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Agriculture, Ecosystems and Environment 105 (2005) 507–522
Agriculture Ecosystems & Environment
www.elsevier.com/locate/agee

Three dimensions of sustainability of farming practices in the North China Plain
A case study from Ningjin County of Shandong Province, PR China

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Received 29 April 2003; received in revised form 6 May 2004; accepted 10 July 2004

Abstract

The current pressure on production resources of the People's Republic of China, such as land and water to feed the growing population, necessitates the assessment of farming practices. This is particularly critical in the North China Plain, which is the food bowl of the country. This study assesses the economic, environmental and socio-institutional aspects of the major cropping systems in the NCP, based on selected site-specific indicators and their established threshold limits. Necessary information for this study was obtained through a survey of 270 farm households from four villages in Ningjin County, soil sample analysis, chemical tests of nitrate concentration in groundwater and crop plants, field observation and discussions with key informants, as well as official reports and publications. The findings of the analysis revealed all cropping systems in the study area are economically viable. However, such achievements have been made at a cost to the environment, degradation of natural resources and risk to human health. The real costs of environmental degradation are mounting, taking the forms of groundwater depletion, soil salinization and compaction, and land subsidence over the decades, as well as nitrate contamination in groundwater and agro-products, farmers' sickness, and loss of insect and pest predators. Sensitivity analysis shows that crop production reacts sensitively to changes of output price and in input costs, which implies an unstable production situation in a long period. Only about 6% of the surveyed farm households applied the recommendations of the corresponding agents for balanced input use. The study stresses that farming practices, which are economically viable, should not be promoted at the cost of the environment,

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doi:10.1016/j.agee.2004.07.012

otherwise, it would cause acute damage to the environmental and economic loss for the future. Several recommendations have been outlined for the promotion of sustainable cropping systems in the NCP.

Keywords: Indicators; Threshold values; Farming practices; North China Plain

1. Introduction

The North China Plain (NCP) produces about one-fourth of the country's total food grains. Increasing pressure on the land has made many of the traditional farming practices increasingly difficult to sustain, such as manuring, composting, mulching, legume-based rotations, field levelling and fertilizing with mud from rivers and canals. To cope with this pressure on the land and to maintain its fertility, farmers in the area—over the past three decades—adopted high-yielding, external-input driven production technologies from western countries to complement and replace their traditional internal-input-based production technologies and practices. At present, crop production in the area depends heavily on irrigation with groundwater and the application of mineral fertilizers and pesticides. In many parts of the NCP, groundwater exploitation exceeds groundwater recharge by a factor of up to 1.5 m (Liu et al., 2001). Without the application of mineral fertilizers the country cannot sustain the food needs of the increasing population (Cheng and Han, 1992; Lo and Xing, 1999). Excessive use of these main inputs has led to land degradation in many parts of the area and has also had adverse impacts on the environment. Groundwater tables have declined due to increased irrigation, resulting in increased incidents of land subsidence. Excessive application of mineral fertilizers and pesticides has led to the contamination of crops, soils and the groundwater.

Pretty (2002) defines that sustainable agriculture seeks to make the best use of nature's goods and services, of the knowledge and skills of farmers, and of people's collective capacity to work together to solve common management problems. Such systems are improving soil health, increasing water efficiency and reducing dependency on pesticides. Uphoff (2002) addresses the importance of advancing agroecological agriculture with participatory practices by arguing that the aim of the agricultural enterprise should be to produce secure and healthy people, not just food, and farmers should be involved actively as partners with scientists and extensionists for devising, testing and evaluating new practices, not just adopting them. Despite the diversity in conceptualizing sustainable agriculture, there is a consensus on three basic dimensions of the concept (Cai and Smith, 1994; Hansen, 1996; Pretty, 1996; Rigby and Caceres, 2001; Wiren-Lehr, 2001). These are: (i) 'ecological soundness', which refers to the preservation and improvement of the natural environment; (ii) 'economic viability' which refers to maintenance of yields and productivity of crops and livestock; and (iii) 'social acceptability' which refers to self-reliance, equality and improved quality of life. Rasul and Thapa (2004) share such a view. Sustainable agriculture in this study is conceptualised, based on three dimensions of the concept, as follows:

- Environmental soundness: reasonable use of external inputs to prevent land and water resources degradation and reduce the risks of human health hazards.
- Economic viability: ensure stable and profitable production activities.
- Socio-institutional acceptance: ensure food self-sufficiency and a greater adoption of resource conservation technologies and practices to control or prevent resource degradation through effective institutional services.

Sustainable agriculture is a time- and space-specific concept. In the long term, equal emphasis will be put on economic, environmental and socio-institutional development at national, regional and local levels (Zhen and Routray, 2003). A common problem in the assessment of farming practices is the acquisition and integration of suitable indicators that are spatially and temporally significant. If suitable specific indicators are selected, it is possible to predict system trends (Pretty, 1996). The interdisciplinary approach encompassing environmental, economic and socio-institutional aspects to assess farming practices in NCP is relatively new. Most studies in the region have been confined to the exploitation of the soil and water resources (Liu et al., 2001; Wang and Lou, 2001). Few studies have focused on water sufficiency and soil fertility analysis (CAS, 2000) and limited efforts have been made so far to assess farming practices using location-specific indicators and their threshold limits. Little is known about the effects of particular farming practices on the environment and the specific economic and socio-institutional factors influencing these practices.

For a typical agricultural area in the NCP, this study attempts to provide insight into the local farming practices. Three dimensional and location-specific indicators and their identified threshold limits are used for the assessment. These indicators cover environmental aspects, such as groundwater and soil conditions and management activities, economic aspect as represented by productivity and income, as well as social-institutional aspect such as food self-sufficiency and effectiveness of the extension services. A long-term assessment of farming practices is addressed using sensitivity analysis. Strategies for economically viable and conservation-oriented crop production are recommended.

2. Study area

Ningjin County is located on the northeastern part of Shangdong Province of the NCP (Fig. 1). It is located between 37°31′ and 37°50′ north latitude and 116°30′ to 117°00′ east longitude. The county has 18 communes with 856 villages. It has a total land area of 822 km^2 and a population of 440,000. The average population density is 535/km^2.

The county allocates more than 80% of its arable land to cereal production. Most farms in the area are small and subsistence based. The per-capita land area is about 0.10 ha. About 10 different crops are grown in the area. Winter wheat (*Triticum sativum*) and summer maize (*Zea mays*) are the principal crops, which occupy 75% of the total arable land, followed by cotton (*Gossypium*) that occupies 18% of the total land area. The remaining 7% of the land is used mainly for the cultivation of vegetables such as chives (*Allium schoengrasum*), etc. Less widely grown crops are peanut, sesame and sunflower. Irrigation is widely practiced, with groundwater as the only water source (IBNC, 2001).

Topographically the area is plain and homogeneous. The average altitude is 15.4 m above sea level. The soils are very uniform; they are of alluvial origin and dominantly loamy and moderately deep (SSODD, 1999).

The area has a continental monsoon climate (SBNC, 2000). It is characterized by an annual average temperature of 12.3 °C and annual precipitation of about 553 mm. The precipitation is unevenly distributed. High rainfall usually occurs in summer (April to September), accounting for about 78% of the total annual precipitation. The rainfall occurring between March and May accounts for only 11% of the total annual rainfall. However, this is the period most critical for crop-water demand. The rainfall occurring from October to February has a share of only 10% of the total rainfall, designating this period as dry. The average evaporation is 1319 mm, which is almost double the annual rainfall. Declining and uneven distribution of rainfall and high evaporation leads to an increase in irrigation-water demand.

The selection of the study area is based on the following criteria.

- Geographically the county of Ningjin is located at the central of the NCP. Agricultural production in the area plays an important role in ensuring food security of the country.
- The county has been adopting high input farming practices. Assessment of such kind of intensive production practices has increasingly attracted attentions of academics, planners and decision-makers. The county can represent the general situation of the NCP in terms of biophysical and socio-economic conditions, as well as agricultural production conditions.
- Selected villages of Dongliu, Daliu, Dagen and Dongcui can represent the general production situation of Ningjin County. Moreover, a project entitled "evaluation of agricultural resource utilization" has been completed in these villages by Chinese Academy of Sciences (CAS) during 1998–2000. The location specific findings of the project such as availability of existing soil and water

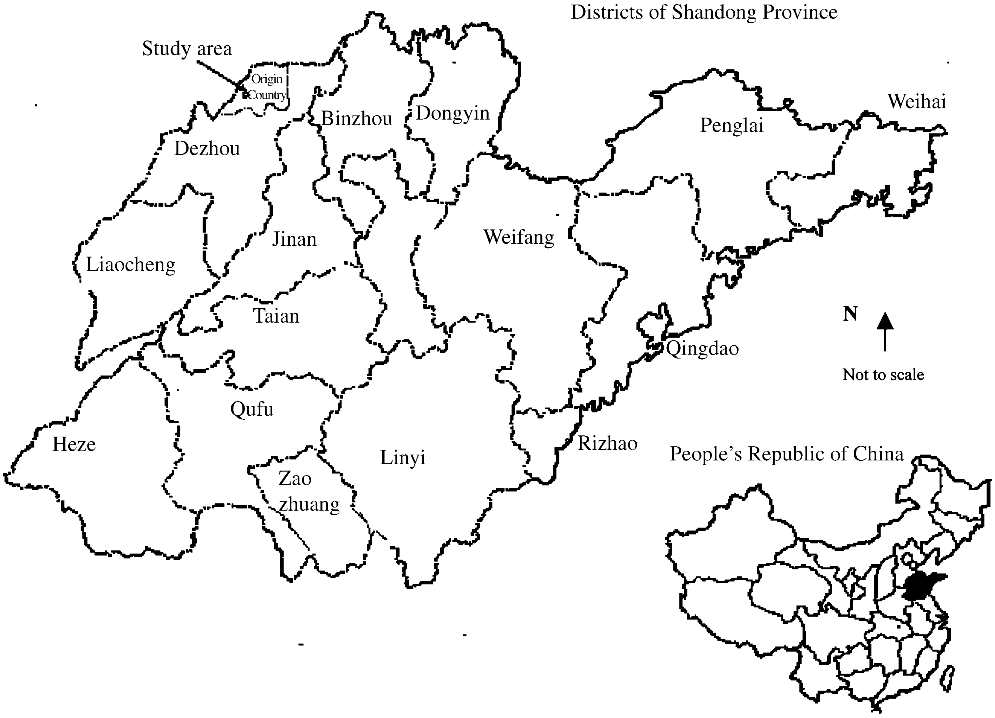

Fig. 1. Location of the study area in PR China.

resources can be used for the research. The four villages have been selected as many of the sample sites for soil survey and groundwater table and groundwater quality monitoring (SSODD, 1999; IBNC, 2001). Availability of site-specific data established strong bases for investigation of change trend of soil and water resources.

- There is no research on assessment of intensive framing activities and its impact on environment and poverty for the future having been conducted in the area.

3. Methodology

3.1. Data collection and analysis methods

Data were collected from both secondary and primary sources. Secondary data from statistical yearbooks and documents were collected from relevant government agencies. Primary data were collected through a household survey, focus-group discussions (FGD), and interviews of key informants, institutional surveys and field observations.

Data on current land management practices included farming practices, amount of irrigation-water use, the use of fertilizers and pesticides for the major crops (i.e., wheat, maize, cotton and chives), and farmers' perceptions and knowledge of resource conservation. A simple random sampling method was adopted to select households for the survey in four selected villages. The household survey was conducted between the first week of June and the last week of July 2001, and continued again from the first week of September until the last week of November 2001. Altogether, 270 households including 169 men and 101 women were interviewed. These are 41% of all households in the four sample villages.

The soil fertility status of wheat and maize fields has been surveyed right after the harvest of maize in September. Wheat and maize are cultivated in a cyclic way around the year. The analysis was performed on the plow layer (i.e., 0–20 cm). A total of 44 soil samples were analyzed for soil reaction (pH), soil organic matter (SOM) content, and the contents of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O). Fluctuations of the groundwater table were analyzed using groundwater-table data for the past 30 years obtained from the Water Survey Station of Dezhou District.

To investigate the environmental impact of current fertilizer-use practices, the nitrate contents of groundwater and chives plants were also measured. The sample tube wells drawing water for irrigation from shallow groundwater were randomly selected. All wells have concrete casings for protection from contamination by surface water and are fitted with electric or diesel-powered pumps. The tube wells were pumped for about 3 min to remove any stagnant water before fresh water samples were collected. A total of 20 samples were collected. All water samples were analyzed at the Irrigation Bureau of Dezhou District. Similarly, nitrate residue in chives plants was surveyed through testing 20 chives plants taken from the fields. Samples were analyzed at the Epidemic Prevention Station of Dezhou District. Net farm return for crop production was calculated using input and output data collected by the household survey. The cost of production inputs, such as labor, seeds, farmyard manure (FYM), mineral fertilizers, pesticides, irrigation, power tillers and land tax constitute the total costs. Total returns include the returns from products and residues, based on local market prices.

3.2. Selection of indicators and threshold values

Indicators have to be based on an understanding of the pressures on the environment and the processes through which human activity induces environmental change (Crabtree and Bayfield, 1998). OECD (2001) has identified a complete set of environmental indicators for agriculture, which includes the linkages and trade-offs between different management practices and their impact on the environment such as: whole farm management involving the overall farming system; and farm management aimed at specific practices related to nutrients, pests, soils, and irrigation. Use of farm inputs and natural resources including nutrient use, pesticide use and risks, and water use is critical to achieve a sustainable production system. Moreover, environmental impacts of agriculture are considered as most vital aspect of current production activities, and assessment indicators proposed cover soil quality, water quality, land conservation, greenhouse gases, biodiversity, wildlife habitats, and landscape. Farm income and private agri-environmental expenditure are proposed as important indicators measuring financial profitability of agricultural production activities. Zhen and Routray (2003) proposed a set of operational indicators for measuring agricultural sustainability in developing countries based on a critical review of relevant literatures over the past 15 years. These indicators include ecological indicators involving soil fertility and irrigation management, economic indicators such as crop productivity and profitability, and social indicators like food self-sufficiency, equality in food and income distribution among farmers, access to resources and support services, and farmers' knowledge and awareness of resource conservation. For the study, the indicators and their rankings were identified from published researches in NCP (Zhang, 1995; Wang et al., 1998; CAS, 2000; Zhang, 2000) and in cooperation with local experts and the farmers. The selected indicators and their threshold values are crop and site-specific. These indicators cover environmental aspects, such as depth to groundwater table, water use efficiency (WUE), soil-quality status as represented by soil pH, SOM content, N, P_2O_5 and K_2O content, and nitrate (NO_3^-) concentration in groundwater and chives plants. The economic indicators are crop productivity, per-capita food production, net farm return (NR) and benefit–cost ratio (BCR). Food self-sufficiency and adequacy and effectiveness of the extension services are used to assess socio-institutional aspect (Table 1). The selection of these indicators is based on the following three criteria. (1) Significance of the indicators for the study area. The selected indicators cover the major farming practices. (2) Practical applicability of the indicators selected. The indicators selected are all location specific; data for the measurement of each indicator are available at the local level. (3) Availability of threshold values of the indicators.

Threshold values are defined as analytically based reference values, for example, a maximum allowable ambient concentration of sulphur dioxide (Braat, 1991). The assumption is that the reference value represents a system condition that is necessary to achieve sustainability. For this study, the threshold values for the selected indicators are taken from the

Table 1
Threshold values for selected key indicators

Selected indicators	Rationale for selection	Threshold level				
		Very poor	Poor	Fair	Good	Very good
PH[a]	Nutrient availability to crops, soil acidity/alkalinity	>8.5	8.0–8.5	7.5–8.0	7.0–7.5	6.0–7.0
Soil organic matter content (SOM) (%)[a]	Defines soil fertility and soil structure, water retention	<0.6	0.6–0.8	0.8–1.0	1.0–1.5	>1.5
Soil nitrogen (N) content (mg/kg)[a]	Capacity to support crop growth, environmental quality indicator	<45	45–60	60–75	75–90	>90
Soil phosphorus (P_2O_5) content (mg/kg)[a]		<3	3–5	5–10	10–15	>15
Soil potassium (K_2O) content (mg/kg)[a]		<50	50–75	75–100	100–150	>150
Water-use efficiency (WUE)[b] (kg/m^3)	Water conservation	<1.0	1.0–1.5	1.5–2.0	2.0–2.5	>2.5
Nitrate (NO_3) concentration in groundwater (mg/l)[c]	Environmental impact of fertilizer use	>50	>50	50	<50	<50
Nitrate (NO_3) residue in chives plants (mg/kg)[d]		>700	>700	700	<700	<700
Net return of crop production (US$/ha) (NR)[e]	NR > 0 implies that crop production is financially viable	<0	<0	0	>0	>0
Benefit–cost ratio (BCR)[e]	BCR > 1 implies that crop production is financially viable	<1	<1	1	>1	>1

[a] Wang and Xin (1998).
[b] CAS (2000).
[c] Zhang (1995).
[d] Hu et al. (1996).
[e] Zhang (2000).

experimental research conducted locally. For instance, threshold values for soil fertility indicators are established by Wang and Xin (1998) based on three years field experiment in the area; maximum concentration of NO_3 of 50 mg/l in groundwater has been proposed by the World Health Organization (WHO, 1984) and further adopted by Chinese Government, which implies that if NO_3 concentration in groundwater exceeds 50 mg/l, there would be potential risks on human health (Zhang, 1995). Threshold values for net return (greater than zero) and benefit–cost ratio (greater than one) are well recognized and further established by Zhang (2000). Indicator values will be compared with predetermined threshold values for making judgment on the condition of the system. The implications and assumptions of the threshold values are (Walker and Reuter, 1996) as follows.

- "Very good" and "good" mean that there is no indication of a problem or problematic trend.
- "Fair" is the borderline condition. Some actions are needed to address the problem or more detailed information should be sought to suggest how to stop a decline in the condition.
- "Poor" and "very poor" mean that there is indication of a problem or problematic trend. Urgent actions are needed to improve the condition.

4. Results and discussions

4.1. Environmental assessment

4.1.1. Groundwater use and its impacts

In Ningjin County, groundwater is the only source of irrigation. Each household has free access to groundwater resources. All irrigation systems are constructed by the farmers themselves using locally available materials and skills. This has led to an increase in the number of wells in the area, from 5872 in 1978 to 10,180 in 2000, with an average density of 20 wells/km^2.

Water is conveyed to the fields by plastic pipes. The farmers pump as much groundwater as possible in order to meet their irrigation needs. The quantity of groundwater actually used for irrigation is significantly higher (ANOVA test, $p < 0.001$) than the recommended quantity for all the crops under study, regardless of farm size and varieties of crops. For instance, the recommended quantity of water for one irrigation of wheat, maize, cotton and chives is 600–750, 525–675, 600–750 and 750–900 m^3/ha, respectively, while the actual quantity of water used is 975, 945, 1005 and 1,065 m^3/ha, respectively. However, the water use efficiency (WUE), which is defined as products produced per cubic meter of water (CAS, 2000), is very low. WUE of wheat, maize and cotton is 1.26, 1.45 and 0.60 kg/m^3, respectively, which is classified as poor to very poor (Table 1). Farmers' perception that groundwater is renewable and inexhaustible encourages them to use this resource in an inefficient way.

4.1.1.1. Depletion of groundwater table. The obvious effect of the over use of groundwater is the lowing of the groundwater table. This finding has been substantiated by farmers' observation and the temporal trend analyses of the groundwater table in the study area. About 97% of the farmers observed a decline of the groundwater table. One-tenth of the wells tend to dry up temporarily during summer season, a few of these wells have been abandoned. According to groundwater-observation data from 50 shallow wells in the study villages, the average depth of the groundwater table (the distance from the water level in the wells to the mean sea level) in 1970 was 12.36 m, which has been subsequently reduced to 7.73 m in 2000, indicating approximately an average annual water table decline of 0.21 m (Zhen and Routray, 2002).

The depth of the water table varies according to the season. It remains relatively stable (i.e., between 8.66 and 8.72 m) between November and February, as there is not much demand for irrigation during that period. However, it starts to decline sharply in April and reaches its lowest level in May at 6.37 m. These are the peak months for the irrigation of winter wheat.

4.1.1.2. Soil salinity and land subsidence. The total dissolved salt content has been used as an indicator of groundwater quality (Kandiah, 1990). For irrigation, salt concentration should be less than 0.5 g/l (CAS, 2000). However, the salt content of groundwater in the area is 0.65–1.40 g/l (IBNC, 2001). Farmlands have been affected by salinity and soil compaction. Moreover, loss of sub-surface hydraulic pressure due to groundwater depletion has resulted in widespread land subsidence in the entire NCP, including the study area. As of 1995, 17 land subsidence areas had been identified (Liu et al., 2001). It is found that the depression cone in the study area had increased from 54 km^2 in 180 to 330 km^2 in 1999. The annual rate of increase of the depression cone has been estimated to be 30 km^2 in the years to come (SSODD, 1999).

4.1.2. Soil fertility management and its impacts

The farmers in the area use fertilizers very intensively to maximize crop yields. The major sources of plant nutrients are inorganic fertilizers followed by farmyard manure (FYM) and crop residues. The inorganic fertilizers used are mainly nitrogen, phosphate, and potassium, which are available everywhere in the area and the farmers have the cash to purchase these fertilizers. The main source of FYM is the livestock reared by households, but some FYM is also purchased. The FYM is applied to the field during the land preparation. Crop residues being used as fertilizer is mainly wheat straw that is left in the field while harvesting the crops.

The weight of inorganic fertilizers applied is converted into content of N, P_2O_5, and K_2O for nitrogen, phosphate, and potassium respectively according to conversion factors defined for NCP (Fan and Fen, 1999). Compared with the application rates recommended by the extension service, FYM and K_2O are used in insufficient amounts, while N and P_2O_5 are over-applied. Nitrogen is significantly overused for all the crops (Table 2).

The study revealed that the majority of farmers (65%) prefer to use a combination of organic and inorganic fertilizers, because of the positive effect of manure on structure, aeration and water holding capacity of the soil. The application of FYM by farmers is limited by its inadequate availability. Farmers are not aware of the recommended dose of inorganic fertilizers and the consequences of over use of such fertilizers. They normally apply fertilizers together with irrigation, which accelerates the rate of nutrients leaching into the groundwater.

Table 2
Actual and recommended fertilizer application rates for different crops (kg/ha)

	N		P_2O_5		K_2O		FYM (1000)	
	RD	AD	RD	AD	RD	AD	RD	AD
Wheat	210–255	375	90–120	150	7–9	45	63–108	34
Maize	165–210	240	90–105	45	5–7	15	63–90	43
Cotton	195–240	360	60–90	105	7–9	NA	NA	NA
Chives	600–750	1035	375–525	660	35–45	645	90–126	49

RD: recommended dose, AD: actual dosage applied by farmers, NA: not applied. *Sources*: SSODD (2001), Field Survey (2001).

4.1.2.1. Soil fertility status. Soil fertility as reflected by the selected indicators (i.e., SOM, N, P_2O_5, and K_2O) has improved over the past 20 years. During 1982–1999, SOM content increased from 0.85 to 1.16%, N from 64 to 70 mg/kg, P_2O_5 from 7 to 15 mg/kg, and K_2O from 108 to 123 mg/kg (SSODD, 1999). Soil pH in the study area has been assessed as *fair* (i.e., moderately alkaline) (Table 3). This means that soil pH should be further improved to ensure crop production and conserve soil resources.

Soil organic matter (SOM) is considered as a key indicator of soil quality (Nortcliff, 2002). The majority (85%) of the farms have *good* or *very good* soil organic matter levels. This can most probably be attributed to the massive return of crop residues to the fields and application of FYM as fertilizers.

The soil tests revealed that a large percentage of farm plots have no problem in terms of nutrient contents (Table 3). About 60% of sampled plots have fair N level. Likewise, they were generally rated as good, with 85% of the farm plots in the good and very good levels of P_2O_5 range. Potassium levels are generally fair in 50% of the households, while 20% of the farm plots have below the required level.

4.1.2.2. Contamination of groundwater and chive plants. Nitrate (NO_3) contamination of groundwater resources and chive plants is one of the immediate effects of overuse and inappropriate method of use of inorganic fertilizers. A study on water quality in the study area found 16 out of the total 20 sampled wells contained nitrate levels that exceed the maximum allowable limit of 50 mg/l (WHO, 1984; Zhang, 1995) for drinking water. A significant positive relationship was noticed between the amount of nitrogen fertilizer used and the nitrate content in groundwater. A similar situation exists in other counties of NCP (Zhang, 1995). Farmers do not consider groundwater pollution as a problem because groundwater normally appears clean to them. They think that water pollution affects the surface water-bodies such as rivers, streams and ponds.

Field crops have also been affected by the overuse of inorganic fertilizers. The level of NO_3 concentration in crops such as chive exceeds the threshold value of 700 mg/kg (Hu et al., 1996). On average, NO_3 content of chive is 1533 mg/kg that is more than twice of the threshold value. A significant positive relationship was found between the amount of N input (which is converted from the total weight of nitrogen applied) and the nitrate (NO_3) content of chive ($r = 0.855^{**}$,

Table 3
Soil-fertility status of the farmland for the sampled households

Threshold levels	pH	SOM (%)	N (mg/kg)	P_2O_5 (mg/kg)	K_2O (mg/kg)
Very poor	–	0.32 (2)	36 (7)	–	–
Poor	8.1 (36)	0.74 (4)	55 (7)	–	68 (20)
Fair	7.7 (44)	0.91 (9)	67 (59)	9 (15)	88 (50)
Good	7.4 (20)	1.18 (71)	81 (25)	12 (64)	127 (30)
Very good	–	1.57 (14)	98 (2)	17 (21)	–

Based on Table 1. Figures in parentheses are percentages of sampled plots. *Source*: Field Survey (2001).

$p < 0.01$), indicating that high NO_3 concentration in chive is caused by high use of nitrogen fertilizer.

4.1.3. Pests and diseases management and its impacts

Pests and diseases are serious problems in the study area. Therefore, all farmers use pesticides, which are cheap and freely available. All of the farmers use knapsack sprayers to spray pesticides, as the capital cost is relatively small. Commonly used pesticides are *omethoate*, *parathion* and *phorate*. These are highly toxic organophosphate pesticides. *Juzhi* is a cyanide compound that is classified as extremely hazardous by the Ministry of Agriculture (MOA). *Lesiben* is a pyrithroid that is defined as slightly hazardous by MOA (1996). To enhance the effectiveness of pesticide's effect, farmers' usually apply high doses. The average application rates of pesticides are two to three times higher than the recommended dosages. For instance, recommended dosage of *omethoate* is 750–1050 and 900–1200 g/ha for cereal crops and cotton, respectively (SCPNC, 2001), while the actual dosage used is 2100 and 1800 g/ha, respectively.

4.1.3.1. Human health hazards. Over use combined with inappropriate handling of fertilizers and pesticides have severely impinged upon farmers' health. About 20% of the farmers reported problems of headache, dizziness, nausea, stomachache, skin rashes and fatigue caused particularly by the use of pesticides. The frequency of their visit to the doctors and money spent on health check-ups and medicine during farming seasons are obviously higher than off-farm seasons of a year. As reported by 21% of the respondents, they have to visit doctors two to three times during the farming seasons. This finding is consistence with the findings of other studies conducted in the area (Zhang, 1995; Wu, 1999). The majority of the farmers (63%) perceived that pesticides and inorganic fertilizers are contaminating soil and water resources. Symptoms mentioned were dying earthworms, which are very useful agents for improving soil structure, and aquatic life such as frogs, as well as diarrhea of animals after taking water from sources near their fields. Pesticide residue was also detected in chive plants, with an average content of *omethoate* 0.09 mg/kg (EPSDD, 2000).

4.2. Economic assessment

4.2.1. Crop productivity

The average yields of major crops in the study area were found to be higher than the national average yields of the corresponding crops. As of 2001, wheat and maize yields in the study area were 5325 and 6045 kg/ha, respectively, while the national average yields were 3975 and 4875 kg/ha, respectively. Similarly, the yield of cotton was 3060 kg/ha, while the national average was 2865 kg/ha; Chive yield was 34,110 kg/ha in comparison with national average of 30,675 kg/ha.

Productivity of crops has increased over the past 48 years. Wheat yield has increased more than ten fold, i.e., from 600 kg/ha in 1962 to 6060 kg/ha in 2000, and maize more than four fold, i.e., from 1650 kg/ha in 1962 to 6300 kg/ha in 2000. The per-capita grain production has increased more than six fold, i.e., from 160 kg/year/capita in 1962 to 850 kg/year/capita in 2000. During the field survey, about 98% of farmers responded that the yield of wheat and maize were increasing gradually. A similar trend was reported for cotton, by 88% of the farmers. Approximately 92% of vegetable growers mentioned about such since the cultivation of this crop in 1993. Farmers' assessment of such yield increase is corroborated by findings of a study covering the entire NCP (SBNC, 2001).

4.2.2. Per capita grain production

The target of agricultural development of the country has been mainly to keep food production at par with population growth. Given high population pressure and limited land resources, crop production and food security in the Chinese context is normally measured using an indicator of per capita grain production. In Ningjin County, per-capita grain production shows a steadily increasing trend over the past 50 years. The annual increment rate was about 14 kg per capita during 1949–1999. As of 2000, per capita grain production had reached 854 kg that is more than double of the national average figure. Most farmers (93%) in Ningjin County have an annual surplus per-capita food-grain production exceeding 400 kg; about 7% of farmers have sufficient production to meet the household demand for food grain. This indicates a remarkable achievement made in increasing the per capita food production, thereby enabling farmers to improve their economic condition.

4.2.3. Profitability

All major crops have net returns (NR) that are far greater than 0, and the benefit–cost ratios (BCR) are also far greater than 1, irrespectively of the villages. The NRs of wheat, maize, cotton and chives are 139, 262, 668 and 8689 US$/ha, respectively; and the BCRs are 1.21, 1.48, 1.79 and 2.88, respectively. Therefore, all major crops grown in the area are financially viable. Chives have higher NRs and BCRs, followed by cotton and food grains.

A financial analysis uses the actual prices at which inputs are purchased and outputs are sold. It examines the potential benefits to the farmers. However, it does not look at environmental impacts. These impacts are often not valued in monetary terms. As defined by Beets (1990), ‘‘sustainable economic development involves maximizing the net benefits of economic development, subject to maintaining the services and quality of natural resources over time’’. Therefore, environmental costs as identified in the previous sections, must be taken into consideration while conducting economic assessment.

4.3. Sensitivity analysis of crop production

Sensitivity analysis was used to analyze possible future scenarios of the production system in the study area related to changes in both inputs and outputs (Hansen and Jones, 1996). And it can predict future environmental and economic situation in relevant to production activities. Results of the sensitivity analysis for five assumed scenarios are shown in Table 6. The figures indicate that—for most of the scenarios tested (i.e., scenarios 1–5 in Table 6)—NRs and BCRs will be declining compared with the current situation. Crop production reacts more sensitively to a fall in output price than an increase in input costs. The net return from wheat production will be negative if input costs increase and output price decrease simultaneously, or if yields decrease in the future. It is anticipated that irrigation cost in the study area will double within the next 10 years if current groundwater-use practice and the depletion of the groundwater continues (CAS, 2000). Under this scenario, production cost will increase and NR and BCR will decrease, which implies in a long term, environmental damage caused by intensive input use will increase but economic benefit from production will decrease and hence lead to poverty for the future. However, if farmers adopt the recommended fertilizer, pesticide and water-application rates—rather than to overuse these inputs as they currently do—input costs can be reduced leading to increases in net returns and BCRs in a long run. In this case, the financial benefit from crop production can be improved (Table 4). Also, the groundwater saved will contribute to narrow the gap between groundwater use and recharge.

4.4. Socio-institutional assessment

Food self-sufficiency and efficiency of the extension services are used to assess socio-institutional aspect of the farming practices. The study reveals that the area has already achieved self-sufficiency in food production. Crop production is safeguarded by growing more than one crop or variety in space and time in a field. The growth trend in food grain production is based on the following assumptions: firstly, increased productivity of food grains was achieved in the mid 1960s and early 1970s due to the introduction of green-revolution technologies, especially fertilizers, irrigation and high-yielding varieties. Secondly, food grain production for a growing population has also been enhanced by the government policy that farmers have to reserve 80% of their arable land for food-grain production. Thirdly, originating from the farmers' traditional thinking is that ‘‘food is the life of human beings’’, they are keen to explore and adopt all means to increase food production to create a feeling of a safe and a stable life with enough food reserves at home.

In a conventional context, agricultural extension is expected to transfer technology to farmers. Farmers need to be aware of, for example, the soil-fertility status in their fields and they need to know how soil fertility can be improved, how pests and diseases can be controlled, and how farm resources can be used more efficiently and how they can be combined to have the greatest possible synergistic effects (Altieri, 1992). They need to know about likely future conditions of the productive natural resources under the current farming

Table 4
Financial viability analysis of crop production for different assumed scenarios

Assumed scenarios	Crops	Net return (NR) (US$/ha)			Benefit–cost ratio (BCR)		
		NR_P	NR_A	Percent change	BCR_P	BCR_A	Percent change
Scenario 1: 10% increase in input costs	Wheat	139	71	−48.7	1.21	1.10	−9.1
	Maize	262	207	−21.0	1.48	1.34	−9.5
	Cotton	668	584	−12.6	1.79	1.63	−8.9
	Chives	8689	8226	−5.3	2.88	2.62	−9.0
Scenario 2: 10% fall in output prices	Wheat	139	59	−57.9	1.21	1.09	−9.9
	Maize	262	181	−30.8	1.48	1.33	−10.1
	Cotton	668	516	−22.7	1.79	1.61	−10.1
	Chives	8689	7357	−15.3	2.88	2.59	−10.1
Scenario 3: 10% increase in input costs and 10% fall in output prices	Wheat	139	−9	−106.6	1.21	0.99	−18.2
	Maize	262	126	−51.7	1.48	1.21	−18.2
	Cotton	668	432	−35.3	1.79	1.46	−18.4
	Chives	8689	6895	−20.7	2.88	2.36	−18.1
Scenario 4: 20% decrease in crop yield	Wheat	139	9	−93.4	1.21	1.01	−16.2
	Maize	262	113	−56.4	1.48	1.21	−18.4
	Cotton	668	388	−41.8	1.79	1.46	−18.5
	Chives	8689	6027	−30.6	2.88	2.3	−20.1
Scenario 5: irrigation cost will double due to decline in groundwater table	Wheat	139	−53	−138.2	1.21	0.94	−22.4
	Maize	262	154	−41.3	1.48	1.23	−16.6
	Cotton	668	529	−20.8	1.79	1.54	−14.1
	Chives	8689	8356	−3.8	2.88	2.69	−6.7
Scenario 6: fall in costs if farmers adopt recommended fertilizer and irrigation amount	Wheat	139	194	+39.5	1.21	1.31	+8.3
	Maize	262	322	+23.1	1.48	1.66	+12.2
	Cotton	668	777	+16.4	1.79	2.06	+15.1
	Chives	8689	8925	+2.7	2.88	3.04	+5.6

NR_P: net return at present, NR_A: net return under assumed conditions, BCR_P: BCR at present, BCR_A: BCR under assumed conditions, percent change: percentage of increase (+)/decrease (−) of net return and BCR under respective assumed scenarios compared to the present situation. *Source*: Field Survey (2001).

practices. They need information about the market to take decisions when and where to sell their products and from where and when to buy inputs. Therefore, the contact between extension agents and farmers, and the services offered to the farmers are important determinants of improved farming practices.

In the study area, four state-own extension agencies operate under the umbrella of the County Commission, i.e., the Agricultural Bureau, the Irrigation Bureau, the Livestock Bureau, and the Commission of Science and Technology. Some private enterprises, such as agricultural input dealers, are also involved in extension in association with their business. The household survey revealed the level of contacts between the agricultural extension agencies and the farmers. Table 5 shows clearly that the contacts between farmers and agricultural extension workers (AEWs) are very weak. Overall, only 20% of the farmers were visited by the AEWs during the year preceding the survey. The number of farmers visiting the extension agencies is equally low (18%). The low level of extension contacts was revealed in group discussion with the farmers. The majority of the farmers do not consider that it is necessary to get extension services. They believe that they have the adequate knowledge and skills needed for farming. However, the farmers felt that useful information on farming practices could be obtained from fellow farmers and television (TV) programs, rather than from AEWs. A large number of farmers have secondary-level education (63%), 35% have primary-level education. This educational background also encourages them to look for and access alternative information sources by themselves.

Table 5
Contacts between agricultural extension workers (AEW) and farmers in four villages

Number of contacts in the previous year	Farmers									
	Dongliu		Daliu		Dagen		Dongcui		All villages	
	No.	Percentage	No.	Percentage	No.	Percentage	No.	Percentage	No.	Percentage
AEWs making visits to the farmers										
Once	7	10	6	9	7	9	15	30	35	13
Two to three times	3	4	4	6	3	4	7	14	17	6
More than four times	–	–	–	–	–	–	3	6	3	1
No visits	63	86	60	86	67	87	25	50	215	70
Farmers making visits to AEWs										
Once	6	8	7	10	8	10	20	40	41	15
Two to three times	1	1	1	1	2	3	2	4	6	2
More than four times	–	–	–	–	–	–	1	2	1	0.3
No visits	66	90	62	89	67	87	27	56	222	82
Total no. of farmers	73	100	70	100	77	100	50	100	270	100

Source: Field Survey (2001).

The contact between farmers and AEWs is not uniform across study villages. In the villages of Dongliu, Daliu and Dagen, the contact is almost negligible. Eighty-six percent of the farmers in these villages were not visited by any AEW. Similarly, an overwhelming majority of the farmers (about 90%) did not visit the AEW. In Dongcui village, the frequency of AEW visits is slightly higher (50%) than in the other villages and the number of farmers making visits to agricultural extension office is also higher (44%) in this village. The higher frequency of visits made by both AEWs and farmers in Dongcui village is because majority of farmers in the village cultivated vegetables such as chives on a 'hot bed', which requires more skills and, hence, advise from the AEWs. The high literacy rate, proximity to the town center and easy access to a well-developed transportation system encourage farmers in this village to visit extension office by themselves whenever the need arises. It should be noted that the AWEs referred to in this study include all levels, from the commune level to the national level.

Information and technologies that are disseminated by extension workers are usually limited to the use and application of fertilisers and pesticides, and livestock rearing. The dissemination of information on groundwater use and conservation, crop diversification, health hazards of current input use, and adverse environmental impacts of existing farming practices are non-existent. Most of the farmers are dissatisfied (50%) or even strongly dissatisfied (23%) with the present extension services and their agents. The lack of services, limited use of the services by the farmers, no participation of the farmers in general extension activities, an inadequate number of extension workers, the high commercial orientation of the services and the low working efficiency of the AEWs are considered by the farmers as the major reasons for the ineffectiveness of the services (Table 5). This has been confirmed by the AEWs and associated with problems such as the number of different extension agencies, whose services are overlapping, with ill-defined and unstable work programs, vague responsibilities of the extension workers, financial constraints and poor professional background. The major sources of information for the farmers are printed materials such as newspapers and booklets, and radio and TV programs (71% of the farmers), followed by discussions with fellow farmers (64% of the farmers), exchange with input dealers (57%), personal experience (50%) and extension agents (21%). However, the farmers still assume that the AEWs have better and more reliable information than the other sources.

5. Salient features of farmers following and not following recommended input use rate

The study clearly revealed that groundwater, fertilizers and pesticides are the main inputs used in

Table 6
Salient features of farmers following and not following recommended input use rate

Indicators	Farmers following recommended input use rate (FFRIR) (n = 16, 6%)	Farmers not following recommended input use rate (FFRIR) (n = 240, 94%)
Age of respondents (years)*	38	44
Land holding size (ha)	0.34	0.34
Labor force (workdays/ha)	45	45
Groundwater use (m^3/ha)**	1335	2040
Nitrogen fertilizer use (kg/ha)**	420	540
Pesticide use (g/ha)**	4800	5850
Farmyard manure (FYM) use (kg/ha)**	38,730	28,815
Soil pH	7.7	7.8
Soil organic matter (SOM) content (%)	1.2	1.2
N content of the soil (mg/ka)	975	1020
P_2O_5 content of the soil (mg/ka)	195	165
K_2O content of the soil (mg/kg)*	98	86
Input cost (US$/ha)**	975	1101
Farm income (US$)	113	114
Off-farm income (US$)**	170	214
Average yield of wheat (kg/ha)	5340	5700
Average yield of maize (kg/ha)	6015	5880
Percentage of farmers having contact with extension workers**	88	27

Note: Only wheat and maize rotational cropping farmers were used for analysis. *Source*: Field Survey (2001).
* $P < 0.05$ (t-test).
** $P < 0.01$ (t-test).

the farming system, and these are also the major causes of problems for the water and soil resources and human health. Balanced and integrated use of inputs is considered as an appropriate way to assure long-term productivity with sufficient economic returns. Therefore, recommended levels of input use based on scientific research have been proposed to the farmers

Two types of farmers were identified, i.e., those who follow recommended input-application rates (FFRIR) and those who do not follow the recommendations (FNFRIR). The justifications for this classification are that recommended input use rates are derived from long-term field experiments in the area. Rates that above the recommended amount will cause wasteful use of inputs, damage of crops and depletion of soil and water resources, rates that below recommended amount are considered insufficient for normal growth of crops. It is therefore vital to investigate salient features of those two groups of farmers. Taking wheat–maize farmers as an example, only 16 farmers (6%) of 256 farmers were FFRIR (Table 6).

Table 6 shows of the 17 indicators that were examined, ten show statistically significant differences between FFRIRfrom FNFRIR. FFRIR are younger than FNFRIR; they are probably more active in learning and acquiring new knowledge and technology, and more open to accept innovations in their farms than the older farmers. They are also likely to be more aware of the environmental effects of excessive input use. FFRIR input-application rates are within the limits of the recommended rates, i.e., lower than the rates applied by FNFRIR. Soil K_2O levels are higher in the fields of FFRIR (98 mg/kg) than those of FNFRIR (86 mg/kg), implying a better balance between the nutrients in FFRIR fields. FFRIR use high quantities of FYM, i.e., nearly 10,000 kg/ha more than FNFRIR.

Because of generally lower input use (i.e., within the recommended ranges), input cost of FFRIR (975 US$/ha) is also lower than FNFRIR (1101 US$/ha). However, there are no significant differences in the yields of wheat and maize between FFRIR and FNFRIR, demonstrating that a sustained level of production rather than maximum yields is more important for maintaining a long-term production.

FFRIR rely mainly on crop production, their income from off-farm activities is lower than

FNFRIR, and the average difference of off-farm income is 44 US$/year. Contact with extension services was found important for the FFRIR. Table 6 shows that 88% of the FFRIR have received extension services either through their visits to extension offices or extension workers' visits to them, while only 27% of the FNFRIR had contacts with the extension service. The household survey revealed that FFRIR normally accept and implement the advice received from extension workers, most of them contact the extension workers with prepared questions. Contrary, those FNFRIR who have contacted extension workers do generally not follow the advice given by the extension workers, claiming that sometimes the services provided by extension workers do not match with their needs.

6. Conclusions and recommendations

The objective of this research was to assess the sustainability of farming practices in the light of its environmental, economic and socio-institutional dimensions. The key indicators used are highly specific to the crops and location of the study. Feedback from the farmers, extension workers, local and regional government decision-makers and researchers confirmed the soundness of these indicators.

Concerning environmental sector, current irrigation practices deteriorate and deplete the groundwater resources. The combination of ignorant attitudes of farmers related to the environmental effects of their water-use practices, low overall water-use efficiencies, an ineffective extension service and unsuitable or non-existing water-use policies and regulations are detrimental to the environment. In this scenario, irrigation-based crop production in the area is unlikely to sustain for a long period.

The dependence on pesticides and their overuse and improper handling has induced serious environmental and human health hazards. Increased use of both organic and mineral fertilizers over the years improved soil fertility. The soil status in general is within the borderline for sustainability implying that the current soil-management practices do not deteriorate the soil resources. However, overuse of mineral fertilizers, particularly nitrogen, contaminates the groundwater and leads to excessive nitrate levels in crops, thus making this practice environmentally unsound.

Some scholars argue that organic farming or low-external-input agriculture is environmentally sound, economically viable and socio-institutionally acceptable while high-external input agriculture is not so (Tisdell, 1996; MacNaeidhee and Culleton, 2000; Rossi and Nota, 2000). However, Dahal (1996) and Rahman (1998) found that organic farming without proper use of additional mineral fertilizers and pesticides leads to a negative nutrient balance in the soil, with negative impacts on environment and economy. On the other hand, exclusive emphasis on yields and farm income through intensive use of mineral fertilizers will cause environmental degradation, also threatening the sustainability of farming practices (Altieri, 1992). China has successfully sustained the productivity level of wheat and rice for over 100 years by meeting 50% of the nitrogen requirement from organic sources. Therefore, balanced and integrated use of mineral fertilizers together with organic fertilizers—on the basis of soil tests—promise long-term productivity with sufficient economic returns. For the maintenance of soil fertility in intensively cropped areas and reduce environmental and human health hazards from overuse of pesticides, greater emphasis needs to be placed on three alternatives: the first option is to promote crops that require relatively less fertilisers. However, those crops have to be economically attractive for the farmers. The second option is to include legume crops in the cropping systems to supplement N requirement and increase the organic material content in soil. Precise information about the N contributions of legumes and rotation effects can lead to design of cropping systems which require less purchased nitrogen and reduce production costs without changing crop yield. Finally, to enhance the efficiency of fertilisers applied by controlling nutrient leaching through appropriate methods of irrigation and fertiliser application. Such action would also be helpful to reduce groundwater contamination. In order to reduce farmers' dependency on harmful synthetic pesticides, it is necessary to promote non-conventional measures of insects and pests control, including herbal insecticides, and promotion of insect and pest predators. Also, the introduction of integrated pest management (IPM) is strongly recommended in order to reduce the use of hazardous synthetic pesticides. There should be adequate opportunities for farmers to be trained, especially in respect to the environmental impacts of current farming practices.

Crop production in the study area is financially viable, though at high environmental costs. However, in a strict sense, it is not economically viable. The financial profitability of all major crops is affected by changes of input costs and output prices. It is essential to adopt the recommended rates of inputs. This will decrease cost (i.e., most farmers over-apply fertilizers) and reduce the stress on the environment for the future. The current extension services are not adequate and effective. The farmers are not encouraged to adoption resource-conservation practices. This is a significant weakness of the socio-institutional dimension in the area. A host of institutional reforms ranging from the reorientation of the agricultural extension service to the enforcement community managed groundwater irrigation should be carried out in the area. One of the primary responsibilities of the extension service should be to make farmers aware of the long-term environmental and economic implications of the over and inappropriate use of resources, including external inputs and groundwater. The groundwater overuse needs to be regulated, for example, by defining water table levels beyond which extraction of water must be restricted. Most importantly, the plans should be developed with the participation of local water managers, who need to be able to enforce these regulations at the water-user level. The introduction of a water-pricing policy is strongly recommended. Water consumption exceeding a defined level should lead to surcharges. An area-based pricing approach (Abu-Zeid, 2001) could be adopted in the area. Farmers should clearly realize that it is they who will suffer first and most when environmental and natural resources degrade. To this end, the agricultural extension workers should receive adequate motivations so as to provide efficient services to the farmers.

Acknowledgement

We would like to extend our sincere thanks to the editor Dr. A. de Rouw and two anonymous referees for their constructive comments on the manuscript. Our heartfelt thanks also go to Mr. Jan ten Have and Johanna Heyde of the Editorial Office for their kind communication and help during the review process of the paper. The research is under the auspice of the national key project for basic research on Agricultural Environment (2002CB111506). The financial support for the study from the Asian Institute of Technology (AIT), the Norwegian University of Science and Technology (NTNU), and the Regional Office of the Food and Agriculture Organization (FAO) for the Asia-Pacific Region in Bangkok is gratefully acknowledged.

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