be developed that allows firstly for closely monitoring the amount and quality of water applied in the agricultural sector and secondly includes negative externalities of water over-use and pollution to create sustainable water-use and irrigation techniques in the NCP.

摘要

水污染和水短缺是制约华北地区农业可持续发展的两个重要因素。当前农业中水资源需求量已远远超过了供给量，加上农业生产中化肥、农药的不合理使用以及不科学的灌溉技术又污染了日益锐减的水资源。华北平原盛产谷物，是中国最主要的农业生产区之一。因此本研究将探讨减少华北平原地区水资源压力可选择的解决办法。本文通过在河北省调研数据的定性和定量分析，以及相关二手资料的查阅，提出了减少水污染和水短缺的策略和建议。研究发现当地农民

缺少对水污染和作物生产中科学用水量知识的了解，用水方式也没有把外部影响充分考虑在内。因此应建立一种新的用水制度体系，不仅能精确检测农业生产中用水数量和质量，而且还要把过度用水和水污染的外部负面影响也计算在内，从而在华北平原开创可持续的用水和灌溉技术。

1 Introduction

The drought during the winter of 2008/2009 in Northern China revealed how vulnerable agriculture in China still is nowadays to climatic and environmental events. The severity size of the recent drought is represented by the fact that after the first rains and snows still 4.7m ha remained affected (AGRA-EUROPE, 2009). Therefore it is important to develop and promote improved agricultural production systems which can contribute to a minimization of men made negative effects on natural resources; especially water.

Even though national policy focused on agriculture as its economic basis and the transformation from traditional indigenous agriculture to modern farming practices began with the foundation of the Peoples Republic of China in 1949. The Chinese agricultural production levels were low and characterised by a production deficit which culminated in the famine during “The Great Leap Forward” in the end of the 1950s. However, in the past 50 years, the use of agricultural inputs increased dramatically. The overall aim was to ensure food security and self-sufficiency for China. Furthermore areas of arable land were expanded and irrigation facilities were installed on a large scale. These advances made China’s agriculture grow more rapidly than that of the USA or the world as a whole between 1949 and 1999 (SHI and CHENG, 2004). In the past 25 years average staple crop productivity in China has doubled – which outnumbered the 25% growth of the population during the same period (BINDER *et al.*, 2007). Recently China’s agriculture is characterised by scarce land, abundant labour and small scale-production using little mechanisation, but China feeds 21% of the Earth’s total population with only 10% of the world’s arable land and only one quarter of the average world water resources per capita (OECD, 2005). However, such high production intensity indicates that the sharp rise in agricultural and food production might have environmental degradation as a downside. This paper aims at presenting and analysing two major aspects of the environmental problems: water scarcity and water pollution that stem from and affect the rural farming systems of the North China Plain (NCP).

The NCP covers seven provinces in the Northern China. It is one of the most important agricultural areas in China and it allows growing of temperate climate crops (BINDER *et al.*, 2007). Improved irrigation technologies, since the late 1960s, allowed farmers to operate double cropping systems; nowadays the NCP is dominated by a winter wheat – summer maize crop rotation system. The grain production in the NCP was intensified and today it is regarded as “China’s granary” (PIOTROWSKI and JIA, 2006). As can be seen in Table 1, the provinces of the NCP supply impressive 73.98% of total Chinese wheat and 35.27% of total Chinese maize. Other major crops grown in the NCP, though produced on a considerably smaller scale, also have high shares of the overall Chinese production and underline the importance of the NCP as an agricultural area.

Table 1 Sown Area and production of major crops in the North China Plain, 2006

	Sown Area (1000 ha)	**Wheat** (10 000 tons)	**Maize** (10 000 tons)	**Peanuts** (10000 tons)	**Cotton** (10000 tons)
PR China	157 020.6	10 446.4	14 548.5	1 466.6	674.6
NCP provinces	60 288.2	7 728.6	5 130.7	1 014.2	338.2
Share to whole PR China	**38.4%**	**73.98%**	**35.27%**	**69.15%**	**50.13%**

Source: China Agriculture Press, 2007

The first part of this work introduces the two main problems related to water, and thus to sustainability, in the farming sector of the NCP: water pollution and water scarcity. In this work sustainability is referring to the 3 basic dimensions of sustainable agriculture (ZHEN *et al.*, 2005). The 3 dimensions are: ecological soundness (i.e. preservation and improvement on the natural environment), economic viability (i.e. maintenance of yields and productivity) and social acceptability (i.e. self-reliance, equality and improved quality of life). Based on the review of related literature, it is assessed how the current farming practices contribute to water pollution and scarcity. The literature findings are compared to own collected data. This part focuses on the perception of environmental problems of farmers in the Hebei province and quantitative findings from Quzhou County. In the following part, strategies to improve water management in the NCP are discussed. Finally, the paper concludes by presenting strategic policy recommendations and suggestions for further research to ensure sustainability of farming in the NCP with regard to water.

Own data were collected in two separated surveys. One survey was conducted in July 2008 in the Hebei province. The structured interviews of this survey focused on quantitative data related to agricultural and non-agricultural operations of farm-households. Another survey was conducted in June and July 2008 – also in Hebei. The aim of the qualitative interviews in this survey was to gain insights into the linkages between local farming practices and environmental awareness of farmers.

2 The Importance of Water for Agricultural Production in the NCP

Water is essential for agricultural production. Particularly the highly intensive production in the NCP depends strongly on the use of water. Therefore any reduction of water supply or quality might threaten the sustainability of agriculture in the NCP. This, as the NCP is one of China's most important agricultural producers, poses a risk to food security in China.

This part aims at describing the problems related to water in the farming systems of the NCP. It is divided into sub-chapters dealing with water scarcity and water pollution.

2.1 Water scarcity

In order to ensure food production, irrigation facilities in the agricultural areas in China have been extended in the past decades. Nowadays, the irrigation system in the NCP covers 71% of the arable land and consumes more than 70% of the total water supply (Baring, 2008). This illustrates the importance and impact of agriculture in the NCP. However the situation is problematic as the basins of the NCP "have less than half of the water per capita in relation to Egypt or Java, which are recognized as water-scarce regions" (Varis and Vakkil Ainen, 2001).

For the Chinese agricultural production, it is challenging that 81% of the water resources are in the country's Southern parts, whereas 64% of the arable land lie in the Northern parts. The present situation in the NCP is dramatic: it holds a considerable share of China's arable land - with a high need of water, but only 6% of China's surface water (VARIS and VAKKILAINEN, 2001). In 2003, the available amount of water per person in the NCP was often less than 1000 cubic meters – which was the lowest in China (World Bank, 2007). Therefore irrigated arable land in the NCP relies on groundwater, which causes groundwater levels to drop up to 1m annually and even led to land subsiding (Binder *et al.*, 2007). Henry (2004) estimated that water tables in the NCP are declining between 0.125m and even up to 3m per year. The situation in the Hebei province is dramatic as 78% of the water used for irrigation stems from groundwater resources (Zhang *et al.,* 2008). Also for other provinces in the NCP the contribution of agricultural irrigation to the depletion of groundwater is high: around or above 50% (World Bank, 2007).

The need to utilize groundwater resources for irrigation is even further accelerated by other factors: competition for water with urban and industrial users, increased demand for food, continuous decline of precipitation, overexploitation of surface water resources and the drying up of rivers. Considering that the estimated increase of annual groundwater use for irrigation is already 6.42% - the future situation is tense as the gap between water supply and demand will widen (Zhen and Routray, 2002). Already nowadays' high water consumption levels led to water shortages in many places of the NCP. The depletion of groundwater tables is most severe in the Hebei province. Deep-aquifers depleted by more than 50 meters between 1970 and 2005 (World Bank, 2007). It was shown that between 2000 and 2003 74.5% of the depletion in groundwater tables in the Hebei province (in total 6109 million cubic meters) can be associated with irrigation (World Bank, 2007). Therefore agriculture and especially intensified irrigation represent a major reason for declining groundwater levels, which is a dilemma as the farmers in the NCP endanger their own future existence. Furthermore, the exploitation of groundwater resources in the NCP leads to an increase in irrigation costs, an increase in soil salinity, compacted/hardened soil, an intrusion of salt-water, an increase in land subsistence and the creation of water logging – therefore it threatens the sustainability of farming and, thus, China's food security.

Even though water is a scarce resource in the NCP, farmers are not using it efficiently. Zhen and Routray (2002) calculated the water use efficiency for the NCP at only 0.7 kg farm produce per m^3 water; the average in developed countries lies at 2.0 kg/m^3.

For the dominant winter wheat – summer maize crop rotation irrigation is essential, because summer maize consumes about 70% of the total rainfall during its growth period in the rainy summer season – leaving insufficient soil moisture for producing subsequent winter wheat. Therefore irrigation is required for winter wheat during the dry winter months, which puts stress on the groundwater resources in the NCP (Binder *et al.*, 2007).

One challenge of the Chinese water sector is the institutional set-up. Henry (2004) criticizes the complex Chinese institutional framework and calls for government action and policy changes. Also Varis and Vakkil Ainen (2001) stated that the Chinese institutional set-up lacks unified water administration and management and that it is "overly complex and prone to rivalries and inefficiencies". Moreover, Kolbe and Zhang (2000) call for the introduction of state regulations and legislations to control ground and surface water through specific farming and fertilisation standards and restrictions for water areas.

2.2 Water pollution

Ground and surface water pollution from agriculture is a major problem in the NCP. Problems with water pollution affect people's living and health via the intake or contact with polluted water (Li *et al.*, 2001). Water quality in the river systems in North China worsened between 2001 and 2005 (World Bank, 2007).

A significant positive relationship between the amount of N fertilisation and the N content in groundwater exists in the NCP. Hence a study on water quality showed that 16 out of 20 wells contained N levels exceeding the maximum allowable limit for nitrate in drinking water (Zhen *et al.*, 2005). Another study in the NCP revealed that about 45% of over 600 groundwater samples exceeded WHO and European limits for nitrate in drinking water (Zhang *et al.,* 2004). In addition, high amounts of applied pesticides also led to contaminations of groundwater resources. This poses a threat to human health.

In some rural areas in Northern China varieties of cancer, which are suspected of being related to high concentration of nitrites or nitrate in groundwater (Morales-Suarez-Varela *et al.*, 1995) or related to the concentration of other chemical pollutants in the groundwater, occur more often in the NCP than in other regions in China (Lu *et al.*, 1986 and Zhang *et al.*, 2000); and the rate of occurrence is also higher than the world average (World Bank, 2007).

Agriculture activities as a major source of non-point pollution contribute a large share to the recent increase in surface and groundwater pollution. Residues of chemical fertilizer are considered as a main agricultural source of water pollution. Between 1995 and 2005 the amount of chemical fertilizer used in the Hebei province rose by more than 37% (NBS, 1996 and 2006). In the regions with intensified agriculture of the NCP the highest concentrations of ammonia in China are reported (WORLD BANK, 2007).

Chemical fertilizers are often not used effectively in China. In the NCP nitrogen fertilizer is applied in too high doses, too early or with an unbalanced ratio of N to P and K. Liew (2004) highlights that an imbalance in nutrient management in China contributes to pollution of water sources such as lakes and rivers.

Around 70% of the annual precipitation in the NCP is concentrated between July and September. These heavy rainfalls or, in other time periods, the flood irrigation – which is typical for the NCP – cause nitrate to move into deeper soil layers. This nitrate is either causing pollution by leaching into the groundwater or it is lost in the deeper layers of the soil where the N cannot be utilized by crops (Ju *et al.*, 2004). The nitrate movement in the soil is influenced by N application rates and fertilisation method. Further, the climatic conditions in the NCP accelerate the negative environmental impacts of the current farming practices.

Currently, to fight water shortages, farmers in some areas of the NCP are using municipal waste water for irrigation (Kendy *et al.*, 2003). The N concentration in municipal waste water is rising due to China's economic growth: changing Chinese diets increase the amount of N in human waste and the advancement of flush toilets and sewerage systems increases the amount of municipal waste water which is discharged untreated into rivers and lakes. The expansion of animal production and consequently the increased amount of animal waste, further adds to the N load in China's waters, causing health and environmental problems such as proliferation of blue-green algae. (Liu *et al.*, 2008). Nevertheless municipal waste water is nutrient-rich thus can further increase over-fertilisation when used for irrigation, but might pose sanitary and hygienic threats.

3 Strategies to Improve Water Availability and Quality in the NCP

This part aims at discussing strategies to improve water availability and water quality in the NCP. China has to feed its growing population based on a small and even declining area of fertile land. Beside this the availability of water over space and time raises some distributional problems. Recent programs like the construction of channels from the

South to the North are aimed to satisfy the needs of water of populous towns and the main agricultural areas in the North (Zhu, 2006). However, besides these large projects initiated by the Chinese central government which are aimed at the supply of water, the situation might also be improved through leverage effects of regional and local strategies, as well as farm management measures. Therefore this part focuses on the local, regional and on-farm aspects of this problem.

Barning (2008) and Ju *et al.* (2004) revealed that the level of education of farmers is low and knowledge transfer systems are deficient – leading many farmers to unconsidered use of environmental resources or pollution. Basic education and agricultural knowledge are essential to understand and consider fundamental agronomic or economic criteria. Optimised or modified management strategies can potentially reduce the environmental burden of farming in the NCP (Ju *et al.*, 2006). Hereby extension services can play a vital role by supporting the knowledge transfer to the farmers. Therefore Mack *et al.* (2005) promote that simple and effective support decision methods should be developed and taught to farmers in order to increase environmental awareness. Promoting environmental awareness among farmers, such as via television programmes, can be essential to prevent negative environmental effects (Kolbe and Zhang, 2000).

Zilkens (2004) analysed several optimised irrigation and fertilisation strategies for the NCP. Optimisation strategies of either irrigation or fertilisation can be related to negative side effects (i.e. ersosion, water balance or slight yield losses). However the positive environmental effects outweigh these side effects when both factors are optimised simultaneously. Nevertheless it should be considered that optimisation strategies might also reduce the productivity or increase the operating expenses. Another strategy is to increase the organic matter content in the soil by cropping systems which include legumes and changed rotation patterns (Zhen *et al.*, 2005). These options can only be useful if the production costs are not rising and the yields are not declining.

According to Gale (2005) low marginal prices of water in China lead to overuse. Therefore Zhen and Routray (2002) strongly recommend water pricing policies. Increased water prices, however, represent a financial burden to the already needy farmers. Several approaches to value water are presented in World Bank (2007); and for the NCP the value of one cubic meter of water is estimated to be up to 5.2¥ (using the method of marginal value). Zhang *et al*. (2008) point out that the price of pumped water in most cases reflects a market price based on the costs for the electricity for the pump. To some extent it also reflects water scarcity – since markets for groundwater develop faster when the groundwater tables decline. However, it is uncertain how far the negative (generation-spanning) externalities of declining water tables and quality are covered by these prices. In addition, due to the privately run decentralized pumping facilities; there hardly exist any controls about the amounts of pumped groundwater (World Bank, 2007). Therefore the implementation and enforcement of water pricing policies seem to be difficult in the institutional setting of the NCP. Higher water prices including negative externalities could lead to declining winter wheat production as it demands more irrigation than maize, due to watering in winter. Such a production drop endangers food security of China. Higher water prices would therefore need to be covered through either higher consumer prices or transfer schemes from the society, such as by environmental taxing. The annual income of rural households in the Hebei province in 2006 was around 65% less than the annual income of urban households in the Hebei province (NBS, 2006). Therefore water pricing policies might pose a threat for the economic sustainability of the farming households in the Hebei province and the NCP in general. Nevertheless water pricing represents a method which reflects the real costs of water. Nowadays in the NCP water is mostly regarded a common good which can be used without directly paying for it. Farmers in the NCP are often supplied by private pumping facilities instead of public pipelines – which limit control mechanisms (Zhang *et al.*, 2008). There are many ways to regulate the water use to a sustainable level by adjusting the prices of electricity or fuel for running pumps or by introducing prices for the use of water, also specific fees or taxes to cover the economic and environmental costs of water consumption and pollution could be introduced. Though, as mentioned before, in the setting of the NCP water pricing might threaten the economic sustainability of the farm households. Consequently it is firstly necessary to better monitor and regulate the private water pumping facilities in order to survey the real amounts of water pumped and to calculate the amount of water used.

Kendy *et al.* (2003) argued that water saving methods in the NCP which reduce pumping of groundwater do not save water as long as the cropped area remains constant, because decreased pumping causes a corresponding reduction of groundwater recharge from excess irrigation, while precipitation and crop evapotranspiration remain unchanged. Therefore the only way to save water in the NCP is to reduce the only significant outflow of the hydrologic system: evapotranspiration. This can be achieved by a reduction of the cropped area, which is unlikely because the agricultural outputs from the NCP are needed to sustain China's food supply – especially in face of rising food demand.

As described above, in the predominant crop rotation in the NCP, winter wheat requires the biggest share of irrigation. Since wheat is one of China's most important staple foods, it is no option to reduce its cultivation. Therefore Binder *et al.* (2007) suggest several agronomic practices to reduce the water amount used by the agricultural sector in the NCP: changes of irrigation schedules to reduce total amount of water use by applying knowledge about water stress, changes of the cropping systems, using drip irrigation instead of the predominant flood irrigation, mulching to prevent soil evaporation and breeding for improved transpiration efficiency. Some of these suggestions are, however, in contrast to the argumentation of Kendy *et al.* (2003), yet they agree on the fact that demand management has a higher potential to alleviate regional water shortages than supply management such as diverting water from the Yangtze River. Also Varis and Vakkilainen (2001) emphasise the need to increase water use efficiency and the abetment of environmental degradation in the NCP, instead of supply management.

4 The Situation in the Hebei Province – Recent Findings

In summer 2008 data were collected in 2 separate surveys. In July 2008, data were collected from 64 randomly-sampled farm-households in 4 randomly-sampled villages in Quzhou County, Hebei province (Survey 1). The structured interviews focused on quantitative data about the operations of farm-households, but also included qualitative questions regarding the perception of environmental quality and its changes in the villages. Another survey was conducted between June and July 2008 in 5 villages in Hebei (Survey 2). The survey was conducted to gain insights into the linkages between local farming practices and environmental awareness of farmers and to identify how farmers value the quality of the soil and local water resources. Farmers, village heads, extension workers and fertilizer sellers have been purposively selected for the qualitative interviews, to allow for a wide spectrum of possible answers. This part presents the findings with regard to water from both surveys, but focuses on the perception of the farmers.

In each of the four villages of Survey 1, sixteen farm households were selected randomly. Then these households were interviewed based on a detailed and structured questionnaire. Unstructured qualitative interviews with village heads and government officials were used to gain background information.

First selected characteristics of the households of Survey 1 are presented in order to introduce the setting as well as factors related to the questions at hand. Then the findings with regard to water and the perception of the farmers are presented.

Survey 1 showed that farmland in the research area is fragmented. Land fragmentation can have beneficial effects on risk management and seasonal labour supply, but it also increases production costs and reduces agricultural efficiency (Tan *et al.*, 2008). Due to the time and efforts needed to reach each field, one can assume that farmers who are having fragmented plots would irrigate less often, but with higher quantities. Therefore the relations between land fragmentation and irrigation in the setting of the NCP are not yet known sufficiently.

As described above, the prevailing winter wheat – summer maize crop rotation requires irrigation in the dry winter months. Yet, only around 30% of the annual rainfall happens between October and June (Binder *et al.*, 2007). According to Survey 1, however, 91.7% of the total irrigation processes happen between October and June. This indicates a remarkable pressure on the water resources and suggests the necessity to create improved farm management strategies.

As described previously, knowledge transfer systems and extension services are deficient. The findings from Survey 1 are in accordance with other studies in the NCP, as 98.4% of the households did not have contact with the extension services in the last 36 months and 85.9% did not receive any agricultural training. This lack of knowledge makes the introduction of agro-environmental policies difficult, as it might be challenging to describe relations between farming practices and water quality and availability to the lowly educated farmers in the NCP. However, if these difficulties can be overcome, knowledge transfer programmes might offer a potential for improvement.

Survey 1 also showed that 76.6% of the households have off-farm income, which generates 44.5% of the total farm households' income. This underlines the significance of agriculture as an income source, but also reveals – in accordance with other studies – the increasing importance of off-farm income. Off-farm income offers alternative income sources, so the farmers' dependence on the land might decrease and with it the need for long-term sustainable strategies. In the future, for many farmers, land might only be needed for food self-sufficiency or in order to diversify economic risks – which would make knowledge transfer and the introduction of sustainable practices difficult.

In Survey 1, none of the interviewed farmers had to pay directly for the use of water. However, all farmers had to pay indirectly through the costs of the electricity or fuel necessary to run the water pumps. These findings are in accordance with other studies in the NCP. However, these results clearly reveal that the interviewed farmers are already indirectly paying for the use of water according to the consumed amount. As pointed out in other studies these indirect costs might be too low. But since the farmers are somehow paying for the consumed quantities of water, the effectiveness of an introduction of water pricing mechanisms might be questionable, as the cost for irrigation are already increasing the more water they are using – so a change in water pricing might only represent a increase in costs.

Table 2 displays the answers of the farmers in survey 1 to the question "According to what do you decide about the amount of irrigation?"

Table 2 Irrigation decision of farmers

	"Own experience"	"Quality of the soil"	"Quality of the seed"	Other answers
Possible Answers	77.3%	15.2%	7.6%	0.0%

Source: own data, Survey 1

77.3% of the farmers base their decision on their own experience. Considering the low level of education and the low degree of training received by the farmers, it is doubtful that this strategy leads to optimized irrigation methods. The remaining farmers stated that they irrigate according to the quality of the soil or according to the quality of the seed. Considering that the qualities of the soil and the seed are not determined by scientific methods, these answers also fall in the range of own experience with the same assumed result. Interestingly none of the interviewed farmers chose the possible answer "price of water". This, however, could indicate that there might be a chance for developing direct water pricing mechanisms, where the prices reflect the demand of the resource.

Contradictory to the findings of other studies and to the drought in the winter 2008-2009, 98.4% of the farmers in Survey 1 stated that the supply of water is constant all-year-round. Only one farmer stated that there are supply shortages in April to June. These answers might represent a local phenomena, a subjective impression of the farmers or an adaption strategy of the farmers who are used to and therefore prepared for less water in the winter period.

Table 3 shows the farmers' perception to changes in water availability in the past years.

Table 3 Farmers' perception towards changes in water availability

Changes in water availability?	"Yes"		"No"
	17.2%		82.8%
If change, decrease or increase of availability?	**Decrease of availability**	**Increase of availability**	
	72.7%	27.3%	

Source: Original data, Survey 1

Remarkably 82.8% of the farmers in Survey 1 stated that there have been no changes in water availability. From those farmers which observed a change, 72.7% stated that the water availability decreased in the past years. However, 27.3% of the farmers observed an increase in water availability in the past years. Since this is also contradictory to the findings in other studies, this might be a local phenomenon in Quzhou county or it might show that the subjective impression of the farmers might differ from the scientific results.

Table 4 Farmers' perception towards changes in water quality

Changes in water quality?	"Yes"		"No"
	4.7%		95.3%
If change, improvement or deterioration of quality?	**Improvement of quality**	**Deterioration of quality**	
	100.0%	0.0%	

Source: Original data, Survey 1

As Table 4 displays, 95.3% of the farmers in Survey 1 stated that there have been no changes in water quality. From those farmers that observed a change, unexpectedly all stated that the water quality improved. These answers are also contradictory to scientific findings from other studies. Without the possibility to analyze water scientifically it is difficult to assess the chemical quality of water, therefore the improvement in water quality – seen in Table 4 – relates more to less debris and garbage swimming in the surface waters. Nevertheless these answers indicate a lack of information and knowledge of the farmers in Survey 1.

In each of the 5 villages of Survey 2 the village head, who can be considered a key informant for each village, was asked to introduce one farm household which performs well in farming and can be considered as well-off and one farm household which performs bad in farming and cannot be considered well-off. This was done to widen the range of possible answers considering different social or economic statuses in the villages.

The head of village 1 stated that there has been pollution of a nearby river because some years ago all the vegetation in the river died. Farmer 1 of village 4 mentioned that there was pollution to the environment as long as there was a chemical factory near by the village, but since this factory is closed there were no more problems with pollution. Also the head of village 3 assumed that there could only be pollution if there was a chemical factory, as there were no such facilities nearby he saw no source of environmental pollution. He even clearly emphasized that farming activities, such as fertilization, have no impact on soil and water resources. Farmer 1 and 2 of village 2 and the head of village 2 also argued that there is no relation between farming practices and water pollution. Farmer 2 of village 2 stated that “surface water cannot be used anyways”. Furthermore, the same people who stated that there is no relation between farming practices and water pollution pointed out that in this village groundwater is used for irrigation since water from above 50m underground would harm the plants due to saline-alkali soil. So, some farmers are aware of the interplay between natural resources and agricultural production. Most clearly farmer 1 of village 4 links agricultural activities to environmental degradation since he claims that fertilizer pollutes surface and ground water if it leaches into it.

The range of answers in Survey 2 is wide and the perceptions of the farmers differ strongly. This indicates that knowledge transfer systems and extension services might be an important tool to enable farmers to assess the state of the environment and the direct and indirect effects of their farming practices.

5 Conclusion

As current practices in the NCP can hardly be regarded sustainable and thus threaten the environment, sustainability and future food security of China, new strategies have to be developed. In this final part recommendations for further research, as well as strategic policy recommendations shall be worked out.

The plots in the NCP are fragmented. Therefore the effects of land fragmentation on the environment and especially on water use and on water pollution under the specific conditions and of the NCP have to be researched.

A knowledge transfer programme can be an efficient tool to reduce environmental impacts of farming in the NCP. The benefits of such an instrument might even surpass the target of reducing environmental impacts, because improved education is the basis of advances of general rural development. The results from own data clearly showed that the level of education and training of the farmers in the NCP needs to be increased. Therefore specific recommendations and systems have to be developed to improve knowledge transfer and services to farmers in the NCP. Related to that it is important to follow participatory socio-economic approaches to reveal why farmers are using current practices and how improvement strategies can be propagated successfully.

The rising importance of off-farm income might have implications on the sustainability of the farming systems in the NCP. Therefore the effects of off-farm income have to be researched further with regard to the influence on the water scarcity and quality of the farming systems. Similarly, the work of Piotrowski and Jia (2006) on the relations between land-use rights and current environmental problems should be further surveyed, as longer and secure land-use rights might move farmers to more sustainable practices.

The effects of changed farm management measures in the NCP have to be widely researched. The fact that the major part of the irrigation happens in the dry winter months indicates that there is a need and potential for developing changed farm management practices. For example, the potentials for the use of slow-releasing fertilisers, inter-cropping with other field crops, integrated pest and fertiliser management or increased use of modern machinery, with regard to the impact of water management in the NCP should be estimated on farm level. The possibilities for research in this field are wide such as change of varieties, irrigation, crop rotation. Suitable farm management practices for the NCP have to be developed.These practices should take into account modern practices and innovations.

Many researchers state that the current institutional framework for water management is inadequate and that it represents one of the causes for the overexploitation of water resources. Therefore plans, based on scientific estimations for water supply and demand, are needed to clearly define and enforce water use rights. Decentralized and regionalised administrations might increase the effectiveness of future policies and the institutional framework has to be updated to nowadays' requirements.

On the regional level, the research about the impacts of agro-environmental policies on the farming system in the NCP should be extended. Scenarios like the polluter-pays-principle or a limited distribution of inputs should be tested. The point of view towards water pricing policies differs strongly between the researchers. This is why the effects and possible achievements of such a strategy have to be carefully surveyed – with regard to the income situation of the farmers.

Finally, the costs of the current practices have to be quantified. The current use of water represents a strain on a natural resource – which creates remarkable external costs. To estimate the costs of using a scarce natural resource and damaging the ecosystem in the NCP has therefore the potential to influence policy makers and farmers towards sustainable strategies. Also the economic sustainability under the impacts of rising water prices, but also rising grain prices as well as the impacts of bio-energy have to be estimated.

Many researchers agree that supply management might be a helpful tool, but increasing water use efficiency and changing local strategies represent the most effective strategy and only choice to ensure the sustainability of farming in the NCP.

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Water Resource Protection Under Changing Climate and Land Use Conditions
气候变化和土地利用条件下水资源的保护

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Abstract

Climate changes and anthropogenic influences on water and land use increasingly threaten the global and local water resources. Without discussing long term climate change issues we just observe an increase of extreme climate and weather situations such as extended and long lasting droughts as well as heavy/storm rainfalls within short times. Along with such climate situations we realize severe human induced influences on e.g. ground water recharge and quality. Even if such challenges may be of global nature they must, eventually, be dealt with in local i.e. microscalic to mesoscalic contexts.

An effective method of investigating such effects and deriving countermeasures in the appropriate contexts is based on scenarios. Well structured and parameterized scenarios may be evaluated by discourse or discussion. They would, in particular, provide input for simulation exercises using water resource models such as groundwater or surface water mass flow models, water ingredients flow models and water demand as well as water quality models. Such models would include geohydrological data, land use data, weather data and others from the past as far as available, from current data sources and from calculated or estimated forecasts.

The paper will start with a short discussion on climate, weather and anthropogenic threats to the water resources as observed in Europe and in China. It will then introduce the components of a model based water resource simulation system and its use for evaluating scenarios. The paper will, in a nutshell, discuss methods and experiences with extending such models from a well understood microscalic context into a mesoscalic context (e.g. of space) where reduced data coverage, granularity and accuracy asks for new approaches when parameterizing and validating such models.

The definition and evaluation of some scenarios developed for China will lead to a discussion about threats to water resources, about possible countermeasures and about the related consequences, in a local as well as in a global context. The paper will conclude with some ideas on future research for improving water resource protection.

摘要

气候变化和人类活动对水资源和土地利用的影响严重威胁着全球和当地的水资源。本文不涉及长期的气候变化问题，仅仅研究了如长期干旱以及短时期的大量降雨这样的气候和天气条下，人类

活动对地下水补给和水质的影响。即使这种挑战是全球性问题，但最终还需要在当地解决。

研究这种影响的有效方法和在适当背景下得出的解决对策都基于情景模拟。参数和结构恰当的情景可以通过阐述和讨论来论证。尤其是它们能够帮助模拟用水模型，例如地下水或地表水水流模型，水的成分循环模型，以及需水量和水质模型，这些模型包含了许多现有的或者是通过计算和推测得到的地质水文数据，土地利用数据，天气数据以及可利用的已有数据。

本文首先介绍了欧洲和中国气候、天气和人为活动对水资源的威胁，然后介绍了基于水资源的模拟系统及水资源使用的评估情景。简要的讨论了这种模型从微观方面扩展到宏观方面（如空间）的方法和经验，减少了数据的覆盖面，间隔和精度，为模型的数据化和有效性提供了新途径。

专为中国开发的一些情景的定义和评估将会在当地和全球范围内促进关于水资源遭受的威胁，可能的对策以及相关结果等方面的讨论。本文最后对今后增强水资源保护的研究提出了一些建议。

1 The Challenge

Climate changes and anthropogenic influences on water and land use increasingly threaten the global and local water resources. Without discussing long term climate change issues we just observe an increase of extreme climate and weather situations such as extended and long lasting droughts as well as heavy/storm rainfalls within very short times. At the recent World Water Forum in Turkey the Chinese Minister of Water Resources, Chen Lei, addressed the situation in China: “China shall take relevant flood control and drought relief measures that are tailored to the country's national conditions, as global climatic changes increase the possibility of frequent and sudden occurrence of extreme weather events, and fast development of the Chinese economy and society also gives rise to new problems, tasks and challenges in flood control and drought relief.”

In particular, the Chinese land and water resources are threatened not only by decreasing or at least irregular precipitation but, much more, by salination and pollution. More than 70% of the Chinese surface water resources exhibit quality level three or less and thus are hardly or no longer usable for drinking water production. Above this, much polluted water is hardly suitable for irrigation. Through this, many Chinese cities and regions rely increasingly on ground water with exploitation rates above recharge rates.

With the Chinese population still growing at ca. 0.8% p.a. and a gross growth rate of economy above 6% p.a. the combination of water availability and land use aspects demand high attention. The alternatives in land and water use for providing drinking water, for supplying irrigation water and industry water give raise to a complex set of scenarios for water and land use in particular when considering urban development, water treatment and reuse technologies and, not at least, the international markets for food and industrial goods. Even if such challenges may be of global or at least national nature they must, eventually, be dealt with in local i.e. microscalic to mesoscalic contexts where the appropriate policies of land and water use have to be developed and actions have to be committed.

2 Scenarios

An effective method of investigating such effects and deriving countermeasures within the appropriate contexts is based on scenarios.

Scenario building has become an integral part of the innovation and policy-making process. In future oriented research, scenario building and evaluating is a method to stimulate different perspectives or images of the future of a certain area to gain more insight into possible future developments. Based on the insights from such visionary views, concerted and focused actions can be derived to positively impact future developments. A scenario is a synthetic description of an event or series of actions and events taking place in a system under internal or external influences. Scenarios may be evaluated by human discourse or discussion but, nowadays, will be effectively explored through the support of computerized dynamic models of the systems under investigation.

Setting up a scenario means

- providing a general description of the problems to be investigated including the goals pursued, the parameter considered and the actions foreseen;
- describing the system under consideration (objects, attributes, capabilities, relations);
- describing the initial system status (initial attribute values = parameters and an initial set of input/output data, capabilities);
- determining the time horizon in consideration and
- providing a set of parameters, time-series of data and, perhaps, changes of capabilities to be preplanned system internal or system external influences driving the system into a new final state at the end of the time horizon as determined.

On execution, such scenarios provide predictions of system behaviors under certain pre-determined dynamic changes of conditions. They do not consider the past and, thus, do not provide a forecast. They rather provide the results of user-determined changes of the system status. Using scenarios supports “playing around” with different assumptions and parameters of the scenarios including a possible optimization of specific parameter and capability configurations. Using scenarios for analyzing different dimensions of a problem space and for deciding about appropriate and optimal actions such as decision support is a well proven procedure.

3 Model Based Simulation for Scenario Evaluation

It should be clear from the general introduction of scenarios in chapter 2. that only model based simulation provides the basis for making full use of the scenario methodology. The definition of the initial system state is equal to defining the initial model structure and parameters. The set of parameters and data (e.g. time series) needed for the transition of the scenario into the new system state corresponds to the run-time data needed for the execution of a simulation run. Optimization within the evaluation of a scenario means repeated simulation runs controlled by an adequate variation of one or more system parameters.

For scenario based decision support in the area of land use and water resource management we need some or all of the following models (Fig. 1):

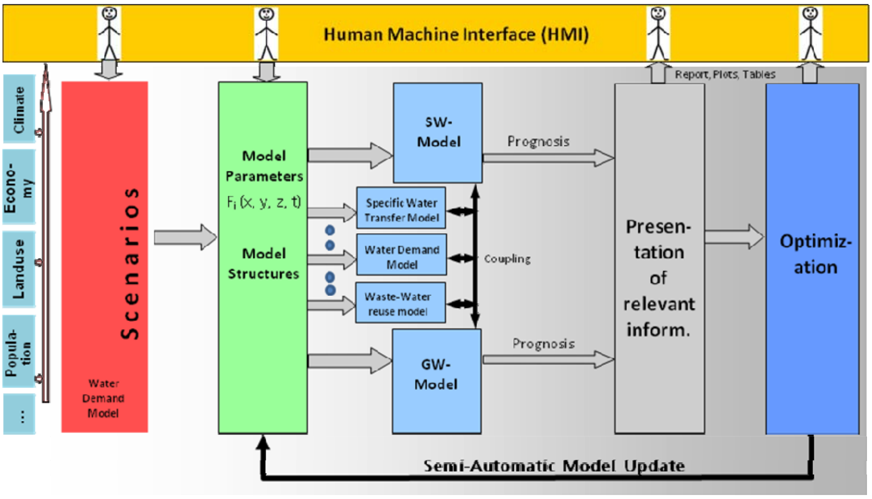

Figure 1 Model Based Decision Support System

● Total Water Balance/Budget of the Modeling Area
as a medium term reference balance for all water resources within the modeling area including waste water use and runoff;
● Surface Water Transport and Storage Models
2-D, concentrated or distributed parameters, for water transport (flow of water)
2-D or 3-D, distributed parameters, for water ingredients flow (water quality)
Catchment areas;
● Ground Water Transport and Storage Models
3-D, distributed parameters, model of ground water table
3-D, ground water recharge model
3-D, surface water to ground water transport (percolation) model
2-D or 3-D, ground water flow model;
● Land Use Model
Showing the spatial distribution and size of different land use classes plus the intercorrelations between land use and rain water / irrigation water infiltration and evapotranspiration;
● Water/Ground Water Exploitation Model

showing the spatial distribution of e.g. ground water exploitation including all kinds of wells for drinking water production, for irrigation or for industry water;

- Water Demand Model

showing the expected water demand depending e.g. on urban area development, agricultural policies or industrial development;

- Special Supply Models (Water supply from regions outside the Model Area)

considering catchment areas outside the model area as well as artificial water transfer such as the South-to-North Water Diversion Project.

It is essential to define an appropriate modeling area where the term "appropriate" relates to the availability of data as well as to "boundary conditions" such as surface and soil characteristics, ground water aquifers, catchment areas or administrative districts.

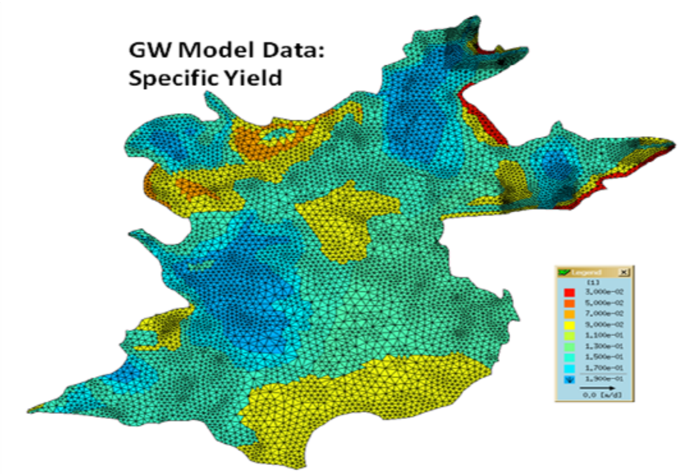

Figure 2 Model Input Data (Example)

All models must be implemented as computer programs in order to support complex, multivariate scenarios including model based optimization tasks. For most of the modeling tasks basic programming tools are available on the market (e.g. ModFlow or FEFlow for ground water level modeling). Other modeling tools have been developed by IITB such as WATERLIB being a surface water modeling library which is listed in the Chinese 948 project.

4 Dealing with Space, Data and Model Parameterization/ Validation

Water supply systems in water scarcity areas in the North Chinese Plain as well as in water scarcity regions all over the world are normally based on more than one water resource. In the North Chinese Plain the original basic use of surface water has shifted to a prevailing overexploitation of groundwater because of scarcity and pollution of surface water. Thus we have to deal in these regions with a conjunctive use of multi-water resources including surface water induding rivers, lakes, and reservoirs, groundwater, water import from regions far away and waste water reuse. The task is to model these different resources, their recharge capabilities and their interactions.

In particular, the characteristics of the groundwater resource, like groundwater recharge, groundwater surface, and groundwater flow as well as groundwater quality respective groundwater pollution are spatially distributed features. They only can be measured at single points for example using observation wells or temporary bore holes. Even if we take a well investigated area like the plain of Beijing Municipality, we have some 150 observation wells and bore holes for an area of 6300 km^2, that means one bore hole ore observation well per about 40 km^2 to monitor groundwater surface or to determine hydro geological parameters. On the other side, we know that parameters like hydrological conductivity, groundwater recharge, and groundwater flow or groundwater pollution are local dependent and may change about one order of magnitude within some hundred meters of distance.

Thus it is obvious that a strong challenge is condensed in the term “appropriate” related to spatial distribution functions and spatial distributed water resource modelling. And it is also obvious that we cannot determine these spatially distributed parameter functions using only a mathematical interpolation within a relative small multitude of directly measured values. To derive these spatial distribution functions, all direct or indirect available information has to be used to get best available estimations and these best available estimations should be proved or improved using spatially and/or timely integrating cause/effect relationships, experienced in the past. The final results of this procedure are maps of the distribution of input parameters and boundary conditions for spatially distributed modelling using FE-calculations.

An appropriate description and quantification of the spatially distributed input features of modelling spatially distributed processes is much more important for the quality of results than a more or less complex mathematical model of the processes itself.

5 Efficient Scenario Building for Protecting Water Resources

If we want to discuss the protection strategies for water resources, we have to talk about what means protection. In a simplified approximation protection means the conservation of an acceptable and defined state mostly the present state of a water resource referring to water quality and quantity, over a long time that means over years and decades of years. Following this definition, the result of an efficient water resource protection will be a sustainable use of the protected water resource. Often drinking water quality is included in protection goals and sustainability definitions in Europe.
Because we don’t know the future we have to make assumptions about chance and tendencies of water relevant features and put it together in scenarios, one scenario for

each possible alternative of future development. Using scenarios to generate model input data sets and to simulate the behaviour of water resources under these scenarios for different time spaces is the only way to assure long time protection of resource and sustainability of water use.

In the North Chinese Plain ground water is the most important water resource for drinking water and agricultural irrigation. Therefore we want to take the protection of groundwater in these areas as an example to discuss the basics of efficient scenario building (limitation of necessary scenarios) for this topic.

The criteria of sustainable use of groundwater in a defined area under consideration will be a steady state groundwater surface, resulting from equilibrium between a total groundwater recharge in the area under consideration on one side and the sum of exploitation and groundwater outflow from the area under consideration on the other side. Groundwater surface is dependent on various influences like changing climate conditions, actual land use and agricultural practice, changing population, industrial activities, etc. Groundwater protection and sustainable use therefore should be defined on a long term bases of several years or even decades.

An existing or increasing overexploitation of groundwater needs a reduction of groundwater exploitation or an increase of groundwater recharge. The most important use of groundwater in the North Chinese Plain is agricultural irrigation, consuming more than 50% of groundwater exploitation. Therefore scenario building should concentrate either on substantial reduction of irrigation water, with or without decreasing food production, or on substitution of ground water. The water to substitute groundwater cannot be taken from surface water because in most areas additional surface water with adequate quality and quantity is not available and foreign water from other regions is too expensive for agricultural use. Thus the only realistic alternative is to use waste water more or less treated to substitute groundwater in agricultural irrigation. In this case the scenarios should cover the decision possibilities either for reduction of agricultural irrigation or for substitution of groundwater with more or less treated waste water. In addition the scenarios have to include the waste water treatment possibilities to model and simulate the effects of irrigation with different treated waste water on soil and groundwater. Important problems to be solved in this field are the avoidance of long term salination of soil and/or groundwater, the hygiene problems and means to deal with the accumulation of residues of industrial waste water components.

6 Future Research Topics

In most water scarcity regions around the world, besides water saving efforts there will come up an increasing necessity to reuse waste water in order to protect drinking water resources. In the field of industrial water cycles and waste water recycling the waste water reuse has a high technical level. But on the other side the dominant waste water resource is municipal waste water and the most important water consumption is agricultural irrigation in these areas. Due to low added values in agriculture, this water consumption sector can pay only low water prices. Therefore an increasing demand of low cost processes to treat municipal waste water adequate for agricultural use will come up. In this field degradable organic carbon is needed for humus in soil and plant nutrients can save expensive fertilizers, so there is no need to separate these components from irrigation water. On the other side we need large scale natural or technical low cost processes to destroy pathogenic germs and pharmaceutical residues in order to guaranty food safety. And we need deep inside into the processes of water borne transportation, migration and degradation of pollution components in the saturated and unsaturated underground. We should be able not only to model in detail theses processes but also to a realistic parameterisation of these models.

Land Use and Groundwater Quality: Simultaneous Elimination of Nitrates and Pesticides from Groundwater
土地利用和地下水质量：同时消除地下水中的硝酸盐和杀虫剂

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Abstract

Modern agriculture needs fertilizing to guarantee a satisfactory growth of crop. Furthermore, losses due to insects, fungi and microorganisms have to be minimized by applying various chemicals. Parts of fertilizers and of pesticides are not consumed but leach into the underground. As a consequence, many groundwaters in agricultural areas contain elevated concentrations of nitrate and pesticides above the standards for drinking water. In a Chinese-German cooperation project the simultaneous elimination of both kinds of contaminants is investigated. (Nitrate is eliminated by means of a biological process which uses a solid substrate. This substrate acts, at the same time, as an adsorbent for pesticides which are eliminated by means of a co-metabolism.) Different substrates and technological solutions are being investigated. The process has been tested in the pilot scale using real contaminated groundwater. The results demonstrate the simultaneous elimination.

摘要

现代农业需要施肥以保证作物的增长满足人类的需要。此外，必须运用各种化学药品来将由于昆虫、真菌和微生物造成的损失减少到最低限度。部分化肥和农药不能被作物完全吸收而渗透到地下。因此，许多农业区地下水中的硝酸盐和杀虫剂浓度高于饮用水标准。中德合作项目，研究了如何能同时消除这两种污染物的方法。硝酸盐可以利用一种固体底物通过生物方法消除

掉。同时这种底物可以作为杀虫剂的吸附剂，通过“共代谢的途径”去除杀虫剂。本试验研究了不同的底土层以及不同的技术解决方案。这一过程已经在试点规模上利用真实的污染地下水通过测试。研究结果表明了能够同时消除地下水中的硝酸盐和杀虫剂。

1 Introduction

The flow of groundwater is part of the natural water cycle between land and ocean. Groundwater is normally well protected against spills by the soil layer above the water table. Intensive agricultural use, however, may lead to anthropogenic pollution of groundwater. Direct contributions stem from application of solid and liquid fertilizers, activated sludge from wastewater treatment, and from the application of plant treatment chemicals like pesticides, insecticides, fungicides, etc. Further affects result from agricultural activities, distribution of water and changes of land use (Rohmann et al. 1985).

Quality of drinking water produced from groundwater always depends on the composition of the raw water and the kind of treatment. Because of the difficulties of removal especially nitrate and polar persistent organic pollutants (POPs) are considered to be critical pollutants (Frimmel 1995) Plant treatment chemicals and their metabolites belong to the POPs; they are highly mobile and their biological degradation is very slow.

Elevated nitrate concentrations are always due to agricultural activities. Especially after 1950 the applied amount of nitrogen-bearing mineral fertilizers was strongly increased in most countries. Take Germany as an example the specific quantity increased from 26 kg N/ha in 1951 to 130 kg N/ha in 1980. Due to the extensive fertilizing the nitrate concentration in groundwater of agricultural regions increased strongly, partly far beyond the existing standards of 90 mg/L NO_3^- or 50 mg/L NO_3^- (after 1998) (Leng et al., 1998, Bi and Li, 2001, Chu, 2004, EU-Trinkwasserrichtlinie 1998, Xiao, 2003) or 10 mg/L N- NO_3^- in other countries. As a consequence, measures for decreasing the nitrogen content of soils and nitrate concentrations in groundwater were discussed and technical processes for nitrate elimination were developed and established (Rohmann 1985, Baldauf 1989, Overath 1990).

Plant treatment chemicals, such as insecticides, herbicides, fungicides, etc. are synthesized and applied since about 60 years. Numerous products with about 400 effective components are produced and applied In Germany, the total quantity amounts to 30.000 t/a. Plant treatment chemicals are partly transported into groundwater by rain. As a consequence, and due to the long time of application, the respective chemicals and their metabolites can be detected in groundwaters of practically all agricultural areas of the world. And in most cases analyses of groundwater show both, elevated nitrate concentrations and contaminations with plant treatment chemicals and their metabolites (Fu et al., 2001, Holden 1986, Pionke et al. 1989, Huang 1995, Land Oberösterreich 1997a und 1997b, Agraval 1999, Donoso et al. 1999, Li et al. 1999, Thapinta et al. 1999, Tonmanee et al. 1999, Liu and Zhang, 1999, Merkel et al. 2000, Zhang, 2001a and b, Boumann et al. 2002, BUWAL 2002, Hu et al. 2002, Kang et al., 2003). Examples are agricultural area in Western Germany where the groundwater contains 45 to 66 mg/L nitrate and up to 0.25 µg/L atrazine, 0.15 µg/L desethylatrazine, 0.35 µg/L diuron and 0.22 µg/L ethidemuron (Rutten 2004).

Elevated nitrate concentrations present problems because they may cause methemoglobinemia with infants. Furthermore, they are possibly reduced to nitrosamines and, therefore, might be cancerogenous. The majority of fungicides and herbicides is cancerogenous, pesticides are scarcely biodegradable and can be concentrated in the human body. As a consequence, standards for drinking water have been introduced in many countries. In Germany the concentration of all treatment chemicals must not exceed 0.5 µg/L, for single chemicals the limit is 0.1 µg/L. Application of some substances (e.g. lindane, DDT, atrazine) has been prohibited.

Production of drinking water from raw waters with elevated concentrations of nitrate and contaminations with plant treatment chemicals requires treatment steps (i) for removal of nitrate, and (ii) for elimination of plant treatment chemicals, thus a fairly complex kind of treatment. Based on these considerations, it was, therefore, the objective of a Chinese-German cooperation project to achieve a simultaneous elimination of both, nitrate, and plant treatment chemicals in one single treatment step in which both types of pollutants are not only eliminated but simultaneously degraded.

2 Research Project

2.1 General concept

Nitrate elimination can be achieved by four different kinds of approaches:

- Membrane processes (reverse osmosis, nanofiltration);
- Anion exchange for chloride and/or bicarbonate ions;
- Biological denitrification (heterotrophic or autotrophic bacteria);
- Electrochemical or catalytic decomposition.

Among these process concepts electrochemical and catalytic degradation have not yet seen commercial application apart from tests in the pilot scale. Membrane processes may lead to a simultaneous elimination of both kinds of pollutants, however, do not achieve a chemical decomposition. Anion exchange does not allow an elimination of plant treatment chemicals. Only the biological nitrate elimination allows a degradation of nitrate and a conversion to nitrogen gas and can possibly be combined with an elimination/degradation of plant treatment chemicals.

One group of biological denitrification processes uses heterotrophic bacteria which need carbon as source of energy. Substrates in technical processes are ethanol or acetic acid, however, further C sources like methanol, molasses, or extracts of straw can be applied. The sessile bacteria need a carrier material like polystyrene, anthracite or volcanic tuff particles. Under anoxic conditions nitrate is reduced to nitrogen gas while the substrate is degraded. Heterotrophic denitrification can also be achieved using solid substrates like Poly-Hydroxy Butyric Acid (PHB) (Müller, 1992) or Poly-β-Caprolactone (PCL). In this case the bacteria are located on the substrate which they slowly consume. The basic consideration of the research project is to use the solid substrate also as adsorbent for plant treatment chemicals which are co-metabolized parallel to nitrate reduction. As a consequence, nitrate elimination and elimination of plant treatment chemicals are achieved in one single treatment step (Boley 2000, Boley 2002, Boley 2003, Boley and Müller, 2004, Hossein, 2004).

The process is to present a possibility for safe drinking water production in rural areas with the respective groundwater contamination problems. Further applications might be the wastewater treatment in aquaculture.

2.2 Partnership

The project involves five German and one Chinese scientific partner and two German companies. Details about the consortium are summarized in Table 1.

Table 1: Partners and competence

Partner institution / Tasks in Project / Responsible person	**Relevant Competence**
Forschungszentrum Karlsruhe, IFG: Coordination, Research groups, Prof. Dr.-Ing. W. H. Höll, Prof. Dr. U. Obst	Equilibria, kinetics column dynamics of PTC sorption, Microbiology, Studies of biopopulation, Bioorganic mass spectroscopy
Technology Center for Water Karlsruhe, Research groups Prof. Dr.-Ing. W. Kühn	Microbiological degradation of pollutants, role of iron and iron compounds Operation of semi-technical pilot plants
Stuttgart University Institute of Civil Engineering, Water Quality and Waste Management (ISWA), Research Group Dr.-Ing. W.-R. Müller	Operation of bioreactors for denitrification, routine analyses
Karlsruhe University (THChair for Water Chemistry Research group Prof. Dr. F. H. Frimmel	Sorption onto polymers, highly specific analyses of PTCs and their metabolites, analyses of water-soluble polymer products, membrane filtration for post treatment
Martin-Luther-University Halle-Wittenberg, Research group Prof. Dr. R. Schnabel	Development of novel solid polymer substrates
Nordic Water GmbH, Neuss, Industrial partner Dipl.-Ing. A. Sack	Dynasand process
Formtechnik in Südbaden, Emmendingen, Industrial partner Dipl.-Ing. F. Hoppe	Roto Bio Reactor process
Tsinghua University, INET, Beijing, Chinese Research group Prof. Dr. X. Zhao, Prof. Wang	Sorption processes, biological denitrification

3 Results

3.1 Fundamental studies

3.1.1 Substrates

Substrates applied in the project are the commercially available Poly-β-CaproLactone (PCL) products CAPA 6500, CAPA 6506, CAPA 6800 and CAPA 6806, originally manufactured by SOLVAY, UK, now owned by PERSTORP, Sweden. All products are raw materials for wrapping foils for food and, therefore, are approved for food handling. Figure 1 shows scanning electron microphotographs from the products.

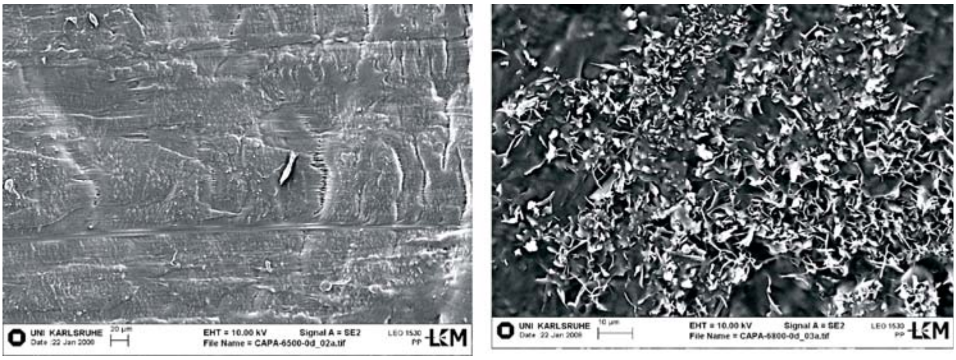


Figure 1 SEM photographs of CAPA 6500 (left) and CAPA 6800 (right)

CAPA 6500 and CAPA 6800 have a particle size of about 4 mm and, thus, as relatively small specific surface with respect to the adsorption of PTCs. CAPA 6506 and 6806 are chemically identical products but are finely disperse materials of particle sizes of 0,5 mm.

In order to improve this specific surface the research group from Martin Luther University Halle-Wittenberg generated compounds consisting of 30 % of PHB and 70 % of CAPA 6506 with increased porosity. Figure 2 shows the respective surface structures.

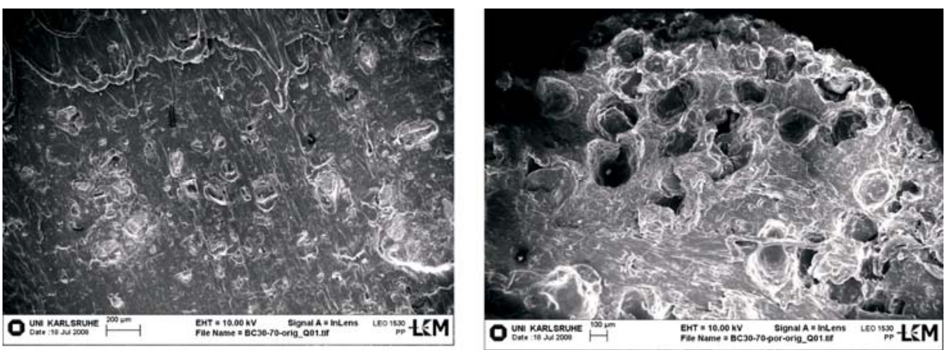


Figure 2 Compounds consisting of 30 % of PHB and 70 % of CAPA 6506. Left: normal product, right: product with increased porosity

The substrates were characterized with respect to their specific surface, adsorption of plant treatment chemicals and release of organics in contact with water. Figure 3 shows isotherms of the adsorption of various plant treatment chemicals onto CAPA 6500.

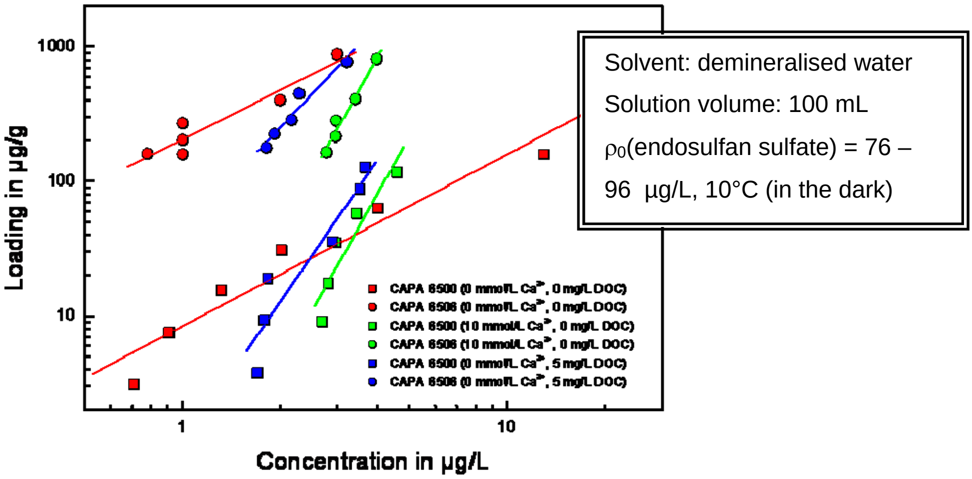


Figure 3 Isotherms of the adsorption of endosulfan onto CAPA 6500 and CAPA 6506

The results demonstrate that the adsorption strongly depends on the particle size and, thus, on the specific surface. Furthermore, dissolved natural organic matter affects adsorption. Investigations of the sorption of endosulfan and atrazine can be summarized a follows:

- Faster and higher sorption of endosulfan sulfate on CAPA 6506
- No influence of the temperature on the sorption of endosulfan sulfate on CAPA 6500 and CAPA 6506
- Decreasing sorption of endosulfan sulfate on the polymers in presence of Ca2+ and DOC
- No significant sorption of atrazine and desethylatrazine on CAPA 6500 and CAPA 6506

3.1.2 Microbiology

The microbial diversity of the microorganisms on the sold substrates was investigated by separation through Polymerase Chain Reactions (PCR) of 16S rDNA-Fragments using the Denaturating Gradient Gel Electrophoresis (DGGE). In nitrate-bearing groundwater both nitrate-reducing and nitrogen-oxidizing bacteria could be detected. In the biofilm that developed on the surface of PCL during experiments at Stuttgart University *Aquaspirillium* und *Acidovorax* (both nitrate reducing) were detected. Figure 4 shows the biofilm on a PCL particle.

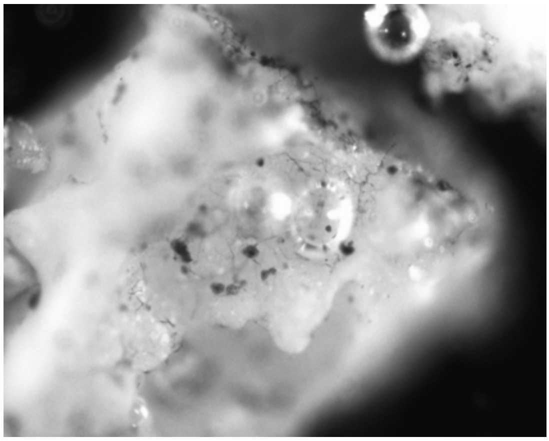


Figure 4 Biofilm on a PHB-CAPA 39/70 particle

The degradation of poly (ε-)caprolactone was controlled by means of measurements of the dissolved organic carbon (DOC) in the respective samples that contained raw water from a test site at Achern where pilot scale experiments were to be carried out. Figure 5 shows the development of DOC in experiments where a mixture of different plant treatment chemical had been added (concentrations 100 – 400 µg/L). No toxic effects of PTCs on nitrate reduction could be detected. The development reveals that a quantitative degradation is achieved within 34 days when oxygen and nitrate had initially been added. Under anaerobic conditions (during which Fe(III) is reduced) no significant degradation was found. As a total, these experiments demonstrated that the microorganisms present at Achern water works can well degrade PCL at aerobic and denitrifying conditions.

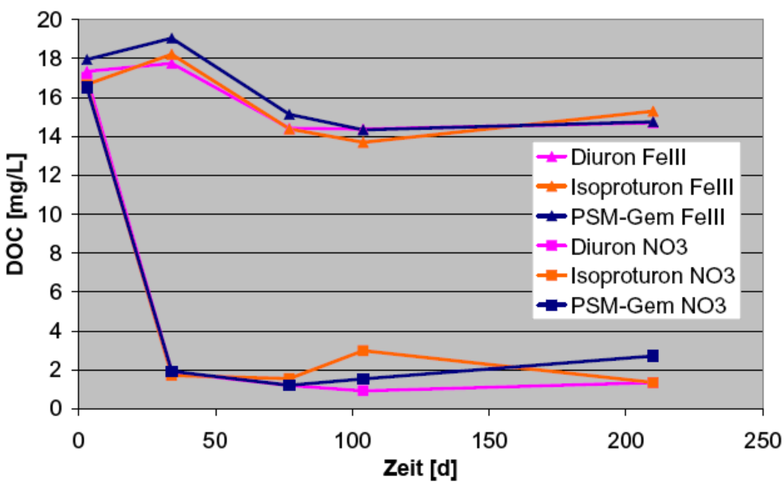
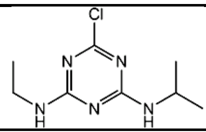
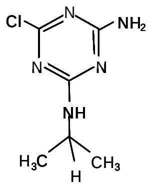
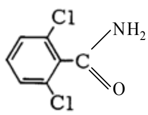
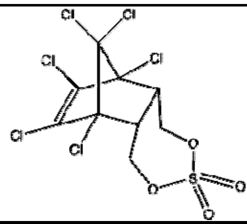
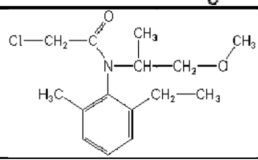


Figure 5 Development of DOC during experiments for degradation of PCL. FeIII: iron-reducing conditions, presence of isoproturon, diuron or mixture of PTCs (PSM-Gem)

3.1.3 Development of analytical methods

Analytical methods for detection and measurement of plant treatment chemicals and their metabolites had to be developed. Some of the respective methods are summarized in Table 2.

Table 2 Plant treatment chemicals and analytical detection methods

Pesticide	Formula	Structural formula	Methods
Atrazine	$C_8H_{14}ClN_5$		**HPLC/MS/MS** Column: Phenomenex-Synergi Polar RP80A Limit of detection: 1 µg/L
Desethylatrazine	$C_6H_{10}ClN_5$		**HPLC/MS/MS** Column: Phenomenex-Synergi Polar RP80A Limit of detection: 1 µg/L
Dichlorbenzamide	$C_7H_5Cl_2NO$		SPME/GC/ECD
Endosulfansulfate	$C_9H_6Cl_6SO_4$		**SPME/GC/ECD** Column: J&W 122-5532 DB-5ms T: 50°C (3 min), 50°C - 280°C (30°C/min), 280°C (3 min). Limit of detection: 1 µg/L (still not sufficient for drinking water)
Metolachlor	$C_{15}H_{22}ClNO_2$		HPLC/MS/MS

3.2 Process development

The original reactor concept comprised a conventional packed bed filled with PHB or PCL pellets. Figure 6 schematically shows the laboratory scale equipment and the concentration profiles of nitrate, nitrite and endosulfan. The results demonstrate that the simultaneous elimination of nitrate and plant treatment chemicals can be achieved.

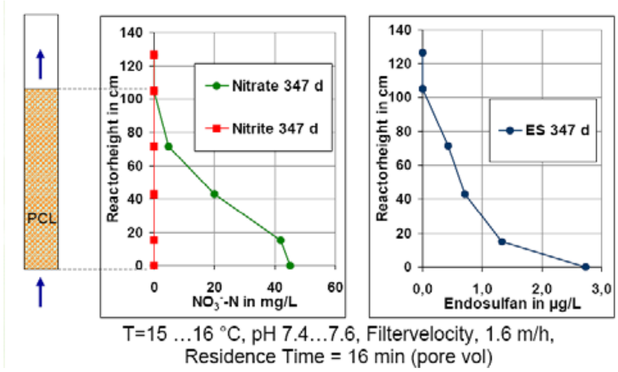


Figure 6 Results of experiments with a packed bed

Results from a similar experiment carried out at INET in Beijing using a compound substrate from PCL and starch are shown in Figure 7.

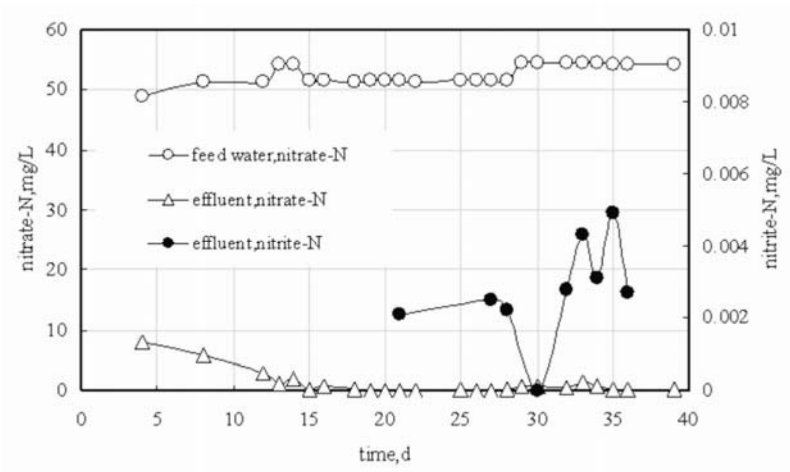


Figure 7 Results of laboratory scale experiments at INET. Substrate: compound of 20% PCL and 80% starch

During denitrification the solid substrate is slowly consumed. As a consequence, the pellets lose size and the bed height decreases. To avoid the resulting difficulties process alternatives have been developed.

The first one is the Rotating Bio Reactor. This type of reactor has been applied to nitrate elimination using liquid substrates. The chambers are filled with porous clay or volcanic tuff material. Due to the friction of particles during rotation dead bacterial mass is stripped off and rinsed out. This principle has been applied to the simultaneous nitrate and PTC removal. Figure 8 shows the scheme and a photograph of the laboratory scale installation.

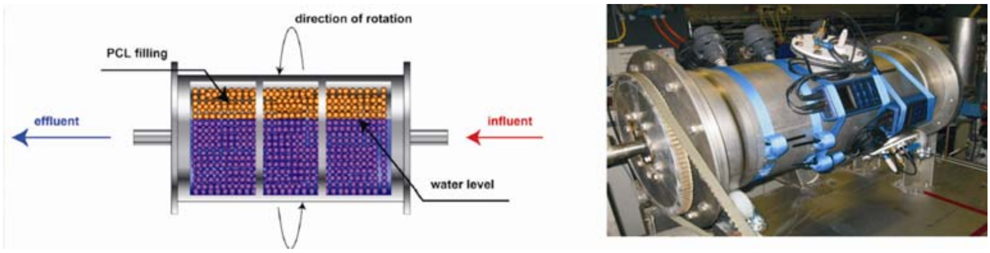


Figure 8 Roto Bio Reactor scheme (left) and laboratory scale installation (right)

The second reactor design is a modified DynaSand filter. In its original form this is an upstream sand filter with continuous backwashing of loaded sand. As Dyna-PCL reactor it is filled with PCL material and slightly modified with respect to the smaller density of the material.

Figure 9 shows a scheme of the reactor. Water passes the sand / PCL layer from bottom to top. The loaded sand or PCL material with microorganisms is transported upwards through the central pipe to the washing / stripping section. The impurities leave this section via the respective outlet while the purified sand / PCL settles on top of the packed bed.

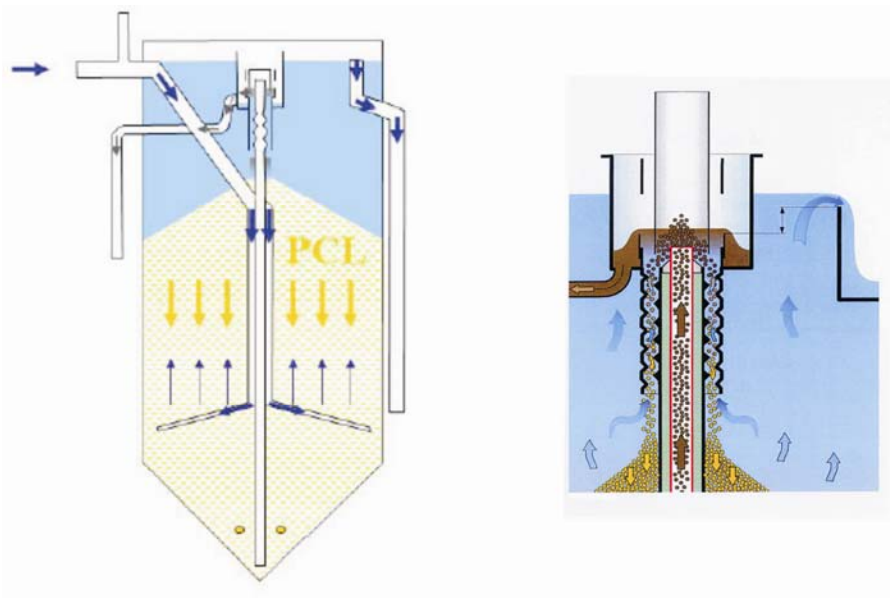


Figure 9 Scheme of DynaSand / Dyna-PCL reactor (left): blue arrows: raw and product water, black arrows: waste water, yellow arrows: flow of substrate. Right: rinsing of contaminated sand / PCL loaded with microorganisms (Nordic Water)

3.3 Pilot-scale demonstration

Both, the Rotating Bio Reactor and the Dyna-PCL reactor have been applied in pilot scale to demonstrate the combined denitrification / elimination of PTCs. The Rotating Bio Reactor plant is tested in the waterworks of the city of Achern. At this site, the groundwater contains about 60 mg/L nitrate and 70 – 80 ng/L dicloro benzamid a metabolite of dichlobenil. Figure 10 shows the plant.

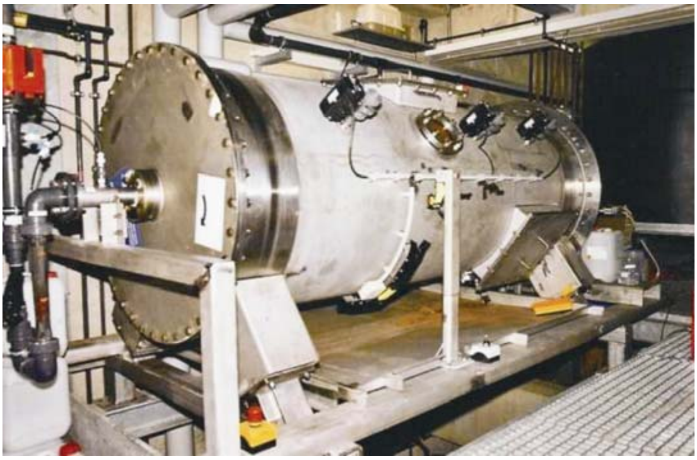


Figure 10 Pilot-scale Roto Bio Reactor, length: 4 m, diameter: 1 m, number of rotations: 4/h, quantity of PCL: 302 L/chamber, flow rate: 300 – 1000 L/h

The Roto Bio Reactor has been in service at Achern for about one year. Development of a denitrifying biofilm required several months. After about half a year, the effluent nitrate concentration reached values down to 5 – 10 mg/L. Initially the formation of nitrite was observed which disappeared completely after the transition period. A decrease of metabolites of dichlobenil has been observed which, however, is not yet satisfactory.

The pilot-scale Dyna-PCL reactor operates at Stuttgart University and uses spiked tap water. Figure 11 shows the reactor.

The Dyna-PCL reactor allows a satisfactory denitrification. The degradation of PTCs has not yet been investigated. A problem with this reactor is the development of nitrogen gas which leads to an intermittent increase of the level of PCL. The problem is still to be solved.

4 Conclusions

Agricultural land use may lead to contaminations of the groundwater with both, nitrate and plant treatment chemicals. Generation of safe drinking water, therefore, requires decreasing the concentrations of both undesirable components. With this respect classical treatment methods need two separate elimination processes. The Chinese-German research project however, tries to combine nitrate and PTCs elimination in one single process step. The results of fundamental investigations so far obtained have demonstrated the following:

Figure 11 Dyna-PCL reactor (left). Empty Volume: 805 L, Mass of PCL: 350 kg. Flow rate:350 L/h. Top view (right, top), formation of gas bubbles during denitrification (right, bottom).

● Solid substrates for biological denitrification like PCL and PHB can act as adsorbents for plant treatment chemicals. Adsorption of PTCs has no negative effect on denitrification.
● Composite substrates with increased specific surface can be synthesized.
● Analytical methods for measuring plant treatment chemicals and their metabolites have been developed although some limits of detection still have to be lowered.
● The process has been realized in two different types of reactors. Successful tests have been carried out in the laboratory scale. Results of pilot scale experiments indicate that a successful scale up is possible.

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Use of Thermography for Water Status Detection in Grapevine
红外热相仪在葡萄水分检测中的应用

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Abstract

Grapevines are preferentially grown under mild to moderate water stress conditions to achieve the best compromise between wine quality and quantity. Water status detection for advanced irrigation scheduling is frequently done by predawn leaf water potential (ΨPD) or leaf stomata conductance (gL) measurements. However, these measurements are time and labour consuming. Therefore, the use of infrared thermography (IRT) opens up the possibility to study large population of leaves and to give an overview on the stomatal variation and their dynamics. In the present study IRT was used to identifying water stress of potted grapevines. In order to define the sensitivity of IRT measurements to water stress, the IRT-based water status information were compared with simultaneously measured ΨPD and gL data. Correlations between IRT-based CWSI data on the one hand and gL and ΨPD on the other showed the potential of IRT for water stress detection. However, the CWSI calculation procedure is laborious and the sensitivity of CWSI for water stress detection still needs to be improved. Therefore, further improvements are necessary in order to apply remote IRT-based systems for irrigation scheduling in the field.

摘要

葡萄最好种植在轻度到中度水分供给条件下，以达到葡萄酒质量和产量之间的最佳平衡。通常，测量叶片含水量或者测量叶片气孔的尺寸大小得到葡萄是否缺水，从而为其浇水提供依据。然而，这样做需要花费很多时间并且烦琐。利用近红外技术研究大量叶片含水量和其动力学特征，有可能得到其缺水情况。本实验对近红外热相仪在葡萄水分检测中应用可行性进行了研究，发现当发生光合作用时，叶片小孔打开，由于能量的消耗，植物将会经历水势的变化，温度也会发生变化。利用红外热相仪能够观测到叶片温度的变化，从而间接地得到叶片的光合作用情况。本文做了如下实验：在温室中，种植十二株葡萄，并连续对其观测十天，用红外热相仪拍摄叶片照片。对这些照片进行分析，同时用 SC-1 气孔计测量叶片气孔的大小，并对照比较叶片潜在含水量和气孔大小的相关关系。每间隔 1 分钟测量一次相关的气象数据（湿度、温度），除红外图像外，叶片面积同时用照相的方法准确测量。利用潮湿多口材料测量湿球温度。在表面预先放一张跟叶片完全一样的纸，等同于叶片完全闭合时候的情形，测量叶片最大

加热量。发现叶片水分含量和孔大小有一定的关系。不过，蒸发时如辐射等其他的环境因素可能也会导致叶片冷却，这些因素可能会影响红外热相仪测量的精确性。为了提高测量的准确性，必须在类似的气象条件下，做更多的相关实验研究。结果显示，红外热相仪用于检测叶片含水量精度必须得到进一步改善，才能将其应用到遥感灌溉定时系统中去。

1 Introduction

Grapevine quality and yield is very sensitive to plant water status. Excessive water stress can impair photosynthesis and fruit sugar accumulation (Bravdo *et al*., 1985) as well as reduces fruitfulness of developing buds and thus reduces yield (Escalona *et al*., 1999). Excessive water supply results in high yield but minor quality. Therefore, precise irrigation regulation by maintaining slight to moderate water stress conditions in grapevine production is beneficial as it assures optimal quality without significantly affecting yield (Dry *et al*., 2000; Santos *et al*., 2003).

Water status detection for advanced irrigation scheduling is frequently done by predawn leaf water potential (Ψ_{PD}) or leaf stomata conductance to water vapour (gL) measurements. However, both measures are labour intensive, time consuming as leaf to leaf variations require much replication for reliable data and not yet possible to be automated.

It is well investigated that leaf temperature tends to increase with water stress (Fluch, 1990; Jones, 1992). Infrared thermography visualizes this increase in leaf temperature as a consequence of stomata closure when the plant is experiencing water stress due to decrease in energy dissipation. Water stress detection with infrared thermography is a non-contact method and thus very fast and practical. It is capable to estimate large leave populations simultaneously and provides an overview on gL variation and dynamics. Thermal images together with software analysis has overcome the problem of non-leaf material inclusion (soil & bark), and it is possible to study selected parts of the canopy.

Leaf temperature however depends not only on gL but also on other environmental factors like air temperature, radiation, humidity and wind speed, which may lead to inaccuracies in thermography-based water status detection. In order to overcome this shortcoming, the crop water stress index (CWSI) was defined (Idso *et al*., 1981; Idso 1982). For CWSI calculation leaf temperatures of maximum transpiration and non-transpiration condition are needed. Attempts were made to obtain these information by spraying water on leaves and by covering the leaves with petroleum jelly, respectively (Jones, 2002; Grant *et al*., 2006; Leinonen *et al*., 2004). Another alternative measure of crop stress is the use of wet artificial reference surface (WARS) (Irmak *et al*., 2000, Möller *et al*., 2006) and taking upper base line temperature, T_{dry} as T_{air} +5°C. To include radiation and wind effects in the computation of the CWSI, efforts are made to derive the CWSI from the energy balance equation (Jones 1999a).

Despite these improvements in CWSI calculation the sensitivity of thermography in terms water status determination is not well investigated. Therefore, the objective of this study is to calculate CWSI for potted grapevines under different irrigation regimes and to determine the correlation between CWSI and well established water status measures like Ψ_{PD} and gL.

2 Material and Methods

The experiment was conducted in a green house of Universität Hohenheim, Stuttgart in Germany from September 19^{th} till 28^{th}, 2008 (day of experiment, DOE 1-10) on twelve potted six year old bacchus grapevines. Eight plants (1-8) were allowed to dry out without irrigation and the soil water content data were simultaneously measured in a ten-minute interval with one two-rod TDR-probe (Trime-IT, Imko Germany) each. The remaining four grapevines (9-12) served as references and were placed in a catchment tray to assure availability of sufficient water. Finally, all twelve grapevine pots were covered with a tinfoil to prevent soil evaporation and soil heating.

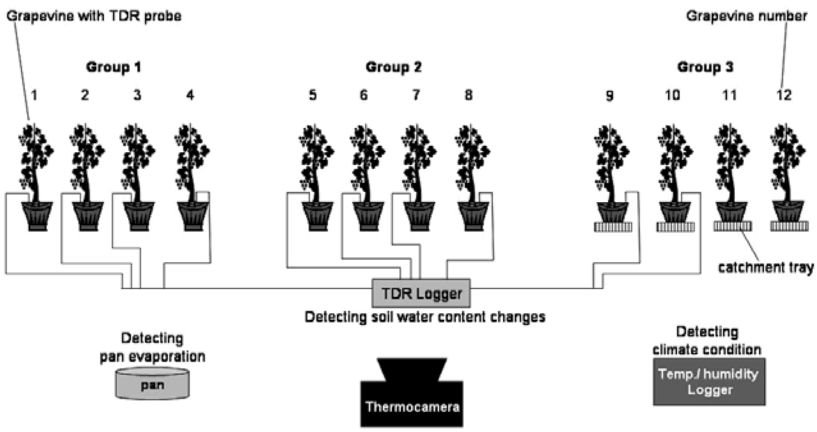


Figure 1 Experimental set-up

2.1 Thermal imaging

Infrared Vario CAM has been used to take the thermal and visible images simultaneously. Irbis-professional-3 software allowed correction for object emissivity, object distance and temperature and relative humidity to analyse the pictures. The emissivity value of 0.98 was used for the grapevines. All the pictures were taken in the afternoon. A wet tensiometer cup was used as a wet reference (approximating maximum adiabatic cooling of the leaves) and black paper served as a dry reference (approximating maximum heating of the leaves) assuming to behave likes a leaf with completely closed stomata.

The crop water stress index (CWSI) was calculated from the measured mean canopy temperature and wet and dry reference temperatures (Jones, 1999a):

$$CWSI = (T_{canopy} - T_{wet})/ (T_{dry} - T_{wet})$$

Where, T_{canopy} is the actual canopy temperature obtained from the thermal image and T_{wet} and T_{dry} are the lower and upper boundary temperatures representing minimum (maximum transpiration) and maximum leaf heating (no transpiration) respectively. Note that T_{wet} and T_{dry} are equivalent to T_{base} and T_{max} in the original formulation of CWSI (Idso *et al.*, 1981).

2.2 Other measurements

Temperature and relative humidity data were logged in a one-minute interval (Hobo U12-011, Hobo USA). One leaf per grapevine was used to determine predawn leaf water potential (Ψ_{PD}) with Scholander pressure chamber due to the limited number of leaves per grapevines. Leaf stomata conductance (gL) was measured with SC-1 porometer (Decagon devices USA) at noon at a three days interval in the beginning and at a two days interval later on. The measurements were made on two preselected leaves on each grapevine with a minimum of three readings per leaf. In addition, daily pan evaporation (E_{pd}) from an open water surface (pan diameter = 21 cm) was determined gravimetrically.

3 Results

During the ten day experiment period three weather phases were identified. During DOE 1-3 the maximum temperature was around 22°C and the relative humidity was 30%. From DOE 4 to DOE 6 the temperature dropped to 18°C and the relative humidity increased to 80%. During DOE 7-9 the temperature increased again as in the beginning of the experiment and simultaneously the relative humidity decreased. According to the temperature and humidity trends, calculated averaged vapour pressure deficit (VPD) values were highest at the beginning and the end of the experiment and distinctly lower during the day 4-7 of the experiment.

At the start of the experiment the volumetric soil water contents (θ) of eight grapevines exposed to drying ranged from 21.9 to 31.6 % (Figure 3). The grapevines were divided into three groups depending on their initial water content (group1= 30%, group 2 = 22%, group 3 = 37%). At the end of the experiment, θ values of the eight grapevines were between 11.4 and 24.6 % in which total θ change during the experiment was between 7.4 (Plant 2 &3) and 11.1 % (Plant 6). Daily pan evaporation (E_{pd}) values showed a similar trend as VPD (Figure 4). At DOE 1 E_{pd} was 2.1 mm and decreased during the subsequent six days to 0.72 mm. During the last three days of experiment E_{pd}

increased distinctly and reached values (DOE 9: E_{pd} = 2.08 mm) similar to that at DOE 1.

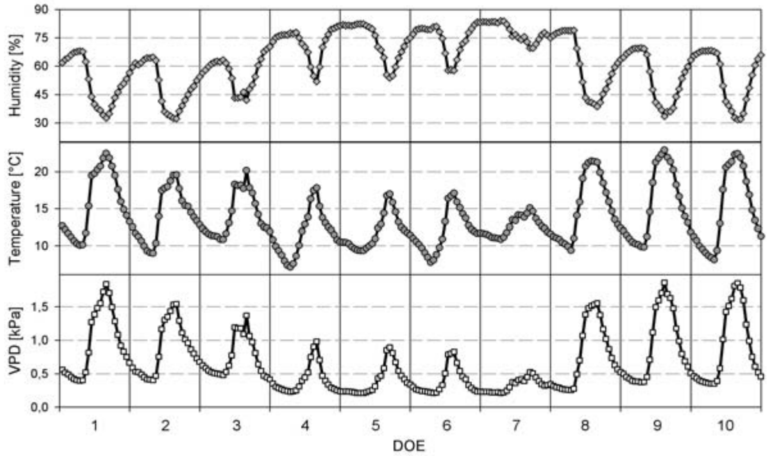


Figure 2 Hourly trends of humidity, temperature and vapour pressure deficit (VPD) during the experiment

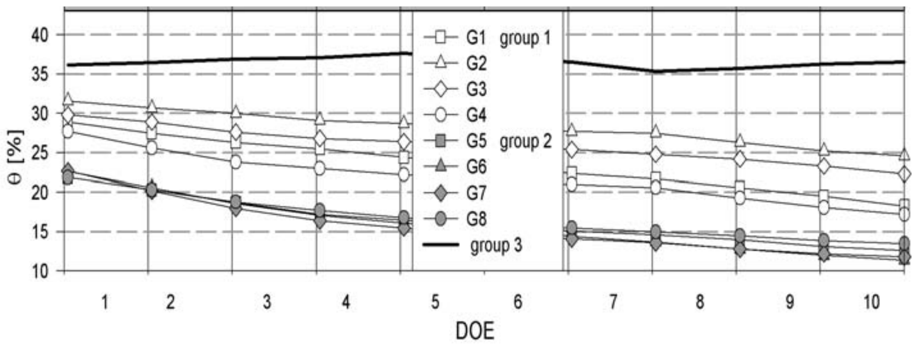


Figure 3 Volumetric soil water content (θ) trend during the experiment

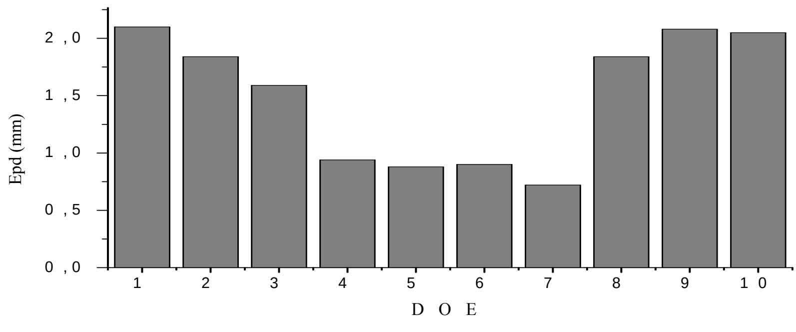


Figure 4 Daily pan evaporation (E_{pd}) measurement during the experiment

3.1 Thermal image analysis

In order to eliminate any incorporation of extraneous surfaces in the study of the leaf temperature such as fruit or bark and to identify the leaf area accurately, two methods were used.

In the first method the temperature frequency histograms were made to analyse the temperature of the dry and wet references and the leaves. For this the temperature of the wet and dry references are used as threshold and any pixel which are outside of the dry-wet threshold range are excluded from analysis. In Figure 5 the dry reference is in the right, wet reference is in the left and the experimental plant is in the middle. It can be seen that the wet reference is cooler than the experimental plant while the dry reference is warmer. It should be noted that the choice of dry-wet references may affect the value of the mean temperature, and the frequency distribution of temperatures obtained.

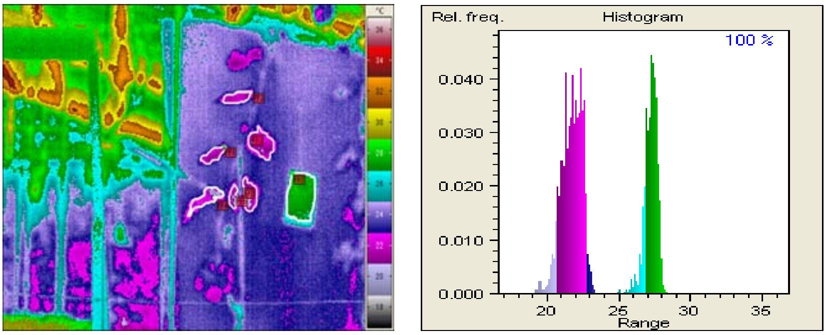
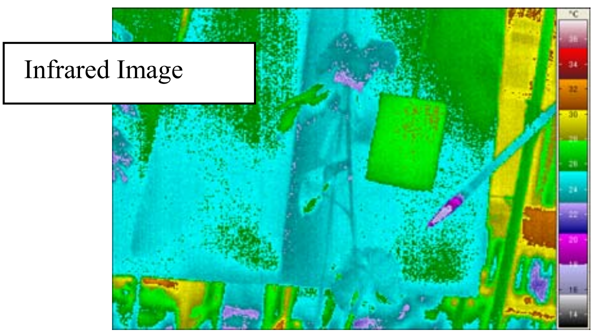


Figure 5 Temperature frequency distribution of the image after excluding the background surroundings of the grapevine canopy

In the second method the infrared image and the visible image were merged together and helped to identify the leaf areas especially when it is difficult to identify the leaves in the thermal image. The merging of the two images helped to analysis the plant temperature accurately by calculating the temperature of each leaf. Results proved that both methods were similar with respect to the leaf temperatures obtained.



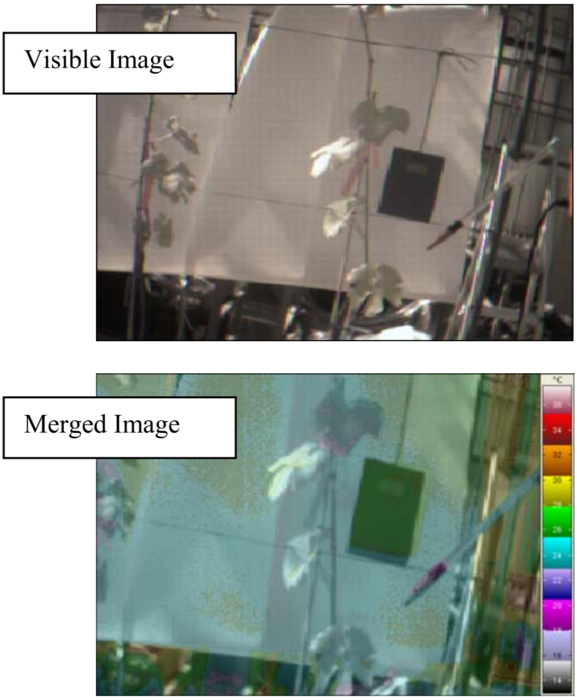


Figure 6 Overlapping of visible and thermal image to identify the plant leaves accurately

3.2 Leaf temperature and CWSI measurements for identifying the water status

The temperature variation of non-irrigated grapevines (Figure 7) illustrate that not all the eight grapevines show the same increase in leaf temperature. It can be seen clearly that the average temperature of plants in group 3 at the start (23°C) and end (23.3°C) of the experiment was the same. Plants which show the highest increase in temperature are the plants in group 2 i.e. plants 7(6.6°C), 6 (5.4°C), and 8 (4.9°C). The different temperature trends are reflected in the calculated CWSI in Figure 8. Plants in group 3 had the lowest values at the experiment end, while CWSI in group 2 increased distinctly and showed highest values at DOE 10.

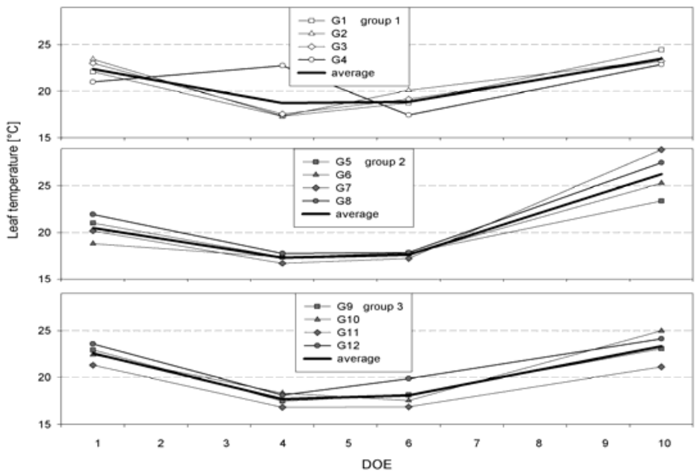


Figure 7 Leaf temperature variation of irrigated (group 3) and non- irrigated grapevines (group 1 and 2)

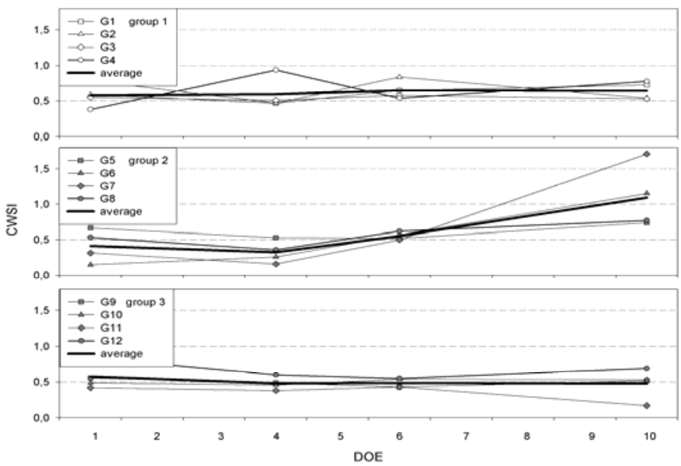


Figure 8 Crop water stress index (CWSI) measurements of irrigated (group 3) and non-irrigated grapevines (group 1 and 2)

3.3 Relationship between leaf water potential, stomata conductance and CWSI

The predawn leaf water potential (Figure 9) of group 3 was always under 2 bar whereas group 2 plants showed continuous increase in Ψ_{PD} and continuous decrease in gL (Figure 11) and reaches its maximum at the end of experiment. This sharp decline in leaf water status and stomata conductance to water vapour indicates the necessity for water status monitoring for precise irrigation scheduling to prevent damage. Values of Ψ_{PD} in between 3-4 bar is mostly considered to be sign of water stress in grapevines. Generally, a good correlation with CWSI was found throughout the experiment except on the last day for group 1 when high Ψ_{PD} is not displayed by the high CWSI (Figure 10). Relationships between CWSI and Ψ_{PD} and between CWSI and gL are shown for individual days in Figs 10 and 12. Low Ψ_{PD} and high gL of group 3 is very well reflected in small CWSI value. A clear inverse relation can be seen in group 2 and 3 between gL and CWSI. It is interesting to note here that it is plants in group 2 which show very good correlation between CWSI and gL and between CWSI and Ψ_{PD}.

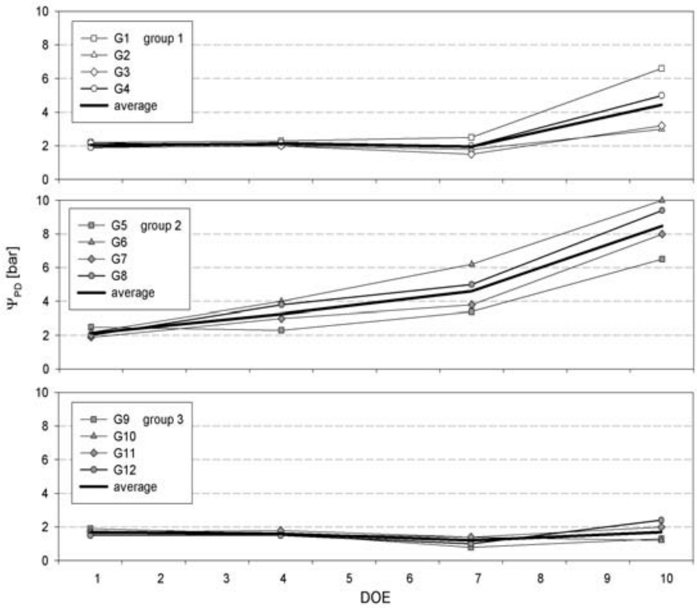


Figure 9 Predawn leaf water potential (Ψ_{PD}) trend during the experiment

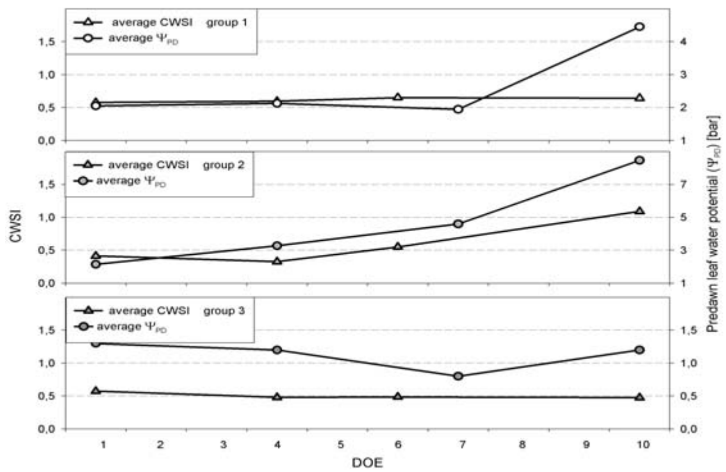


Figure 10 Crop water stress index (CWSI) vs. predawn leaf water potential (Ψ_{PD}) measurements

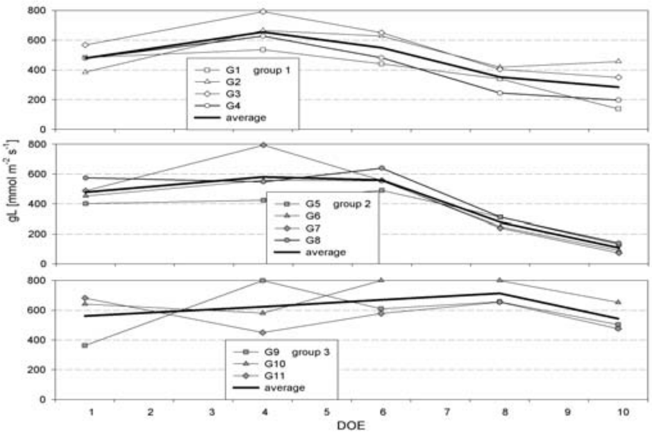


Figure 11 Stomata conductance to water vapour (gL) trend during the experiment

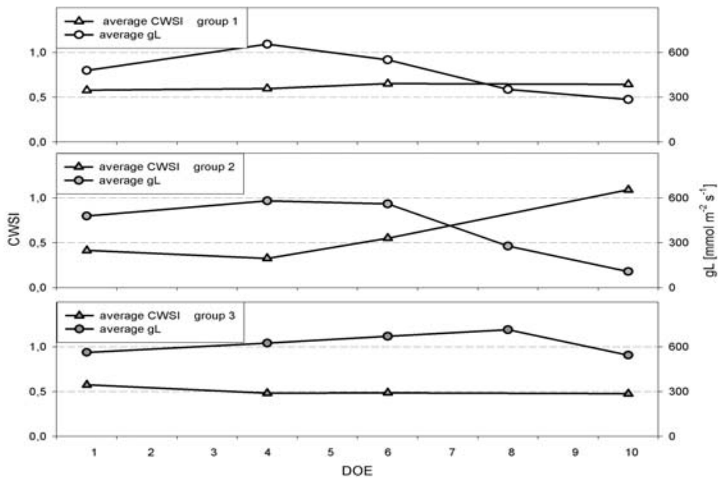


Figure 12 Stomata conductance to water vapour (gL) vs. crop water stress index (CWSI) measurements

4 Discussion

The effective use of thermal sensing is to estimate plant temperature and to study plant water relations. This can be used further as an indicator of stomatal conductance because the leaf temperature is a function of evaporation rate and transpiration from the leaf. The leaf temperature affected by other physiological processes is very rare (Jones *et al*., 2008) for example it can be due to increase in respiration rate (Seymour, 1999) but the heat generated is too small to have an effect on leaf temperature.

The use of different wet and dry reference surfaces to determine the limit of canopy temperature distribution has been used (Jones *et al*., 2002). But the selection of the leaf area based on the references threshold may lead to the inclusion of non-leaf objects if the temperature of the leaf is close to either of the references. Even the time difference between spraying the leaves and taking the thermal image is not error free. Therefore, this will overestimate the temperature difference between the stressed and non-stressed plants. It has been suggested to use the variation in temperatures within the canopy (Fuchs, 1990; Leinonen and Jones, 2004) to determine water stress but no evidence was found in our result to support this hypothesis as there was no large variation within the canopy to distinguish between stressed and non-stressed plants, which is in accordance with findings of Grant *et al*., 2006.

The continuous measurements of the soil water status showed (Figure 3) that maximum change in θ at the end of the experiment was shown by Plants 6 and 7 in group 2 under severe water stress, while Plants 2 and 3 in group 1 revealed lowest $\Delta\theta$ values and finally least water stress. An explanation with different hydraulic properties or poorly installed TDR probes is unlikely since all grapevine soils showed similar water contents when being saturated after the experiment (40% < θs < 46%). Therefore, it is more obvious that the differences in θ between the grapevines resulted from different root water uptake and transpiration capabilities.

During the experiment it was found that the atmospheric evaporative demand in the beginning and the end of the experiment was similar (Figure 4). Thermal imaging has the potential to substitute direct leaf measurements and to provide a more robust signal of the crop water status. In the present study, it has been demonstrated that thermal images can be used as an alternative to direct gL and Ψ_{PD} measurements. The least increase of temperature in the reference plants in group 3 and the subsequent low CWSI, Ψ_{PD} and high gL values shows the potential of thermal imaging in distinguishing the two irrigation regime. There was a clear linear relationship between CWSI and Ψ_{PD} and inverse relationship between CWSI and gL. It is interesting to note that group, which showed the highest increase in temperature was the same group, which showed the maximum decline in gL and maximum increase in Ψ_{PD} .

5 Conclusions

In conclusion, it is evident from the data presented here that infrared thermography can be a useful method in irrigation scheduling but the use and selection of appropriate dry and wet reference threshold temperatures is important to avoid any inclusion of non-leaf objects in the image analysis. One of its major advantages when compared with predawn leaf water potential is the possibility to study large areas of canopy. While an estimation of stomata conductance to water vapour and predawn leaf water potential requires meteorological data, the CWSI measurements are sufficient for detection of the plant water status and require no additional information. It is a more rapid and practical approach as it requires only thermal camera and no other special equipments. Further research should also focus on consider the impact of leaf angle variation within the canopy.

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UNESCO's Contribution to Water and Land Management in Arid and Semi-arid Zones
联合国教科文组织（UNESCO）在干旱和半干旱地区土地和水资源管理中的贡献

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Abstract

UNESCO's contribution to enhancing the knowledge base and capacity to sustainably manage the arid zones of the world is continually growing for more than sixty years (1948 to date). This paper summarizes this journey starting with ideas of 1948, to the Major Project of Arid Zones, to the International Hydrological Decade (IHD), to Man and the Biosphere Programme (MAB) and the International Hydrological Programme (IHP). With regard to MAB and IHP more emphasis is given to their contribution to arid zone, citing two flagship projects; G-WADI and SUMAMAD.

摘要

联合国教科文组织在世界范围内提高干旱地区可持续管理的基础知识和能力方面的努力已经持续了 60 多年（从 1948 年至今）。本文将概述这个过程，从 1948 年概念的提出，到干旱地区的主要项目，到国际水文十年（IHD），到人与生物圈计划(MAB)和国际水文计划（IHP）。关于人与生物圈计划和国际水文计划，本文将重点论述它们对干旱地区的贡献，并以“干旱地区水资源及其发展信息全球网”和“贫瘠干旱地区可持续管理”这两个旗舰项目为例加以说明。

1 Introduction

Within the framework of its mandate in sciences, UNESCO has given a special focus to sustainable development of land and water resources in the arid and semi-arid zones of the world. This global initiative was started in the early fifties by a project that revealed a wealth of information and enhanced the global knowledge-base on arid and semi-arid zones. This was followed by many specialized initiatives in the years to come; most important of which are:

- The establishment of the International Hydrological Programme (IHP) in 1975 following the International Hydrological Decade (1965 – 1974).
- The Man and Biosphere Programme (MAB) which has been launched in 1972.

Within these two programmes the knowledge-base and skills on the management of natural resources have been greatly enhanced.

The intended presentation will mainly focus on the continued contribution of these two programmes to arid and semi-arid zones with special focus on two current global initiatives:

- The Global Network on Water and Development Information in Arid Lands (G-WADI).
- The Sustainable Management of Marginal Arid and Dry Lands (SUMAMAD).

2 Arid Zone Programme

When UNESCO became functional in 1946, no specific reference was made to its involvement in water and natural resources concern in Arid Zone. However, two years after its operation, UNESCO's family started voicing the importance of creating an International Institute for Arid Zones through a decision taken by its General Conference which was held in Beirut/Lebanon in 1948. Huge exchanges and many meetings were held to fulfill the decision resulting, in April 1951, in holding the first session of the Advisory Committee on Arid Zone Research in Algiers. Though the proposed Institute was not materialized, yet various highly specialized meetings were held resulting in the approval of the "Major Project on Scientific Research on Arid Lands" by the ninth session of the General Conference held within November 1956 in New Delhi. This project had contributed significantly to the knowledge-base and capacity development and laid the ground for the establishment of two major intergovernmental programmes of UNESCO, namely; the International Hydrological Programme (IHP) and the Man and the Biosphere (MAB) programme.

Two important testimonies for the achievement of the major project have been well documented in three publications that I encourage the reader to review. These are:

- "The UNESCO Water Adventure: From Desert to Water" by Michel Batisse.
- "The Future of Arid Lands: Papers and Recommendations from the International Arid Lands Meetings" by Gilbert F. White.
- "The Future of Arid Lands – Revisted" by Charles F. Hutchinson and Stefanie M. Herrmann.

Both Michel Batisse and Gilbert White had themselves been closely involved in the project and their testimonies should be given great consideration. I quote, from the introduction of Mr. Nino Chiappano to the first publication, a conclusion drawn by Mr. Batisse on the Major Programme.

"In the end, and after approximately a 15-year period, the Unesco programme had neither shrunk the deserts nor stopped erosion, which then more than ever before

threatened the world. But it had contributed to clarifying the interlinked series of problems in arid lands and their economic, ecological and social repercussions. It had stimulated interest in questions previously neglected such as groundwater and salinity. It had opened the way towards an interdisciplinary approach to developing lands. It had served as the loom for weaving a lasting worldwide network of human contacts and dependable interchanges. It had acted as a catalyser for a multitude of national and local initiatives whose list would undoubtedly be impressive. It had led to fruitful cooperation not duplicated by other organizations. It left a precious heritage of achieving success in finely tuning and synthesizing a number of topics on which the scientific community had worked very hard (Batisse, 2005)."

The contributions compiled in Gilbert white work have been recently revisited by Hutchinson and Herrmann with a view of looking at the state of knowledge in 1956 and the recent development in the subject. Though it is strongly recommended for the reader to read both contributions, yet as a brief introduction to these valuable contributions. I quote the covering remarks from Hutchinson and Herrmann.

"The Future of Arid Lands, edited by Gilbert White and published in 1956, comprised papers delivered at the "International Arid Lands Meetings" held in New Mexico in 1955. At these meetings, sponsored by UNESCO and the American Association for the Advancement of Science, experts considered the major issues then confronting the world's arid lands and developed a research agenda to address these issues.

The Future of Arid Lands – Revisited, commissioned by UNESCO in 2005, reexamines this earlier work. Written by researchers from the University of Arizona, this volume first looks at the state of science in 1956 and attendant contemporary views of arid lands development. It then considers how scientific understanding of the processes governing arid lands has since evolved, before extracting lessons from these comparisons that might guide current and future arid land managers and speculating on what the future might hold for arid lands.

Reflecting the shift in drylands thinking from a piecemeal or a 'magic built' approach to a system-based approach that considers people as integral to solving problems, this volume will appeal not just to land managers, but to everyone involved in environmental issues who wishes to gain a better understanding of the state of arid lands science today (Hutchinson and Herrmann, 2008).

3 The International Hydrological Decade (IHD)– 1965–1974

Concern about water issues in arid zone had always been an important part of UNESCO's Major Project, however, it was in 1961 where the idea for a world hydrology program was proposed in October during an IAHS symposium held in Athens. This led the Executive Board of UNESCO in its November 1961 meeting to include in its 1963-64 programme intergovernmental activities on scientific hydrology. Following this, the advisory committee on Arid Zone Research in its 1962 meetings in Tashkent and Moscow reached an agreement on the creation of the IHD.

The twelfth session of UNESCO's General Conference in its meeting in Paris (November, 1962) approved the procedure of the implementation of the IHD and officially closed the Major Project on Arid Lands. The Decade was then officially launched in November 1964 in Paris and its first Coordination Council were: Algeria, Argentine, Australia, Brazil, Canada, Gechoslovakian, France, Germany, India, Indonesia, Japan, Mexico, Nigeria, Pakistan, Senegal, Sudan, Sweden, United Kingdom, United States, USSR and Yugoslavia.

The IHD made significant process in:

- Regional hydrological investigations.
- Capacity building and training of hydrologist

Quoting from Batisse (2005):
"With Decade activities continuing to increase on all fronts, there was an impressive proliferation of meetings, consultants, missions, courses, seminars and publications – all extremely technical and thus making any detailed account of them not possible here. In the field, the work of National Committees multiplied the numbers of Decade stations, experimental and representative basins, water balance investigations on watercourses and contributions to cooperative research projects. The Secretariat's report at the fourth session of the Coordinating Council was especially eloquent in this respect"

Following this mid-decade assessment summarized in Batisse words, the IHD continued its magnificent contribution to both scientific and operation hydrology. However, good stories has always to come to an end, but this is not the case with regard to the IHD. Though 1974 had witnessed the ninth and final session of the Decade Coordination Council as well as the convening of its last major activity "the International Conference on Decade Results", yet the same year witnessed the launching of the first phase of the International Hydrological Programme (IHP) as a legitimate child of the IHD. It must also be mentioned that the founders of the IHP had known, from the beginning, that water is vital to all ecosystems and gradually this believe has been translated into the creation of the Man and Biosphere Programme (MAB) as an earlier child of the IHD born before the IHP.

4 The International Hydrological Programme (IHP) –1975 to Date

IHP is UNESCO's international scientific cooperative programme in water research, water resources management, education and capacity-building, and the only broadly-based science programme of the UN system in this area. Since its launching in 1975 it became an important part of UNESCO's actions implemented so far in seven phases.

IHP's Primary Objective are:

- To act as a vehicle through which Member States, cooperating professional and scientific organizations and individual experts can upgrade their knowledge of the water cycle, thereby increasing their capacity to better manage and develop their water resources.
- To develop techniques, methodologies and approaches to better define hydrological phenomena.
- To improve water management, locally and globally.
- To act as a catalyst to stimulate cooperation and dialogue in water science and management.
- To assess the sustainable development of vulnerable water resources.
- To serve as a platform for increasing awareness of global water issues.

The planning, definition of priorities and supervision of the execution of IHP are ensured by the Intergovernmental Council. The Bureau of the Intergovernmental Council of the IHP co-ordinates the work of the Council between sessions.

Huge development continued to widen the scope of the programme in its different phases to respond to arising needs of the water communities of UNESCO's member states.

The current seventh phases is focusing in the following themes in addition to few x-cutting projects:

- Global changes and water resources.
- Integrated watershed and aquifer dynamics.
- Land-habitat hydrology.
- Water and society.
- Water education and training.

Arid and semi-arid zones always occurs a top priority in all of the IHP phases. Even when water became the principal priority of the science programme (2002 – 2007), UNESCO member states asked the secretariat to give special focus to arid zones issues; and during periods of reduced funds to IHP as in the fifth phase (1996 – 2001), arid zones themes were given a higher priority and saved from budget reduction. The contributions of IHP to arid zones included among others:

- Huge wealth of publications .
- Wide range of capacity development; research and training programmes including regional and international research and training centers.

- Regional and global networks such as G-WADI.
- Pilot schemes in arid and semi-arid zones linked to its x-cutting projects and networks.

One of the flagship projects of IHP is its global network on "Water Development Information for Arid Lands (G-WADI)" which will be briefly introduced.

5 Water and Development Information for Arid Lands – a Global Network (G–WADI)

G-WADI's primary aim is to build an effective global community through the integration of selected existing material from networks, centres, organizations, and individual who would become members of G-WADI. The network will promote international and regional cooperation in the arid and semi-arid areas. The activities initiated within the network will expand in a dynamic way to meet emerging needs along the lines of these objectives. Although G-WADI is open to new initiatives, its specific objectives are as follows:

- Improved understanding of the special characteristics of hydrological systems and water management needs in arid areas;
- Increased capacity-building of individuals and institutions, matching supply with need;
- The broad dissemination of understanding of water in arid zones to the user community and the public, especially as a basis for improved management;
- Exchange of experience, as through case studies;
- Sharing of data to support regional research and the strengthening of data networks to underpin sound management;
- Awareness raising of the potential of advanced technologies for data provision, data assimilation, and system analysis;
- Promotion of integrated basin management and the development and use of appropriate decision support tools.

In its six years of age, G-WADI has contributed in advancing the knowledge-base on water management in arid zones and gave support to region initiatives, important of which is the establishment of the Asian G-WADI Network currently coordinated from China.

6 The Man and the Biosphere Programme (MAB) – 1970 to Date

The Man and the Biosphere Programme (MAB) proposes an interdisciplinary research agenda and capacity building aiming to improve the relationship of people with their environment globally. Launched in the early 1970s, it notably targets the ecological, social and economic dimensions of biodiversity loss and the reduction of this loss. It uses its World Network of Biosphere Reserves as vehicles for knowledge-sharing, research and monitoring, education and training, and participatory decision-making.

MAB's work over the years has concentrated on the development of the World Network of Biosphere Reserves (WNBR). The biosphere reserve concept was developed initially in 1974 and was substantially revised in 1995 with the adoption by the UNESCO General Conference of the Seville Strategy and the Statutory Framework of the World Network of Biosphere Reserves (WNBR). Today, with more than 500 sites in over 105 countries, the WNBR provides context-specific opportunities to combine scientific knowledge and governance modalities to:

- Reduce biodiversity loss;
- Improve livelihoods;
- Enhance social, economic and cultural conditions for environmental sustainability;
- Thus contributing to the pursuit of the Millennium Development Goals, in particular MDG 7 on environmental sustainability.

Biosphere reserves can also serve as learning and demonstration sites in the framework of the United Nations Decade of Education for Sustainable Development (DESD).

Many of these biospheres have been established within arid and semi-arid zones and hence they served in enhancing considerably the knowledge base and capacity in these zones. In addition to WNBR, MAB has contributed significantly to arid zones through its publications, capacity development activities, networks and pilot projects. In particular, these achievement were more significant when they worked with IHP in joint projects and themes where the experience and knowledge from both are integrated to develop sustainable development models for arid and semi-arid zone. One of these flagship projects, where both programs have been integrated, is the one on "Sustainable Development of Marginal Dry Lands-SUMAMAD".

7 Sustainable Management of Marginal Dryland (SUMAMAD)

The overall objective of this pioneering programme, which integrate the experience of MAB, IHP, ICARDA and UNU in developing a Sustainable Development Model for Marginal Drylands, are:

- Improved conditions and alternatives options for drylands dwellers;
- Reduced vulnerability to land degradation in marginal lands through rehabilitation efforts of degraded lands;
- Improve productivity through identification of wise practices using both traditional knowledge and scientific expertise.

These have been translated into six immediate objectives as follows:

- To facilitate the sustainable and integrated management of marginal drylands;
- To investigate alternatives and non-conventional sources of water and encourage their use;
- To promote healthy living conditions by analyzing the supply and quality of fresh-water resources;
- To support efforts of researchers and scientists working in the targeted region;
- To support on-going scientific capacity building programmes;
- To disseminate scientific findings.

To achieve these objectives nine pilot sites have been selected from biosphere reserves and water basins in the arid areas of China, Pakistan, Iran, Uzbekistan, Syria, Jordan, Egypt and Tunisia. Applied researches and training of trainers activities were held in the various sites of the network with relevant publications issued and disseminated globally.

8 Conclusions

It is rewarding to note how an embryonic research programme discussed in 1948 has grown into a global interest and sustainable follow-up to enhance the knowledge base and capacity development in the arid zones of the world. UNESCO's Major Project on Arid Zones which was then launched in 1956 demonstrated a good example for world-wise cooperation in an interdisciplinary manner to address such important issue and reaches significant results. This successful project had led to the birth of two extremely important intergovernmental programmes, IHP and MAB which made good follow-up to the recommendations of the Major Project extending these cooperation with sister UNESCO intergovernmental and global programmes such as the Intergovernmental Oceanographic Commission (IOC) and International Geological Correlation Programme (IGCP), in addition to relevant units in UNESCO's broader mandate in education, culture, communication and social and human sciences.

These foresited fathers of the arid zone programmes must be commended for their wise vision, dedication and cleverness. Though greater understanding on arid zones have been attained, yet still there are lot of areas that needs more work from this generation and in the future. The more we learn about arid zones, the more we discover our ignorance in certain directions.

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Summary and Conclusions: Sustainable Land Use and Ecosystem Conservation

Outcome of the ERSEC International Conference on
Sustainable Land Use and Ecosystem Conservation
May 4-7, 2009, Beijing, P.R. China

1 Introduction

Ecological Research for Sustaining the Environment in China (ERSEC) is a joint effort between the Chinese Ministry of Education (MoE), the German Ministry of Education and Research (BMBF) and the UNESCO Office Beijing to promote the practical use of ecological research results in China by initiating and fostering a dialogue between scientists and policy-makers. Being the bilateral partner of BMBF for the scientific-technological cooperation, Chinese Ministry of Science and Technology (MoST) also joins in the initiative.

This year 2009 is the Sino-German Year of Science and Education and also the 30th Anniversary of Cooperation between China Agricultural University and University of Hohenheim, Germany. The ERSEC International Conference 2009 'Sustainable Land Use and Ecosystem Conservation' has been organized along with these two events. This combined event aimed to provide a forum for exchange of information in order to encourage the networking between Sino-German research projects funded by BMBF / MoST as well as the German Research Foundation (DFG) / National Science Foundation of China (NSFC), the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ, German Technical Cooperation), and other German and Chinese organizations. Thereby the participants of the conference contributed to increase the international visibility of the Sino-German research cooperation in the field of sustainability and environmental protection. Moreover the conference promoted the application and extension of scientific research results through specific recommendations for policy-makers, facilitated the exchange and integration of multi-disciplinary research regarding sustainable land use, water management, food security, climate change, ecology and environmental technologies and encouraged international research cooperation by providing a platform in multilateral forums to discuss and share the bilateral research.

The rapid social and economical development in China in the past three decades has brought huge impact on environment. The conflict between economical development and environmental protection has increased. With the acceleration of industrialization and urbanization, the quest for natural resources is increasing, which causes serious land degradation, desertification and loss of forest cover and subsequently bring challenges to sustainably protect the environment. Due to lack of appropriate advanced techniques, currently China’s energy use efficiency is still very low, whilst industry, electricity, transportation and building construction sectors are facing many difficulties in promoting Green Techniques. China’s agriculture is under pressure caused by climate change and degradation of eco-system. The threat posed by pollution of China’s water resources is particularly great, because China’s per capita endowment of water is only a quarter of the world's average. Due to imbalanced regional ecological rehabilitation effectiveness, the western part of China, especially northwest China, is facing huge challenges in sustaining environmental sustainability. Science and technology play an important role in creating sound knowledge for the sustainable use of resources. Whilst technological innovations offer answers and solutions, the integration and diffusion of scientific knowledge into the respective policy framework needs to be addressed, rather than simply placing emphasis on funding research. These policies related aspects as well as regulations and norms play a critical role in the development of an institutional infrastructure necessary for the planning and implementation of sustainable development.

2 Outcomes of the Conference

The ERSEC 2009 International Conference gathered specialists from China, Germany and other parts of the world. Additionally presentations of real case studies have been included, and an active discussion on the main topics of the conference has been promoted.

Targeted primarily at political decision-makers and institutions that deal with land and water resource management in China as well as the public, the conference provided scientists from the associated Sino-German land and ecosystem research projects as well as other interested scientists with a platform for an interdisciplinary exchange all participants, particularly with and institutional experts. The discussions aimed at deriving or refining recommendations for implementing socio-economically viable and environmentally friendly policy measures in non-technical terms. The presentations and a summary of the discussions are published in this workshop volume.

The five sessions of the Conference addressed the following principal topics:
1. Key Speeches (poverty in rural areas and food threats by invasive alien species)
2. Sustainable Ecosystem and Environment Management
3. Nutrient Cycling
4. Water Management
5. Agriculture and Economy

The following sub-chapters summarize the major topics addressed, the problems reported, the approaches applied, the major findings and strategies developped, implementation barriers, and recommendations.

Major topics addressed

The topics addressed at the conference included all relevant issues of sustainable land use and ecosystem conservation and provided a comprehensive overview of research activities currently or recently dealing with such topics. The detailed topics were as follows:

- Grain for Green / Grain for Blue (Rozelle, 2009)
- Invasive alien species (Wan and Guo, 2009)
- Biodiversity issues and management (Wan, 2009; Moinuddin and Xi, 2009; Sauerborn et al.,2009a; Tennigkeit et al., 2009; Tang et al., 2009; Liyanage et al., 2009)
- Carbon cycles (Wan, 2009; Huang, 2009)
- Relationship between society, economy and ecology (Sauerborn et al., 2009a)
- Agro-biodiversity and climate change (Waldmueller, 2009)
- Water ressource protection (Steusloff and Birkle, 2009)
- Ecological security for both man and nature (Innocent et al., 2009)
- Ecosystem service valuation (Moinuddin and Xi, 2009)
- Intercropping systems (Li, 2009; Feike et al., 2009)
- Sustainable pesticide use (Devi et al., 2009)
- Nitrogen – deposition, processing and management (He et al., 2009; Ju, 2009; Ganeshram,2009; Shi, 2009)
- Global change effects (Butterbach-Bahl et al., 2009; Yin, 2009, Haas et al., 2009)
- Recycling of organic residues (Lu and Yan, 2009)
- Sustainable water ressources management (Fuhrmann, 2009; Salih, 2009; Monninkhof et al., 2009)
- Rainwater harvesting (Monninkhoff et al., 2009; Xu et al., 2009)
- Increasing impacts of global biofuel development (Huang et al., 2009)
- Various bioenergy issues, incl. Jatropha (Huang et al., 2009; Schweers et al., 2009; Makkar et al., 2009)
- Biotechnology / Bt cotton (Waibel et al., 2009)
- Efficient use of fertilizer (Böber et al., 2009; Sun et al., 2009)
- Land use development (Liyanage et al., 2009; Tang et al., 2009)

Problems reported

Severe problems were reported dealing with all respective areas of the conference programme, General, Sustainable Ecosystem and Environment Management, Nutrient Cycling, Water Management, Agriculture and Economy:

General:
- Poverty in rural areas (Rozelle, 2009)
- Food threats by Invasive Alien Species (Wan and Guo, 2009)
- Modern life style vs. poverty (Sauerborn et al. , 2009a)
- Public health problems due to pesticide poisoning (Devi et al., 2009)

Sustainable Ecosystem and Environment Management:
- Land consumption/ development pressure by urban development (Kagelmacher, 2009)
- Loss of genetic ressources, destabilization of ecosystems, long-term shortages in food supply and poverty due to climate change (Waldmueller, 2009)
- Severe decline in forest cover, fragmentation of tropical rain forests (Moinuddin and Xi, 2009)
- Degradation of steppe soils / volatilisation of C (Butterbach-Bahl et al., 2009)
- Grassland degradation (Wilkes and Tennigkeit, 2009)
- Biodiversity shortcomings (Tennigkeit et al., 2009; Liyanage et al., 2009; Tang et al., 2009)

Nutrient Cycling:
- Fertilizer overuse and water pollution (Ju, 2009; Shi, 2009; Monninkoff et al., 2009; Yang, 2009; Höll et al., 2009; Kühl et al., 2009; Ganeshram, 2009)
- Fertilizer efficiency with decreasing ground water tables and general water shortage (North China Plain: Sun et al., 2009; Shandong Province: Monninkoff et al., 2009; Kühl et al., 2009; Global and local: Steusloff and Birkle, 2009; Xu et al., 2009)
- Safety and risk of P input (Werner, 2009)
- Recycling of organic residues (Lu and Yan, 2009)

Water Management:
- Water shortage;
- Deacreasing ground water tables and general water shortage (North China Plain: Sun et al., 2009; Shandong Province: Monninkoff et al., 2009; Kühl et al., 2009; Global and local: Salih, 2009; Steusloff and Birkle, 2009; Xu et al., 2009)
- Climate change effects vs. sustainability goals (Yin, 2009)
- Water pollution;
- Pollution (Chao lake: Fuhrmann, 2009; Yangtze river, Shandong: Monninkoff et al, 2009; Yang-Yellow River: Höll et al., 2009; Kühl et al., 2009; Taihu lake: Shi 2009,

River Tyne and Tweed river estuaries: Ganeshram, 2009)
- Drinking water safety and water shortage and pollution vs. sustainability of farming and society (Wagner, 2009; Kühl et al., 2009) ;
- Water recycling (Xu et al., 2009);

Agriculture and Economy:
- Increasing competition between food and bioenergy production (Huang et al., 2009; Schweers et al., 2009)
- Handling of Bt crops (Cotton: Waibel et al., 2009)
- Spatial (urban-rural) social disparities (Paulussen and Weinand, 2009)
- Handling of urea fertilizer and environmental consequences (Böber et al., 2009)

Approaches applied

The approaches applied in the different Sino-German projects include analytical, model based, empirical and statistical, participatory and integrated approaches as follows:

Analytical:
- Remote Sensing (Yin, 2009; Schweers et al., 2009)
- Roto-Bio-Reactor (Höll et al., 2009)
- 15N-Tracer (Ganeshram, 2009)
- Thermography (Zia et al., 2009)

Model based:
- Ecosystem services (Moinuddin and Xi, 2009)
- GIS based approaches (Kagelmacher, 2009; Steusloff and Birkle, 2009; Yin, 2009; Monninkhoff et al., 2009; Berkhoff et al., 2009; Schweers et al., 2009)
- Comprehensive database, rapid alert system, risk assessment (Invasive Alien Species; Wan and Guo, 2009)
- Ecosystem-Model at island scale (Vitousek, 2009)
- Decision Support System (DSS) for scenario evaluation (Steusloff and Birkle, 2009; Monninkhoff et al., 2009)
- Integrated Hydrological Model (Huangshui River Basin: Monninkhoff et al., 2009; Berkhoff et al., 2009)

Empirical and statistical:
- Household Surveys (Yin, 2009; Kühl et al., 2009; Böber et al., 2009)
- Qualitative empirical methods (Tang et al., 2009; Böber et al, 2009)
- Econometric models (Waibel et al., 2009; Böber et al., 2009)
- Bio-economic model (Waibel et al., 2009)

Participatory:
- Participatory approaches in general (Waldmueller, 2009; Shi, 2009)
- Policy meetings (Yin, 2009)
- Praxis-oriented training (Paulussen and Weinand, 2009)

Integrated:
- Co-operative interdisciplinary Sino-German projects (Sauerborn et al., 2009a)
- Integrated modeling approaches (Berkhoff et al., 2009)

Major Findings and Strategies Developped

The major findings of the Conference`contributions indicate that policy and social measures are as important as technology development for optimal management of resource allocation and application. However, there still is a high demand for simple, easy-to-use technologies to reach practical farmers.

General:
- Limited success of conservation set aside concerning poverty alleviation (Rozelle, 2009)

Sustainable Ecosystem and Environment Management:
- Agro-biodiversity management improves biodiversity (Waldmueller, 2009)
- Competitive advantages of intercropping systems under certain conditions (Li, 2009)

Nutrient Cycling:
- Over-fertilization is a serious problem in intensive agricultural production areas in China (He eta al., 2009; Ju, 2009; Shi, 2009; Sun et al., 2009)
- Input from wet and dry deposition of inorganic and organic N species into agricultural field cannot be omitted with up to 90 kg N ha^{-1} yr^{-1}, nearly 60% of which could be utilized directly by crops (He et al., 2009)
- New fertilizer recommendations should fully take into account the N supplying capacity of the soil and N deposited from air and irrigation water (Ju, 2009)
- Policy and social issues are as important as technology for optimal management of fertilizer use in rice production for higher efficiency and better environmental quality (Shi, 2009)
- More technologies, simple, easy-to-use need to be developed
- Grazing management has largely affected the biosphere atmosphere exchange of N_2O
- Decreasing winter emissions
- Increase in N_2O emissions from sheep folds as well as of CH_4
- Decreasing uptake of CH_4
- Increasing emissions from sheep (Butterbach-Bahl et al., 2009)

Water Management:

- Agriculture has been the first contributor to water pollution in the upper Yangtse river area and efficient control of water pollution from farming will be a big challenge in the future (Yang, 2009)
- Simultaneous denitrification and pesticide removal from groundwater has been demonstrated (Höll et al. , 2009)

Agriculture and Economy:

- Organic residue recycling biogas-system for organic waste control (Lu and Yan, 2009)
- Energy saving by semi-centralized treatment (Wagner, 2009)
- Support by Science and Education improves knowledge transfer; partnerships are important (Paulussen and Weinand, 2009)
- Economic advantages of Bt cotton at farm household levels (Waibel et al, 2009)
- Villagers are aware of negative environmental changes (Tang et al., 2009)

Implementation Barriers

Rapid developments in recent years hinder the implementation of innovations in the field of sustainability, such as:

- Weak knowledge transfer systems from science to practice
- Rapid urban development (no time for density planning; Kagelmacher, 2009)
- Economic restrictions (“sky farming”; Sauerborn et al., 2009b)
- Trade off between biodiversity and economic demands (Waldmueller, 2009)
- Educational urban-rural disparities
- Missing consensus building body in Biodiversity protection (Tennigkeit et al., 2009)
- Private land ownership does not allow proper assessment of biodiversity (Liyanage et al., 2009)

Recommendations

Clear recommendations could be provided at the conference, including the following:

- Urban re-densifying, requiring cross-sectorial thinking (Kagelmacher, 2009)
- Balance between all 3 pillars of sustainability (ecology, economy, social issues; Sauerborn et al. , 2009b)
- Bridging the trade-off between 4F production and metropolitan areas (e.g. “sky farming”, including compensation payments; Sauerborn et al., 2009b)
- National bioenergy and biodiversity strategy (Waldmueller, 2009)
- Data integration (Invasive alien species: Wan and Guo, 2009; biodiversity status: Waldmueller, 2009; urban development: Kagelmacher, 2009; ecosystem services: Moinuddin and Xi, 2009)
- Optimized grazing management schemes (Butterbach-Bahl et al., 2009)

- Optimized crop management systems (according to water consumption; Sun et al., 2009)
- Water saving strategies, greywater recycling, waste water reuse (Monninkhoff et al., 2009)
- Careful handling of bioenergy crops due to competition with food crops (Huang et al., 2009; Schweers et al., 2009)
- On site training of farmers (Böber et al., 2009)
- Improvement of knowledge transfer from science to farmers (more technologies, simple, easy-to-use, need to be developed ; Shi, 2009)
- Sustainable agro-biodiversity management systems (Tennigkeit et al., 2009)
- Considering removement of government subsidies to agriculture, particularly fertilizer (Ju, 2009)
- Introduction of sectoral approaches (Wilkes and Tennigkeit, 2009)
- Implementation of Analog Forestry (Liyanage et al., 2009)

3 Roundtable Discussion and Conclusions

The topics addressed and problems indicated at the ERSEC 2009 International Conference have shown that China's issues are also global problems (including loss of land for agricultural purposes, water scarcity, over-fertilization, population growth, urban-rural disparities, global change).

China has undergone strong development during the recent decades which shows that the country is able of profound rapid changes. The future challenge is to balance social development with environmental and economical development. Investment in humans is important to balance different speeds of development.

Current development in China is that life style changes from traditional Chinese (plain life) to Western style. This means that its ecological footprint is even getting bigger. How can the good practices of Chinese tradition be transferred into future development under consideration of advanced Western technology?

With increasing living standards, livestock production is becoming more important in China and must be taken into account in future research (nutrient fluxes). Intensive livestock production entails serious issues related to manure management and feed demand. Their might not be enough land for the future feed demand for meat production, resulting in imports of meat and thereby nutrients.

Many isolated problems have been identified and isolated solutions for these found, however, as many problems are interrelated, interdisciplinary research for overall solutions is required in the future. Especially joint work of economists and ecologists is needed.

Currently, knowledge is available but not accessible. Knowledge transfer from science to policy makers, local authorities, extension service and local population (farmers) need to be improved (e.g. fertilizer recommendations). The Five Elements in Chinese philosophy say that nature and human beings are linked by material flows. Human actions are also governed by flows of information and money. For a better harmony between man and nature an understanding of flows and their feedbacks is essential. Holistic views of systems and related flows will allow increasing people's understanding and resulting actions. Knowledge transfer system must be developed. Scientists must learn about specific local situations and problems need to be solved locally.

The value of natural resources must be reckoned and public goods (ecosystem services) must be put in monetary terms. Knowledge on sustainable resource use could then be transferred into action if farmers can save/make money when managing environmentally sound.

Legal regulations are important but laws must also be enforced. Chinese media should report on existing environmental problems. More openness is still needed for a sound environmental development.

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可持续土地利用与生态保护

2009 年 5 月 4 日——7 日在中国北京召开的
“可持续土地利用与生态保护”中国环境可持续发展生态研究项目（ERSEC）国际会议总结

1 背景

中国环境可持续发展生态研究项目是中华人民共和国教育部、德国联邦教育科研部以及联合国教科文组织驻华代表处共同努力的结果。旨在通过在科学家和决策者之间展开对话，来促进中国生态研究成果的实际运用。作为德国联邦教育科研部科技合作的双边伙伴，中国科技部也积极参加了该项活动。

2009 年是中德科学和教育年，同时也是中国农业大学和德国霍恩海姆大学合作 30 周年纪念。这次“国际可持续土地利用与生态保护会议”就是在这两个重要事件的背景下举办的。这项综合性的活动旨在通过开办信息交流研讨会来加强由德联邦教育科研部（BMBF）、中华人民共和国科学技术部、德国技术合作公司（GTZ）、中国国家自然科学基金委员会(NSFC)、德国科学基金会（DFG）以及其他中德合作组织资助的中德合作科研项目之间的交流与合作。因此，与会者们极大地促进了中德在可持续发展、环保等领域科研合作的国际知名度。通过向决策者们提供专门建议，大会提高了科学研究成果的应用和推广，使有关可持续土地利用、水资源管理、食品安全、气候变化、生态和环境技术的多学科研究的交流和整合更加便利。这次国际性研讨会为讨论和共享双边合作研究经验提供了平台，从而极大地促进了相关国际科研方面的合作。

中国在过去 30 年中飞速的社会和经济发展已经对环境造成了重大影响。经济发展与环境保护之间的矛盾正日益显现。随着工业化和城市化进程的加速，对自然资源的需求也在不断增加，这将引起严重的土地退化、荒漠化及森林覆盖率降低，由此对环境构成了极大威胁。由于缺乏合适的先进技术，中国的能源利用效率还较低，与此同时，工业、电力、交通、建筑部门在推广“绿色技术”方面仍然面临着许多困难。如何将低碳经济模式引入经济快速增长的社会是中国面临的另一项挑战。中国的农业正承受着来自气候变化，生态系统退化和人均耕地面积少的压力。污染对中国的水资源的威胁尤其巨大，因为中国人均淡水水资源占有量只有世界平均水平的四分之一。由于区域生态恢复的不平衡，中国的西部，尤其是西北部，面临着维持资源环境可持续性的巨大挑战。显然，中国西部脆弱的生态环境是社会经济发展和发挥其潜在优势的最主要制约因素。

科学和技术在创造可持续资源利用的先进知识方面发挥着重要作用。技术革新为我们提供了解决问题的方法，科学知识向相关部门的整合和扩散必须受到充分重视，而不仅仅简单地强调对科研工作的支持。在发展制度的基础设施中，相关的政策，规章和标准起着决定性的作用，这对可持续发展的规划和实施是很有必要的。

2 会议总结

2009 年国际可持续土地利用与生态保护会议聚集了来自中国、德国以及世界各地的专家们。大会还囊括了现实案例分析，与会专家针对大会的主要议题进行了积极的讨论。

这次会议的重点直接针对中国在土地和水资源管理方面的相关决策者、政府机构以及广大公众。这次会议为中德土地生态研究领域的专家们以及其他领域的科学家们构建了一个互动平台，他们充分讨论，整合，交换了他们的研究结果。大会讨论的主要目的在于运用非专业性语言来形成并完善既具有社会经济可行性和又有助于环保的政策建议。此次会议报告和讨论的内容随后将以会议记录的形式出版。

大会讨论的五个主要方面有：
1. 主题演讲 （农村地区贫困问题、入侵物种对食品的威胁）
2. 可持续生态环境管理
3. 养分循环
4. 水资源管理
5. 农业经济

以下章节总结了主要议题、提出的问题、解决方案、重要发现、策略方针、实施障碍和建议。

主要议题

大会讨论的主要议题涵盖了土地可持续利用和生态保护的方方面面，全面纵览了当前和近期相关领域的科研活动。具体议题如下：
- 粮食绿色革命 / 清洁粮食生产 (Rozelle, 2009)
- 外源入侵物种 (Wan and Guo, 2009)
- 生物多样化问题与管理 (Wan, 2009; Moinuddin and Xi, 2009; Sauerborn et al., 2009a; Tennigkeit et al., 2009; Tang et al., 2009; Liyanage et al., 2009)
- 碳循环 (Wan,2009; Huang, 2009)
- 社会、经济和生态的内在联系 (Sauerborn et al., 2009a)
- 农业生态多样性与气候变化(Waldmueller, 2009)
- 水资源保护(Steusloff and Birkle, 2009)
- 人与自然的生态安全(Innocent et al., 2009)
- 生态系统服务评估(Moinuddin and Xi, 2009)
- 农作物间套作生产体系 (Li, 2009; Feike et al., 2009)
- 杀虫剂的可持续利用(Devi et al., 2009)
- 氮沉降、处理及管理 (He et al., 2009; Ju, 2009; Ganeshram,2009; Shi, 2009)
- 全球变化之影响 (Butterbach-Bahl et al., 2009; Yin, 2009, Haas et al., 2009)
- 有机废弃物回收利用(Lu and Yan, 2009)
- 可持续水资源管理 (Fuhrmann, 2009; Salih, 2009; Monninkhof et al., 2009)

- 雨洪利用 (Monninkhoff et al., 2009; Xu et al., 2009)
- 对例如麻风树等生物质能作物的若干问题研究 (Huang et al., 2009; Schweers et al., 2009; Makkar et al., 2009)
- 生物技术／抗虫棉 (Waibel et al., 2009)
- 肥料的高效使用 (Boeber et al., 2009; Sun et al., 2009)
- 土地利用开发 (Liyanage et al., 2009;, Tang et al., 2009)

提出的问题

在大会所涉及的五个领域中的每一领域都有问题被提出。这五个领域具体包括：综合领域、可持续生态系统和环境管理领域、养分循环领域、水资源管理领域、农业与经济领域。

综合性问题：

- 农村地区的贫困问题 (Rozelle, 2009)
- 入侵物种对粮食作物的威胁 (Wan and Guo, 2009)
- 现代生活方式和贫困的对比 (Sauerborn et al., 2009a)
- 杀虫剂中毒害物质对公众健康的危害 (Devi et al., 2009)

可持续生态系统和环境管理：

- 城市化给土地利用／发展带来的压力 (Kagelmacher, 2009)
- 气候变化所导致的遗传资源消失、生物系统退化、长期粮食供应不足和贫困问题 (Waldmueller, 2009)
- 森林覆盖率严重退化及热带雨林破碎化 (Moinuddin and Xi, 2009)
- 草原土壤退化／碳挥发(Butterbach-Bahl et al., 2009)
- 草原退化 (Wilkes and Tennigkeit, 2009)
- 生物多样性的缺陷 (Tennigkeit et al., 2009; Liyanage et al., 2009; Tang et al., 2009)

养分循环：

- 过度施肥和水资源污染 (Ju, 2009; Shi, 2009; Monninkoff et al., 2009; Yang, 2009; Höll et al., 2009; Kuehl et al., 2009; Ganeshram, 2009)
- 中国北方平原的肥料效率与地下水位下降和地下水短缺 (North China Plain: Sun et al., 2009; Shandong Province: Monninkoff et al., 2009; Kuehl et al., 2009; Global and local: Steusloff and Birkle, 2009; Xu et al., 2009)
- 钾肥使用的安全性及风险研究 (Werner, 2009)
- 有机废弃物的循环利用 (Lu and Yan, 2009)

水资源管理：

- 水资源短缺
- 中国北方平原地下水位下降和总体水资源短缺(North China Plain: Sun et al., 2009; Shandong Province: Monninkoff et al., 2009; Kuehl et al., 2009; Global and local: Salih, 2009; Steusloff and Birkle, 2009; Xu et al., 2009)
- 气候变化和可持续发展目标之对比 (Yin, 2009)
- 水污染
- 污染 (Chao lake: Fuhrmann, 2009; Yangtze river, Shandong: Monninkoff et al, 2009;

Yang-Yellow River: Höll et al., 2009; Kuehl et al., 2009; Taihu lake: Shi 2009, River Tyne and Tweed river estuaries: Ganeshram, 2009)
- 引用水安全、水资源短缺、污染等问题同可持续性农耕、可持续社会之对比 (Wagner, 2009; Kühl et al., 2009)
- 水资源循环利用 (Xu et al., 2009)

农业经济：
- 生物质能与粮食作物之间的矛盾日益加深 (Huang et al., 2009; Schweers et al., 2009)
- 正确处理转基因粮食(Waibel, 2009)
- 尿素肥料的使用及其环境代价(Böber et al., 2009)

使用的调研方法

中德项目所使用的调研方法包括：分析的、基于模型的、实验的、统计的、参与式的和综合的调研法。

分析调研法：
- 遥感监测 (Yin, 2009; Schweers et al., 2009)
- 转动生物反应器 (Höll et al., 2009)
- 15N 示踪技术 (Ganeshram, 2009)
- 热成像技术 (Zia et al., 2009)

基于模型的调研法：
- 生态系统服务 (Moinuddin and Xi, 2009)
- 以地理信息技术系统为基础的模型调研法 (Kagelmacher, 2009; Steusloff and Birkle, 2009; Yin, 2009; Monninkhoff et al., 2009; Berkhoff et al., 2009; Schweers et al., 2009)
- 综合数据库、快速报警系统及风险评估 (Wan and Guo, 2009)
- 岛屿规模的生态系统模型 (Vitousek, 2009)
- 情景分析中应用决策支持系统（DSS）(Steusloff and Birkle, 2009; Monninkhoff et al., 2009)
- 综合式水文模型(Huangshui River Basin: Monninkhoff et al., 2009; Berkhoff et al., 2009)

实证分析与统计调研法：
- 入户调研(Yin, 2009; Kühl, 2009; Böber, 2009)
- 定性实证研究方法 (Tang et al., 2009; Böber et al, 2009)
- 经济计量学 (Waibel et al., 2009; Böber et al., 2009)
- 生态经济模型 (Waibel et al., 2009)

参与式调研法：
- 综合参与式调研法(Waldmueller, 2009; Shi, 2009)
- 政策会议(Yi, 2009)

- 实习培训 (Paulussen and Weinand, 2009)

综合性调研法：
- 中德跨领域合作项目(Sauerborn et al. , 2009a)
- 综合模型法 (Berkhoff et al., 2009)

会议主要发现及提出的相关策略

会议的主要发现表明在实现对自然资源分配和使用的优化管理上，科技革新为此提供客观条件，适当的政策和社会活动与科技发展扮演着同等重要的角色必须受到充分重视。与此同时，对可供农民人口使用的简单、容易操作的技术的需求仍很高。
综合性发现和策略：
- 保护区所采取的一些旨在促进当地社区经济发展与生物多样性并重的措施成效有限，更凸显了当地的平困问题 (Rozelle, 2009)

生物系统可持续发展和环境管理：
- 农田生物多样性管理改善了景观水平的生物多样性 (Waldmueller, 2009)
- 在中国西北地区，一定条件下间作系统具有明显竞争优势 (Li, 2009)

养分循环：
- 过量施肥在中国的集约化农业生产体系中是一个严重问题 (He et al., 2009; Ju, 2009; Shi, 2009; Sun et al., 2009)
- 华北平原地区氮素干、湿氮沉降对农田养分输入的贡献必须受到重视。每年每公顷农田所接受的氮沉降量高达 90 千克，其中 60%可直接被农作物吸收，因此这部分氮素不容忽略 (Liu, 2009)
- 当前氮肥推荐应综合考虑土壤、大气沉降和灌溉水的供氮潜力 (Ju, 2009)
- 为了达到养分高效及保持更好的环境质量，政策和社会活动与技术对水稻生产中肥料养分的综合管理同样重要 (Shi, 2009)
- 过度放牧极大地影响了中国北方牧场生物圈和大气圈之间的温室气体如二氧化氮的交换
- 冬季排放的减少
- 羊厮肥导致甲烷和二氧化氮排放量的增加
- 减缓甲烷排放上升的速度
- 羊厮肥产生的温室气体排放的增加 (Butterbach-Bahl et al., 2009)

水资源管理：
- 农业已经成为长江上游的主要污染源，而且未来对农业水污染的有效管理极具挑战性 (Yang, 2009)
- 研究发现地下水的反硝化作用与杀虫剂清除作用可以同时进行 (Höll et al. , 2009)

农业经济：
- 利用有机废弃物再生沼气系统来处理有机废弃物在中国非常重要(Lu and Yan, 2009)

- 通过半集中化处理来实现节约能源是可行的 (Wagner, 2009)
- 由科技和教育作支撑的知识传播和合作伙伴关系至关重要 (Paulussen and Weinand, 2009)
- 抗虫（Bt）棉在农户水平上的经济优势已得到验证 (Waibel et al., 2009)
- 农民人口对环境恶化的认识有所加强 (Tang et al., 2009)

执行阻碍

近年来，过快的发展阻碍了诸多可持续发展领域有关倡议的实施，例如：
- 由科学知识到实践的传播系统较弱
- 过快的城市化进度，而难以保证城市周密规划所需的时间 (Kagelmacher, 2009)
- 经济限制 (“天空农业”)（ Sauerborn et al. , 2009b)
- 生物圈的保护和经济发展需求的矛盾 (Waldmueller, 2009)
- 城乡教育投入不均
- 在建立生物多样性保护机构上缺乏共识 (Tennigkeit et al., 2009)
- 个人土地所有制不利于对生物多样性作出合理的评价(Liyanage et al., 2009)

大会建议

- 需要形成跨领域思维模式来重新审视城市密度问题 (Kagelmacher, 2009)
- 平衡可持续发展的三个支柱（生物、经济和社会）(Sauerborn et al. , 2009b)
- 实现 4F 生产与大城市区域之间的平衡（例如：“空中农场”，包括补偿金措施）(Sauerborn et al. , 2009b)
- 制定生物质能和生物多样性国家策略 (Waldmueller, 2009)
- 集成 IAS、生物多样性状况、城市发展和生态服务数据 (Invasive alien species: Wan and Guo, 2009; biodiversity status: Waldmueller, 2009; urban development: Kagelmacher, 2009; ecosystem services: Moinuddin and Xi, 2009)
- 优化放牧管理计划 (Butterbach-Bahl et al. , 2009)
- 优化对粮食作物体系的管理 (according to water consumption; Sun et al., 2009)
- 制定节水措施、中水循环利用、废水回用 (Monninkhoff et al., 2009)
- 充分考虑生物质能作物与农作物的竞争关系，谨慎发展生物质能作物(Huang et al., 2009; Schweers et al., 2009)
- 实地培训农民 (Böber et al., 2009)
- 改善科技知识向农民人口传播的渠道（需要发展简单、易操作的技术） (Shi, 2009)
- 建立可持续农业生物多样性管理系统 (Tennigkeit et al., 2009)
- 考虑取消政府对农业尤其是肥料的补贴 (Ju, 2009)
- 具体部门策略的介绍(Wilkes and Tennigkeit, 2009)
- 实行类比林业 (Liyanage et al., 2009)

3 圆桌会议讨论与结论

在 2009 年中国环境可持续发展生态研究国际会议上所讨论的主要议题和提出的问题都表明了中国所面临的问题也是世界的问题（包括耕地流失、水资源缺乏、过

度施肥、人口增长、城乡差距和全球变化）。

中国近几十年的飞速发展证实了中国完全有能力在短期内产生深刻的变化。未来的挑战在于中国必须在环保和经济发展之间寻求社会发展的平衡点。对人力资源的投入在平衡各种不同的发展速度中起着至关重要的作用。中国正处于由传统朴素的生活方式向西方生活方式转变的转型期。这意味着中国的生态足迹将进一步扩大。中国必须探索一条新路，将中国的优良传统结合西方先进的技术一同引入到未来的发展中去。 随着人们生活水平的进一步提高，畜牧业生产的重要性在中国日显突出，因此未来的科研项目必须考虑到畜牧业（养分通量）。大量的畜牧业生产会给肥料管理和饲料供应带来一系列的问题。将来中国可能没有足够的耕地来满足肉类产品生产的饲料需求，这将导致肉类和养料需要靠进口来供给。

大会提出了许多独立的问题及其相应的解决方案。然而，由于大部分的问题都彼此关联、纵横交错，因此将来很有必要展开跨领域的综合科研项目，来研究针对这些问题的全面性解决方案，尤其应加强经济学家和生态学者之间的合作。

目前，有关知识是存在的，但是其并不能被每个人都享有。将科技知识以恰当的形式传播给决策者、地方官员、从事政府推广性服务的实体和当地百姓（当地农名人口）有待进一步提高 （例如，肥料推荐）。在中国的五行学说中就提到人和自然是通过物质的流动联系在一起的。信息和资金的流动也会影响到人类活动。在人类和自然之间寻求更大的和谐，我们必须理解以上这些物质的流动及其产生的影响。对整个系统及其发展方向的全面观察将有助于加深我们的理解从而提出解决方案。知识推广系统有待进一步完善。科学家们必须加深对各个地区具体情况的了解，不同的问题应该因地制宜地来解决。

自然资源的价值必须得到充分认识，公共产品（生态服务）必须以金钱的形式体现出来。当广大农名人口意识到环保经营可以帮他们节约资金，那么自然资源可持续利用的知识就会转变成行动。

法律规范至关重要，因此必须加强相关法制建设。中国媒体应充分报道现存环境问题。环境发展的透明度应进一步加强。

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