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Comparing impacts of new cropping systems on biodiversity in traditional rural China

Li Li

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Declaration

I hereby declare that this dissertation is my own work and has not been submitted for another degree, either at University College Cork or elsewhere.

Candidate: Li Li

Signature:

Date:

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General abstract

This study selected six geographically-similar villages with traditional and alternative cultivation methods (two groups of three, one traditional and two alternatives) in two counties of Henan Province, China—a representative area of the Huang-huai-hai Plain representing traditional rural China. Soil heavy metal concentrations, floral and faunal biodiversity, and socio-economic data were recorded. Heavy metal concentrations of surface soils from three sites in each village were analysed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS, chromium, nickel, copper, cadmium, and lead) and Atomic Absorption Spectrophotometer (AAS, zinc). The floral biodiversity of four land-use types was recorded following the Braun-Blanquet coverage-abundance method using 0.5×0.5m quadrats. The faunal biodiversity of two representative farmland plots was recorded using 0.3×0.3m quadrats at four 0.1m layers. The socio-economic data were recorded through face-to-face interviews of one hundred randomly selected households at each village. Results demonstrate different cultivation methods lead to different impact on above variables. Traditional cultivation led to lower heavy metal concentrations; both alternative managements were associated with massive agrochemical input causing heavy metal pollution in farmlands. Floral distribution was significantly affected by village factors. Diverse cultivation supported high floral biodiversity through multi-scale heterogeneous landscapes containing niches and habitats. Faunal distribution was also significantly affected by village factor nested within soil depth. Different faunal groups responded differently, with Acari being taxonomically diverse and Collembola high in densities. Increase in manual labour and crop number in villages using alternative cultivation may positively affect biodiversity. The results point to the conservation potential of diverse cultivation methods in traditional rural China and other regions under social and political reforms, where traditional agriculture is changing to unified, large-scale mechanized agriculture. This study serves as a baseline for conservation in

small-holding agricultural areas of China, and points to the necessity of further studies at larger and longer scales.

Chapter 1 Review of agricultural management and its impact on biodiversity and soil properties

1 Introduction

Technological achievements in biological and chemical industries during the past fifty years have led to major changes in agriculture (Khush 1999; Grigg 2001; Evenson and Gollin 2003). This was characterized as the “Green Revolution”, and has helped to alleviate the rising pressure on food security imposed by the rapidly growing human population. The impact of this fast developing agri-industry on global ecosystems has attracted considerable attention since agriculture is fundamental to human survival and is likely to be one of the major contributors to global environmental change (Gall and Orians 1992; McLaughlin and Mineau 1995; Tilman et al. 2001; Lichtenberg 2002).

One important negative impact of agricultural intensification is decline in biodiversity in farmland areas, which undermines vital ecosystem services and regulatory processes (Harlan 1975; Naeem et al. 1994; Hector 1998). Studies worldwide have shown that decline in biodiversity is linked to intensive agricultural practices (Gall and Orians 1992; Naeem et al. 1994; Matson et al. 1997; Krebs et al. 1999; Evenson and Gollin 2003; Hutton and Giller 2003; Benton 2007). The structure and functions of agriculture, being human-dominated, are shifting towards a semi-artificial ecosystem heavily depended upon anthropogenic managements (Swift and Anderson 1993). Other factors such as: solar radiation, temperature, humidity, precipitation, and the extinction and re-colonization of species play weaker roles in agricultural regions. This increasing threat to biodiversity has led to the popular demand of sustainable agriculture which relies on natural ecosystems and is dependent on productivity and richness of species (Gall and Orians 1992; Swift and Anderson 1993; Altieri 1999).

Agricultural intensification can also affect ecosystem services, often negatively, such as: nutrient cycling, climate and water regulation (Power 2010). Biodiversity is at the centre of these processes (Naeem et al. 1994; Giller 1996; Altieri 1999; Hughes and Petchey 2001; Gardner et al. 2009). Decline in biodiversity and loss of ecosystem services is greater in tropical regions where agricultural expansion has taken over forest areas (Gibbs et al. 2010), which has increased the global greenhouse gas emissions (Friedlingstein et al. 2010). Conservation based agriculture has been adopted worldwide in response to such problems (Baveye et al. 2011; Palm et al.). Recent studies have shown that conservation based agriculture can increase soil organic matter and water quality (Lal 2004; Baker et al. 2007; Palm et al. ; Stockmann et al. 2013), but data from small-holding regions are limited. Chinese agriculture has adopted some conservation based agricultural practices such as no-tillage or strip-tillage cultivation (Derpsch and Friedrich 2009). However, since these methods have been implemented mainly on large mechanized farms with high input levels (Derpsch and Friedrich 2009), its efficiency in agricultural regions with small-holding requires more empirical evidence. No-tillage cultivation has increased corn yield in the US (Ismail et al. 1994; Triplett and Dick 2008; Paul et al. 2013), but only with increased inputs such as herbicide. The changes in Chinese agri-industry could promote the existence of large mechanized farms and more implementation of conservation agricultural practices Therefore studies of ecosystem services in rural China should be given more attention.

Some traditional agricultural practices in developing countries, usually highly populated regions such as China, approach those required of sustainable agriculture. These practices generally involve more manual labour instead of agrochemical input. However, these traditional practices are threatened by increasing food demand of the ever-growing human population which is predicated to grow to 8.9 billion by 2050 (47% increase from 6.1 billion in 2000) (Dept. of Economic and Social Affairs 2004). High use of agrochemicals has been introduced in these areas to reach maximum yield, damaging its conservation potential.

In developed countries, trade-offs between agricultural production and biological conservation (Green et al. 2005) has been targeted by the introduction of alternative more environmental-friendly management with less agrochemical input, for example organic cultivation employing no agrochemical input and minimum tillage. This review evaluates the advantages and weaknesses of these alternative managements, and the changes necessary to implement such methods in high-demand agricultural regions.

2 Review of effects of alternative agricultural management on biodiversity

Agricultural soil is the habitat of plants and a diverse collection of organisms including fungi, bacteria and invertebrates, which contribute to the maintenance and productivity of agri-ecosystems. In farmland regions, floral[1] species play a crucial role in maintaining the functions and structural stability of agricultural ecosystem (Altieri 1991; McLaughlin and Mineau 1995; Swanton and Murphy 1996), providing habitats and refuges for ground dwelling insects and pollinators (Hooper and Vitousek 1997; Altieri 1999; Brose 2003; Duffy 2009; Hawes et al. 2010). Soil fauna broadly refers to soil animal communities whose lifespan includes a specific period during which they reside in the soil and can affect various bio-chemical soil processes. These organisms include communities such as Protozoa, Platyhelminthes, Rotatoria, Nematomorpha, Mollusca, Annelida, Tardigrada, Arthropoda, and vertebrates Amphibia, Reptilia and Mammalia (Yin 2000). Soil fauna are an important part of soil ecosystems and its main ecological functions include bioturbation and organic decomposition. By actively producing soil nutrients, it is both directly and indirectly involved in the material and energy cycles of ecosystems. Along with other soil organisms, soil fauna help maintain productivity and the sustainable development of terrestrial ecosystems.

Farmland biodiversity conservation has advanced with much effort. Well-established

[1] This paper refers to farmland plants as non-crop species

examples of this include the EU's Agri-Environmental Scheme (AES) (Yussefi and Willer 2007), the Conservation Reserve Program (Reichelderfer and Boggess 1988; Burke et al. 1995; Johnson and Clark 2001) in the USA, and the Australian Landcare Program (Curtis and de Lacy 1998; Lockie 1999). These methods attempted to conserve biodiversity through measures such as lowering agricultural intensity and/or inputs (conservation agriculture) (Hobbs 2007), using manure and biological control to replace agrochemicals (organic farming), and/or increasing landscape heterogeneity which benefits biodiversity by increasing potential habitats. In EU alone, the total area (converted and in-conversion) under the Agri-Environmental Scheme has increased from 4.3 million hectares in 2000, to roughly 7.6 million hectares in 2008 (Directorate General for Agriculture and Rural Development 2010).

Since the implementation, researchers have examined their effectiveness in protecting biodiversity (Kleijn et al. 2001; Reidsma et al. 2006; Henle et al. 2008; Gabriel et al. 2010; Smith et al. 2010; Winqvist et al. 2012; Gabriel et al. 2013). These environmental-friendly management changes had mixed effects on biodiversity as species reacted both positively and negatively to changes in land management (Kleijn et al. 2001; Kleijn and Sutherland 2003; Feehan et al. 2005; Kleijn et al. 2006; Kleijn et al. 2011). Positive effects varied with field or crop types (Mäder et al. 2002; Bengtsson et al. 2005; Feehan et al. 2005; Hole et al. 2005; Blomqvist et al. 2009; Gabriel et al. 2013). In general, however, environmental friendly cultivation involves decreased agrochemical input and improved soil fertility and biodiversity.

Responses of biodiversity to agri-environmental managements have been generally positive, but most studies were based on actual cases implemented specifically for conservation. This has limited relevance in intensive agricultural areas where adopting such measures on a large scale can be problematic. In China for example, state policy dictates that food self-sufficiency should be maintained above 90% and food crop self-sufficiency has long been maintained at 100% (National Development

and Reform Commision 2008). With current cultivated land area serving a growing population, food security goals can only be achieved through increasing crop yield per unit area. In 2011, Chinese corn (*Zea mays*) and winter wheat (hybridized *Triticum* species) yields were 5748kg/ha and 4909kg/ha (National Bureau of Statistics 2012a), as compared to the USDA figure of 9086kg/ha and 3105kg/ha(National Agricultural Statistics Service 2013). Chinese yield must increase to meet the nation's development goals and conservation efforts need to focus on methods coexisting with highly intensive agriculture.

3 Review of agricultural impact on soil properties

Hybridized crops have been widely adopted which rely heavily on the input of agrochemicals (e.g. fertilizers, pesticides and herbicides) which have drastically boosted the world's agrochemical consumption (Matson et al. 1997). The usage of fertilizers worldwide has increased by 21.04% from 1980 to 2002 whilst at the same period, Chinese consumption has more than doubled (Food and Agriculture Organization 2013). In traditional agricultural areas where little industrial contaminations exist, agricultural input is the major source of heavy metal accumulation in soils. This contamination is derived from agrochemicals such as pesticide, herbicide, fertilizers, and irrigation using ground water supplies (Micó et al. 2006; Huang et al. 2007; Tang et al. 2010).

Various studies point to the unsustainable nature of these extensive production methods (Pingali et al. 1994; Pimentel et al. 1995; Singh 2000; Lichtenberg 2002; Mann et al. 2009; Tang et al. 2010; Hodson 2013). However, there is less research comparing the impact of soil elemental concentration in alternative and traditional agricultural practices. Researchers have examined the possible nutrient benefits which followed the changes made in on-site managements such as: reduced nitrogen leaching related to changes in manure application (Rode et al. 2009) and increased nutrient efficiency by limiting mono-cropping and promoting regional production cycles (Granstedt 2000). While these changes would not directly affect heavy metal

concentrations in farmlands, higher efficiency in fertilizer usage could result in less overall input and, therefore, reduced risk of heavy metal pollution.

Another change evident in agricultural management is phytoextraction capabilities of plant species—the ability of some plant species (e.g. maize and soybean) (Leita et al. 1993; Arthur et al. 2000; Murakami and Ae 2009) to absorb and transfer heavy metal elements from the soil and thereby reducing the heavy metal concentrations of the habitat. This low-cost, environmental-friendly method could indicate the benefit of maintaining high floral diversity in contaminated areas.

4 Conservation theory and questions

4.1 Main hypotheses in biodiversity conservation

Current hypotheses involved in biodiversity conservation fall into two main categories (Kleijn et al. 2011). Firstly, the "land use-moderated conservation effectiveness hypothesis" (Kleijn and Sutherland 2003), which aims at boosting biodiversity through lowering land-use intensities (and disturbance frequencies) in extensively managed farmlands. Secondly, the "landscape-moderated conservation effectiveness hypothesis", which is a larger scale approach to conservation aimed at balancing extinction and repopulation by adding to landscape heterogeneity (Tscharntke et al. 2005; Kleijn et al. 2011).

These hypotheses may be used in selecting potential conservation sites and changes in planning management. However, they are not all-purpose remedies as local actions still need to incorporate domestic agricultural conditions, socio-economic factors, and case-specific goals balancing production requirements to maximize conservation efficiency.

4.2 Scale of conservation planning

Gabriel et al. (2010) indicated the necessity of incorporating various scale levels in

planning and evaluating biodiversity conservation actions. Because agriculture production generally covers a large area within a region, species responded differently to management efforts requiring different ecosystem conditions and ecological resources at various scales. Sedentary species, such as farmland insect and plant species, generally benefited from positive changes in management (Hald 1999; Hole et al. 2005) while more mobile species, such as birds and some pollinators, likely responded to factors beyond the farmland (Benton et al. 2002; Chamberlain et al. 2010). In most developing countries with extensive agriculture practices, choosing the appropriate scale for farmland conservation affects not only the relevant plot or landscape factors involved in protecting biodiversity, but also the proper policy encouragements and regional acceptability.

4.3 Sustainable agriculture under the changing climate

Climate change may negatively affect agricultural production, especially wheat production in drought susceptible regions (Ortiz et al. 2008), such as China where food security is of the utmost importance (Piao et al. 2010). Agriculture is a main source of greenhouse gas emissions which contribute to global warming (Lal 2004). Future agricultural cultivation should not only adapt to the changing climate by ways of genetic modification and hybridization, but also actively reduce its negative effects. In east and south Asian regions such as China and India, farmlands comprising small-holdings face unprecedented challenges with the changing climate, social and political conditions (Lobell et al. 2008). Alternative cultivation practices, such as conservation through reduced tillage and rotation, should be tested and adopted to meet this growing issue. Recent studies have examined changes in agricultural greenhouse gas emissions in China (Thomson et al. 2006; Feng et al. 2013; Ma et al. 2013), but there has been little research interest in differences caused by cultivation changes, or in the scenario of Chinese social reform.

5 Chinese Application

China has one of the largest agri-industries in the world. There is extremely strong

emphasis on agricultural production and much interest has been given to monitoring the response of agriculture to the series of social and political policy reforms, the latest of which is the Household Contract system (Hong and Tao 2002) and the fast growth of manufacturing and tertiary industries in rural areas. These resulted in a more fragmented agricultural landscape in rural areas (Li and Wang 2003).

While agricultural intensification puts increasing pressure on agri-ecosystems, the lack of a national agricultural conservation plan or relevant policies and the drive for food security have prevented any systematic implementation of eco-friendly management plans in the country. Villages or large farms with organic management schemes (other than research sites) were either results of food-safety market demand (Sanders 2006) or historic remnants (Lo 1996). These examples, not unlike environmental-friendly agriculture management schemes in developed countries, have limited practical importance due to the increasing demand prominence of crop yield.

These factors have stipulated research interest in relevant areas of ecology. The loss of diversity in flora (Chen et al. 1999b; Wu and Chen 2004) and fauna (Chen et al. 1999a; Chen et al. 1999b; Lin et al. 2005; Du et al. 2010; Zhu et al. 2013) have been recorded in response to increased agricultural input, pollution and other human disturbances. Functional roles and ecosystem services of biodiversity in agricultural landscapes have been recognized (Wu et al. 1998), ****such as the effect of floral diversity in reducing pests and reducing chemical substances (Hou and Sheng 1999). Examples, where reduced tillage benefited fauna communities and micro-organisms in paddy fields (Gao et al. 2004), have been explored. Yet there remains a lack of acknowledgement of these issues.

In modern China (post 1949), the basic unit in traditional agricultural practices changed from community to household due to the Household Contract System in the late 1970s (Lin 1992; Li and Wang 2003). Farmers within a village learn from each

other, so changes in cultivation are generally found between villages rather than within. Therefore, comparisons of environmental impact caused by cultivation and management differences are best done at the village scale. A representative example of alternative management schemes—village level specialization—is developing in rural areas. This is defined when a large number of households commit to a single, or a chain of production or services, making this the primary source of revenue (Li et al. 2009). At the end of 2010, China has 51486 specialized villages, with an average village income 15.56% higher than that of others in the country, and mean income of the participating households 25.82% higher than that of farmers in other villages (Ministry of Agriculture 2011). The central government has treated specialized-village growth as one of the main themes in rural development. Current research on specialized villages focused around its formation history, spatial extrapolation, and its response to geographical variability (Li et al. 2009). Due to lack of a conceptual framework in biodiversity protection in rural areas, no attention has been paid to the environmental impact of such changes in agricultural patterns. In Chinese traditional rural areas, specialized villages mostly focus on cash crop production with high input level. Whether or not these changes damage or benefit the agri-ecosystems, especially to the already threatened biodiversity levels, is unknown.

These villages formed out of farmers' need to maximize profit rather than any conservation scheme or policy. They are regulated by socio-economic factors including their living conditions (e.g. income level, residential condition), agricultural awareness (e.g. education level, conservation awareness), and cultivation behaviour (number and type of plots and crops, access to farmlands). These are the background regulators of local environment determining and working through direct factors such as agrochemicals levels. While biodiversity response to direct disturbance has been studied extensively (Chen et al. 1999b; Chen et al. 2000; Yue 2001; Wu and Chen 2004; Lin et al. 2005; Du et al. 2010; Zhou et al. 2012; Zhu et al. 2013), these underlying factors have been neglected (possibly due to difficulty

and uncertainty of small scale socio-economic data of villages). Attention should be given to this issue if effective conservation plans at the regional level are to be developed.

Chinese social structure and culture have produced villages which vary in their development status and economical factors. Yet, the geographical layout of villages is similar—with plots of farmland distributed around or near a congregated residential area. The above socio-economic factors differ greatly between villages, and are therefore better explored at the village scale. Evaluating biodiversity differences at the village level also excludes confounding factors in smaller scales such as the spill-over effects or concentration responses (Kohler et al. 2008; Brudvig et al. 2009; Gabriel et al. 2010; Kleijn et al. 2011). Village area ranges from 69 to 147 hectares, and species interference from spill-over effects is more likely to occur within village at the plot-level. This can also be concluded for concentration effects which alter species distribution mostly at the plot level.

6 Rationale for own study

Agricultural sustainability in the developing countries, such as China, faces unprecedented challenges. Semi-sustainable, traditional cultivation dominates agricultural areas, and policy levers and population demand put pressure and uncertainty on its development.

Alternatives to traditional agriculture management, if not already in existence, should be developed to meet the ever-growing need for global conservation. This review points to the necessity of examining these alternative approaches—whether they were developed as sustainable agriculture or not—and evaluate their conservation potential. Monitoring the changes and causes related to the new management methods provides much needed insight of local conservation planning, which is the basis for any effective large scale actions or policy changes.

Furthermore, evaluation of differing systems of agricultural management is only useful when appropriate scales are selected for the analysis. Choosing the right scale, for both agricultural disturbances and ecosystem responses, eliminates confounding effects and ensures rigorous analyses. Chinese studies of agricultural management change and environmental impacts should start from the village scale to meet the domestic situations: household production differentiated at the village scale, with increasing yield pressure and reduced total available land area.

Therefore, this project uses data for agricultural inputs, biodiversity, and soil at the village scale from selected, alternatively cultivated villages in traditional rural China, to examine their potentials for biodiversity conservation in the upcoming agricultural and social reform. I aim to examine the following aspects: (1) do these alternative methods have conservation relevance, are they valid approaches to regional biodiversity protection; (2) what contributing factors are important in affecting agricultural inputs associated with these alternative approaches; (3) what factors can be targeted for effective conservation planning, both in relation to policy-making and socio-economic processes.

Chapter 2 Study area and methodology

1. Study area

The agricultural ecosystems in the lower Yellow River basin result from historical, natural, and anthropogenic activities. Over the past fifty years, local people have been involved in massive exploitation of natural resources, which accelerated after 1979 when the household responsive system was adopted in China (Hong and Tao 2002). This policy change led to extensive exploitation of land resources (Li and Wang 2003), and significant changes in the local ecosystem structure and functions. Specifically, changes occurred in land uses, habitat/biological diversity, and ecosystem stability. An understanding of the changes and their causes is essential for informing further research of local ecosystem functions and underpinning the goal of protecting biodiversity and promoting sustainable development in the region.

Chinese agricultural practices show significant temporal and spatial characteristics. Before 1978, the country's farmlands were collectively owned and managed by the administrative villages and decisions were made by village leaders. This decision-making process resulted in rather simplified cultivation types and created unified landscapes. Following the implementation of the household responsive system in 1979, farmlands and user rights were divided into holdings and distributed equally to villagers. However, these allocated holdings were not distributed contiguously so one family might receive several spatially separate plots. This, plus the fact that households had greater control over cultivation selection and practices, resulted in a more diverse agricultural landscape, with influences from geographical elements, different market situations, and local policies (Li and Wang 2003). These highlight the necessity of analysing Chinese agricultural impact at local scales.

Henan Province is located in the central-eastern region of China. It is the largest province in terms of agricultural population and total crop production, with a

substantially long history of agricultural land use. Its total crop yield has remained first place in China for more than a decade, with its 2012 crop yield—including main cereal types such as paddy rice, wheat (hybridized *Triticum* species) and maize (*Zea mays*)—reaching 56,386 million tonnes (National Bureau of Statistics 2012b).

Yellow River is one of China's main water systems and is unique in the world. The river body carries a substantial amount of suspended silt sediment acquired by erosion from The Loess Plateau, and this silt has been reshaping the structure of waterways. Historically, the Yellow River has had several major course alterations, each significantly changing the surrounding landscapes. Much of the nutrient rich soil in these regions was deposited in the last Yellow River course change in 1938, which act as a baseline for the development of local ecosystems. Currently, the local reaches of the Yellow River are confined by a series of levee-lined courses, because of the high sedimentation effect of the river, and gradual changes in the riverbed that are still ongoing.

Agricultural practices in these regions result in diverse cultivation patterns. While traditional wheat/maize rotation (double-cropping) plays the major role, alternative methods are spreading. For example, some villages specialize in honeysuckle (*Lonicera japonica*) plantation, garlic (*Allium sativum*) plantation, or diverse vegetable production covering more than a dozen vegetable types.

The selected study areas are located on both the north and south side of the Yellow River, within Fengqiu County, Xinxiang City and Zhongmou County, Zhengzhou City. Area selection was based mainly on agricultural intensity and soil-type maps (Station of Soil Fertilizers and Office of Soil Census 1995; Office of Soil Census 2004).

1.1 Village selection

The village was chosen as unit of comparison for this study, rather than households,

to better reflect stability and representativeness in cultivation patterns.

Table 1 Brief description of the six sample villages

Villages	Cultivation type	Number of main harvests yearly[a]	Population	Total area (hectare)	Per capita income[b] (RMB)
Zhu-cun-pu	Double (winter wheat/maize)	Two	970	100	5000
Dong-yang-si	Double (winter wheat/maize)	Two	804	120	4800
Qian-gang	Mono (honeysuckle)	One	1500	93.33	8000
Dong-ying	Mono (garlic)	One	1450	133.33	8000
Chang-zhai	Poly (vegetable)	Multiple	1100	68.93	13000
Wan-zhai	Poly (vegetable)	Multiple	872	147	12000

[a] Representative crops

[b] Income from crop production

Socio-economic data correct for year 2010

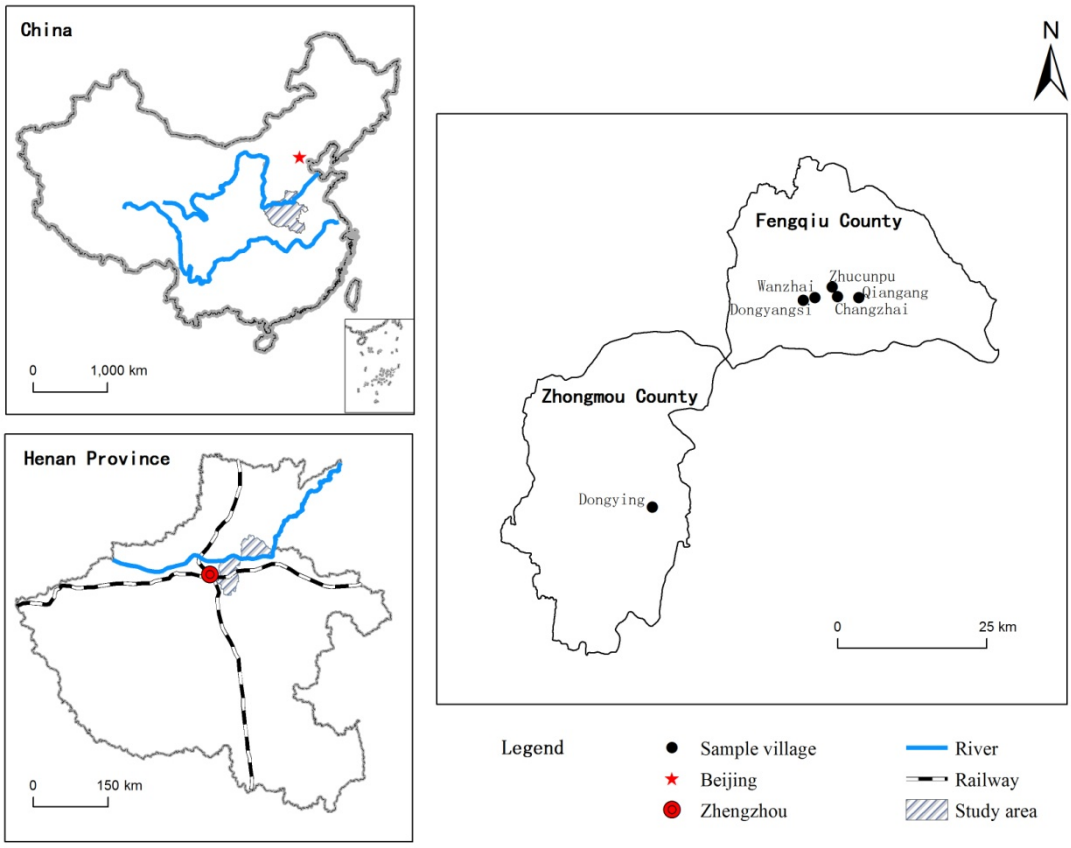


Figure 1 Map of the study area and location of the villages sampled

Study area selection was done in two steps. The first step was based mainly on agricultural intensity data at the county level and provincial soil-type maps. This step focused on village comparability. To ensure these villages have the same baseline, selection was focused on areas with the soil type mud-sand formation (similar to Fluventic Ustochrept of the USDA classification). This type was mainly formed after the 1938 river catchment change. Village pool was established by matching scanned soil type maps and village location maps. Also, villages have to be cultivation focused, with minimal non-agricultural influence present. As for extrapolation potentials, each village was carefully chosen to represent stable cultivation patterns of their respective type, with a minimum of ten years dedicated to the specific approach, this way they can represent the input and output conditions of their own kind.

The second step was to choose individual villages. Specialization mainly comes in two forms, diverse and specified, plus one traditional village for comparison, each sample group should contain three villages in total. Considering the available workload and timeframe for fieldwork, I decided to select two groups of three villages. So with the pool identified, I visited the potential villages and interviewed village leaders and representative households, and witnessed first-hand what the cultivation status within each village was.

Following these criterion, I selected six villages in the end, representing three types of cropping practices: (Table 1; Figure 1; see supporting document four for land use maps): Zhu-cun-pu and Dong-yang-si (Fengqiu County), representing traditional cultivation (winter wheat/maize double-cropping); Chang-zhai and Wan-zhai (Fengqiu County), representing diverse cultivation (vegetable and other cash crops poly-cropping with basic food crop production); and Qian-gang (Fengqiu County) and Dong-ying (Zhongmou County), representing specified cultivation (focusing on one cash crop with basic food crop production). However, because my selection prioritized comparable soil type and cropping type, I was not able to match all

villages in their total area. This was later dealt with by using mean biodiversity, soil data, and input for comparisons.

Table 2 Annual Agrochemical Inputs of the Six Villages including fertilizer, pesticide and herbicide (data summarized from social surveys)

Villages	Base fertilizer	Additional fertilizer	Pesticide	Herbicide
Zhu-cun-pu	Compound 750-2250 kg/ha×time; manure 7500-15000 kg/ha×time	Carbamide 300-600 kg/ha×time, 3-4 times	Chlorpyrifos 3.75-7.5 L/ha×time, 1-2 times	Acetochlor, Napropamide, Pendimethalin, etc. 1.5-7.5 L ha×time, twice
Dong-yang-si	Compound 700-2200 kg/ha×time; manure 7000-12000 kg/ha×time	Carbamide 300-500 kg/ha×time, 3-4 times	Chlorpyrifos 3.75-7.5 L/ha×time, 2-3 times	Acetochlor, Pendimethalin, etc. 2-9 L/ha×time, twice
Dong-ying	Compound 375-750 kg/ha×time; manure 4500-37500 kg/ha×time	Carbamide 225-525 kg/ha×time, twice; Ammonium bicarbonate 300-525 kg/ha×time, once	Beta-cypermethrin 3-4.5 L/ha×time, 2-6 times; Imidacloprid 0.45-0.675 kg/ ha×time, 2-7 times	None
Qian-gang	Compound 450-1350 kg/ha×time; manure 2250-15000 kg/ha×time	Carbamide 300-600 kg/ha×time, 1-2 times; Nitric acid-phosphor compound 150-600 kg/ha×time	Chlorpyrifos 3.75-7.5 L/ha×time/ ha, 2-4 times;	Acetochlor, Pendimethalin, Dibutralin, etc. 1.5-7.5 L/ha×time, twice
Chang-zhai	Compound 600-750 kg/ha×time; manure 22500-45000 kg/ ha×time	Carbamide 300-1200 kg/ha×time, 1-2 times; Ammonium bicarbonate 600-750 kg/ha×time, 2	Organic phosphate (e.g. Omethoate) 2.25-3 L/ha×time, 2-4 times	Dibutralin, Pendimethalin, etc. 1.5-2.25 L/ha×time, once

Wan-zhai	Compound 700-900 kg/ha×time; manure 17500-35000 kg/ha×time	Carbamide 300-1000 kg/ha×time, 3-4 times	Beta-cypermethrin 3-4 L/ha×time, 1-3 times; Organic phosphate (e.g. Omethoate) 2-3 L/ha×time, 1-2 times	Dibutralin, Pendimethalin, etc. 2-3 L/ha×time, once

Fengqiu County is located at the North-eastern part of Henan Province. Zhu-cun-pu village is ten kilometres south-east of the county seat, one kilometre south to the country-level road. Traditional plantation in the village dates back to nearly one hundred years. Main crops are winter wheat (October to June next year) and maize (June to October) (Table 2). Soil species belongs to mud-sand formation (Liang-he soil of the Chao soil group) (general group similar to Fluventic Ustochrept of the USDA classification) (Soil Management Support Services 1992) (see supporting document four for land use map).

Chang-zhai village is south of Zhu-cun-pu village, with same soil type and similar cultivation history. The village has been cultivating sweet potato (*Ipomoea batatas*) seedlings since the end of nineteenth century. During the 1980s market mechanisms began to control seedling cultivation. To maximize profits, farmers started poly-cropping multiple vegetable crops. Sweet potato seedlings in spring were followed by garlic (*Allium sativum*) intercropped with maize. Other examples such as celery (*Apium graveolens*), coriander (*Coriandrum sativum*) and spinach (*Spinacia oleracea*) were planted after garlic harvest. Diverse cultivation boosted village income using largely manual labour. The migrant working force in this village is among the lowest in the county (see supporting document four for land use map).

Qian-gang village is 4km east of Zhu-cun-pu, with winter wheat and maize double-cropping rotation. In early 1990s it was introduced to honeysuckle (*Lonicera japonica*) cultivation. This species has high medicinal and market values, but requires more human labour and fertilizer input, and it is highly sensitive to herbicides (perish after exposure). Honeysuckle cultivation requires on average four fertilizer inputs (base-application and three additional ones) (Table 2). Pesticide input is concentrated in May and June, between six to seven times with 3000-4500 ml (or 450-675 g solid equivalent) each time per hectares (see supporting document four for land use map).

Zhongmou county, one of the nation's garlic production centres, is south-east of Zhengzhou City. Dong-ying village is east of the county, with the same soil type. The village converted focus to garlic cultivation over two decades ago, but before that it maintained a winter wheat and maize double-cropping rotation. Over 85% of the village's farmland (Table 1) is dedicated to garlic cultivation. Garlic plantation requires three to four fertilizer inputs (base and additional) yearly with, on average, two pesticide inputs concentrated at March and April. Herbicide inputs are concentrated in September and October. Reduced frequency is made up by larger applications which can be as high as 7500 ml per hectare (see supporting document four for land use map).

Dong-yang-si is to the west of Zhu-cun-pu village, with same cultivation and soil. The village had a higher percentage migrant work force (farmers moving to work in towns and cities leaving their own allocated farmland managed by the remaining family members). Therefore, general income is slightly higher than Zhu-cun-pu, but income from agriculture remained at the same level (see supporting document four for land use map).

Wan-zhai village is also to the west of Zhu-cun-pu, with same soil type and vegetable poly-cropping methods similar to that of Chang-zhai village. This village started later in following Chang-zhai's agricultural methods (see supporting document four for land use map).

Due to inability to locate untouched forest patches in close proximity to the study villages for comparison (control), attempts were made to identify abandoned plots of land (either planted with trees or simply abandoned) as possible reference sites to compare diversity data.

2 Method and data

Extensive field surveys were conducted to collect various data to better understand the local agricultural practices. These included plant species diversity, soil surveys (both soil chemical properties and soil fauna), and socio-economic interviews.

During the interviews, test samples were collected at random sites in villages Zhu-cun-pu, Chang-zhai, Qian-gang and Dongying. These trials helped with coordinating and planning of later surveys.

2.1 Floral data

Plant species surveys were performed in summer of 2012 (August, coded 201208), spring and summer of 2013 (April, coded 201304 and August, coded 201308). Data collected represent changes in plant species diversity across years and across seasons (spring and late summer, Table S1a-c). Due to accessibility issues, villages' records were coded in the order they were sampled in: 1, Zhu-cun-pu; 2, Chang-zhai; 3, Qian-gang; 4, Dong-ying; 5, Dong-yang-si; 6, Wan-zhai. They were then reorganized into groups easier for recognition: traditional villages 1 Zhu-cun-pu and 2 Dong-yang-si, specified villages 3 Qian-gang and 4 Dong-ying, diverse villages 5 Chang-zhai and 6 Wan-zhai (will be referred to by village names for clarity).

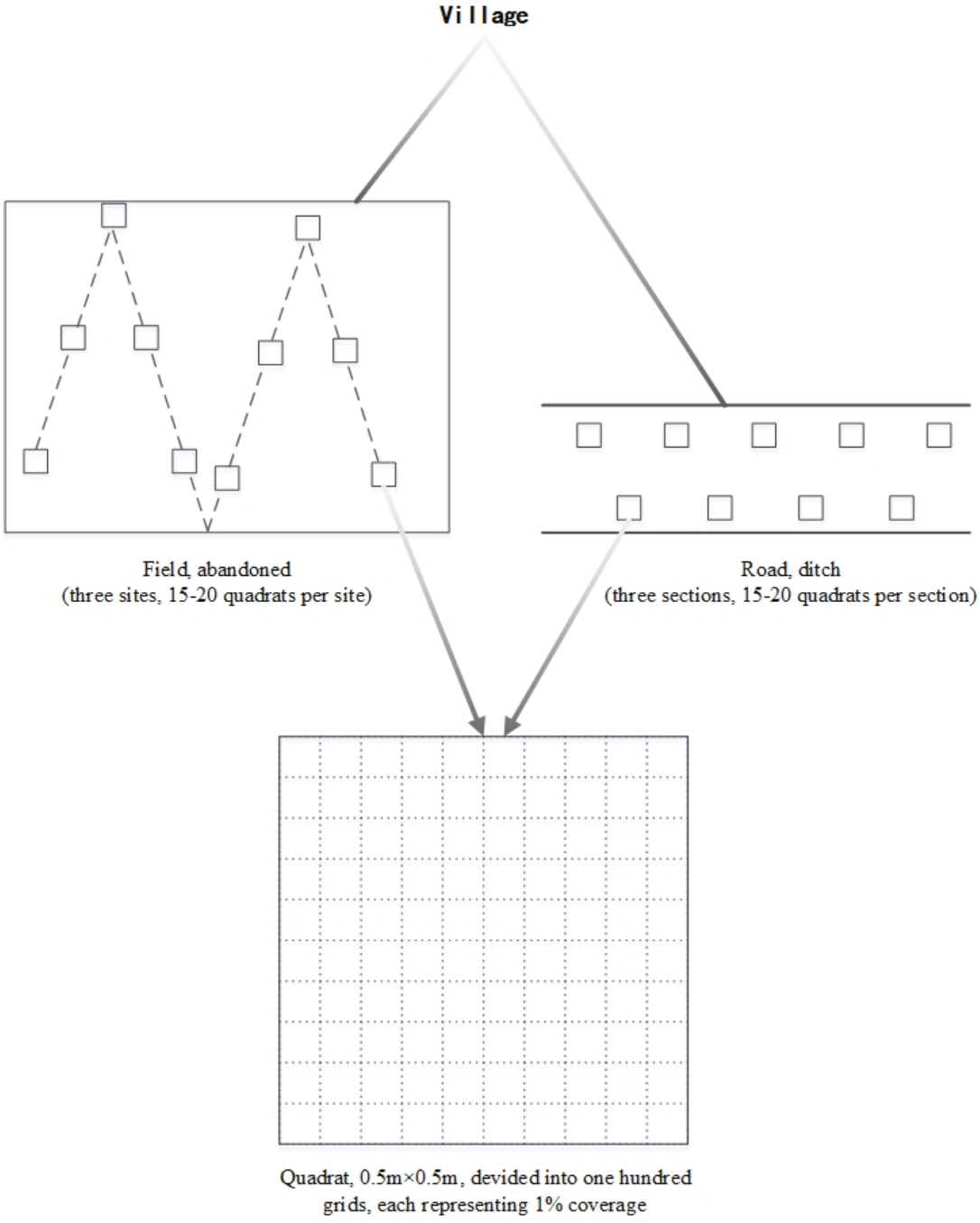


Figure 2 Sampling methodology and quadrat representation (figures represent patterns instead of actual distances)

Surveys were performed using a wooden quadrat (with dimensions 50 cm×50 cm). Species accumulation curves were recorded at first to identify the appropriate number of quadrats for each land type. For patches of land (field, abandoned sites) a zigzagged pattern was followed (Figure 2) with random number of steps; and for strips of land (road, ditch) directionality was followed with random number of steps. Number of quadrats with which accumulation curves reached peak ranged from nine to fifteen. Generally fifteen to twenty quadrats were counted in each land type.

Species data was recorded using the Braun-Blanquet cover-abundance scale (Braun-Blanquet 1932; Southwood and Henderson 2009): + for minimal presence; one for some shoots with less than 5% coverage; two for some shoots with 5% to 25% coverage; three for a moderate amount of shoots with 25% to 50% coverage; four for a large amount of shoots with 50% to 75% coverage; and five for background presence—large amount of shoots with over 75% coverage.

Diversity indices were calculated for each site, including: number of taxa; coverage, mean coverage within sample sites based on a 0.25 m^2 quadrat; Margalef's Richness (Margalef 1958; Southwood and Henderson 2009), which accounts for sample size; Shannon-Wiener Diversity Index (SHDI) (Shannon 2001; Southwood and Henderson 2009); Simpson's dominance index (Simpson 1949; Southwood and Henderson 2009); and evenness index E_{var} (Smith and Wilson 1996; Beisel et al. 2003). (Table S2a-c)

ANOSIM (Analysis of Similarities)—both one-way and two-way crossed were performed to test and compare the village type and land type factors (with Bray-Curtis dissimilarity as the measure of distance) (Clarke 1993). First a one-way analysis was performed on time factor to test if there was apparent separation of the data (Table S3a). Then two-way crossed analysis was performed with village type and land type factors for statistic comparison (Table S3b).

To best utilize benefits of non-Euclidean distance comparison measures (in this case diversity data), constrained ordination (redundancy analysis, RDA) was performed on Hellinger-transformed floral data (Legendre and Gallagher 2001; Legendre and Legendre 2012) based on factor village type, displayed with factor land type and grouped by time. Value along the plotted gradient (arrow) then roughly translate to increasing levels of input (from traditional to specified to diverse), so point positions (scaling=3) of sites can better reflect the subjected influence.

Regression models were established for mean flora coverage and agricultural input factors. Data at the village level limited number of variables possible for linear regression (six villages, maximum five independent variables). Fertilizers (kg/ha, divided into four categories: compound, potassium, phosphorous, potassium) were separated from other variables for regression there were no interactions between the two groups. This resulted in two regression models: model one included pesticide, herbicide and general factors; model two included fertilizers (Table S4). Fit for regression models were tested with Q-Q plots and distribution histograms (Figure S1-4).

2.2 Faunal data

Soil surveys covering soil chemical properties and soil fauna were conducted in October 2011 and 2012. Two representative plots were selected based on face-to-face interviews with the village leaders and elder farmers—to identify which plots best represented the village's cultivation status. Soil fauna samples were collected in two groups: the first was marked H for hand-picked. These samples were collected for each layer of soil in the sample site for a volume of 0.009 m^3 (using a 30 cm×30 cm quadrat, each layer was 10 cm deep, four layers in total. Specimens were stored in a small bottle filled with 75% ethanol solution on site. The second was marked T for funnel extraction. These samples were collected using soil sample rings with a volume of 7.854E-4 m^3 (5 cm Ø, 10 cm length) and then extracted back in the lab using Tulgren Funnels (Southwood and Henderson 2009)

for twenty four hours (samples were left for a further twenty four hours to test extraction rate, which proved that twenty four hours were enough). Each sample was marked using five reference codes: Village-Field-Plot-H(T)-Layer; with Zhu-cun-pu Village as 01, Chang-zhai Village as 02, Qian-gang Village as 03, Dong-ying Village as 04, Dong-yang-si Village as 05, Wan-zhai Village as 06. They were then taken back to the lab for extraction and classification. Species classification followed the guidelines laid out by Yin Wenying (Yin et al. 1998; Yin 2000) (Table S5).

Fauna abundance was classified into three categories: 1, rare group, species abundance not greater than the 10^{th} percentile of all species; 2, common group, species abundance between the 10^{th} and 90^{th} percentile; 3, main group, species abundance not smaller than the 90^{th} percentile. Diversity indices (similar to floral data) were also calculated for each site, layers (also referred to as depth) and in general, only for fauna data coverage is changed to density: number of specimens per cubic meters (Table S6).

Partial ordination of fauna sample sites were performed (NMDS) (Legendre and Gallagher 2001; Legendre and Legendre 2012) using Bray-Curtis distance (Clarke 1993), with 3 reduced dimensions and 200 iterations. Stress was tested by plotting ordination distance against observed dissimilarity (Figure S5).

2.3 Soil chemical data

Soil sample for chemical analysis were gathered in the same plots as fauna species (three per village). Thirty surface soil pre-samples were collected with a shovel (a thin slice going down twenty centimetres) while walking zigzag patterns in the plots similar to floral survey (Figure 2); these thirty pre-samples were then crushed, mixed together, and reduced to one kilogram using the quartering method (ISO 2006). All sites were GPS coordinated for future reference.

These samples were then taken back into the laboratory and spread on a flat surface,

while multiple random scoops of 200 g were taken and then grinded and screened using No. 100 (0.15 mm) sieves. The soil digestion (element extraction) was conducted following the Chinese national standard GB/T 17141-1997 (1997) using HCL-HNO3-HF-HCLO4 with hot plate heating, integrating blank, parallel and national standard soil samples for quality control (see supporting document for details). The elements Cr, Ni, Cu, Cd, and Pb in the sample solutions were analysed using a Thermo X Series2 ICP-MS (Inductively Coupled Plasma Mass Spectrometry) of the Thermo Fisher Scientific, USA; Element Zn was analysed using AA-6601F Atomic Absorption Spectrophotometer (AAS) of the Shimadzu Corporation, Japan. Machine recovery inner-control elements were also added in the analytical process (using elements Rh and In standard solutions) for quality control—overall control recovery rates were between 90%-107%, parallel sample errors≤3%.

2.4 Social-economic data

Extensive social surveys were carried out from August to October in 2011. One hundred households were randomly selected with help from village leaders in each village. Social economic data covered all aspects related to agricultural practice, including: cultivation (e.g., number of plots, size of plots, crop types); agriculture input (e.g., fertilizers, agrochemicals); spatial characteristics (e.g., distance from plots; distance from roads); household status (e.g., income, living condition); education (e.g., level, environmental awareness). Data was pre-processed by referring to county production records to remove ineffective entries which involved households with data (from questions) strongly contradicting those visually observed or gathered from village norms.

Chapter 3 Heavy metal contamination as affected by different cultivation types in Chinese traditional rural areas

Abstract: Agriculture intensification increases soil pollution in farmlands. Environmental-friendly management methods have been developed and evaluated based on their conservation potentials but this has not been the case in intensive agricultural regions in China. I selected six villages with three types of management schemes, analysed soil concentrations of heavy metal elements, chromium, nickel, copper, cadmium, lead and zinc of surface soil samples collected from representative farmlands in order to assess the effects of cultivation changes on soil heavy metal concentrations. Results show that given the same high input/output background, different managements clearly have different effects on heavy metal concentrations. Traditional cultivation has the lowest concentrations and therefore, is better in terms of sustainability. Villages with alternative managements had higher concentrations, especially with high eco-toxicity elements such as cadmium. After adjusting the potential ecological risk assessment indices, cadmium had the highest, single-element potential risk and the biggest contribution to the total potential risk in the area. Potential for alleviating heavy metal pollution can be found in diverse villages but requires the support of long-term, empirical evidence. The results point to possible conservation benefits of diverse cultivation management.

Key words: cultivation type; soil pollution; heavy metal; potential ecological risk

1 Introduction

Technological innovations in biological and chemical sectors have improved the efficiency of agri-industry over the past fifty years (Khush 1999; Evenson and Gollin 2003), simultaneously causing unprecedented impact on the ecosystem structure and functions in agricultural regions (Tilman et al. 2001). Being closely related to human livelihood, agricultural soil properties are vital because they affect the human health and safety.

Heavy metal pollution problems in agricultural soils are caused by excess build up of high eco-toxicity elements such as: mercury (Hg), cadmium (Cd), lead (Pb), chromium (Cr), and the metalloid element arsenic (As). Moderate eco-toxicity elements such as copper (Cu) and nickel (Ni) may also be involved. These elements pose higher threat because they are more resilient to biodegradation and leaching effects, and are more likely bio-concentrated (Hodson 2013). Hence, these elements have attracted research attention (Facchinelli et al. 2001; Micó et al. 2006; Hodson 2013). The background element status of agricultural soils come from their soil parent materials (Brady and Weil 1996). They are then affected by human cultivation such as the application of agrochemicals (e.g. fertilizers, pesticides, herbicides) (Nicholson et al. 2003; Alloway 2013); non-agricultural direct input such as local industrial run off and nearby traffic and transportation conditions (Pagotto et al. 2001; Ma et al. 2007; Wei and Yang 2010). Non-agricultural environmental sources include atmospheric fallout and ground water pollutions (Davis and Birch 2011; Schreck et al. 2012; Alloway 2013). Since agricultural input is the main source of heavy metal contamination and the most direct for control efforts, understanding its influences on heavy metal pollution in farmland regions, warrants much attention.

China has one of the largest agri-industries in the world (Food and Agriculture Organization 2013) with extremely strong emphasis on agricultural production which has caused severe environmental consequences (Xu et al. 1992). Agri-industry characteristics shifted due to the series of social and political policy reforms, the latest of which is the Household Contract system (Hong and Tao 2002) and the fast growth of manufacturing and tertiary industries in rural areas. The industrial development attracted human labour to non-agricultural jobs, leaving fewer people available in farmlands and, hence, agricultural production turned to rely heavily on agrochemical input. These factors increase the necessity of pollution research in Chinese rural areas (Huang et al. 2007; Tang et al. 2010; Wei and Yang 2010).

In China, specialized pattern of agriculture at the village level represent a current trend of changes in agricultural management still based on the household production unit formed in the last three decades (Lin 1992; Li and Wang 2003). This change is made when a large number of households in a village commit to a single or chain of production or services, making it the primary source of revenue (Li et al. 2009). Current research focuses on these specialized villages include its formation, spatial expansion, and response to geographical elements (Li et al. 2009). However, little attention has been paid to the environmental impact of such changes in agricultural patterns, despite the fact that specialized villages mostly focus on cash crop production with high input levels. By taking soil samples from representative villages with these management schemes and analysing their heavy metal contents, I try to answer the following questions:

1. Do changes in village scale agricultural practices affect levels of heavy metal contents? Are the soils in question exposed to ecological risks?
2. If so, how are these influences formed?
3. What are the main agricultural-input factors involved?
4. What changes would the development of alternative cultivation methods bring upon the regional heavy metal pollution status?

2 Area and methods

Henan province, having traditionally been focus of agriculture, has led China's wheat and grain yield for more than a decade (National Bureau of Statistics 2012c). Its agricultural practices are typified by the Huang-Huai-Hai alluvial plain with the traditional rotation of winter wheat (*Triticum aestivum*) and maize (*Zea mays*). This system has the longest history in Chinese agriculture and, in the recent decades, has involved higher agrochemical inputs. The forces of the market economy also pushed for the development of specialized villages, where village level production involving a large number of households. Specialized villages can be found in two forms: diverse cultivation utilizing farmland potentials leading to an increase in per area

revenue through extensive intercropping involving different cash crops (mostly vegetables). Others may involve raising village scale production potential by extensive mono-cropping. Both methods increase income revenue but their cultivation patterns involve different levels of agrochemical, irrigation and manual labour input which caused different effects on the surrounding environment.

2.1 Village selection

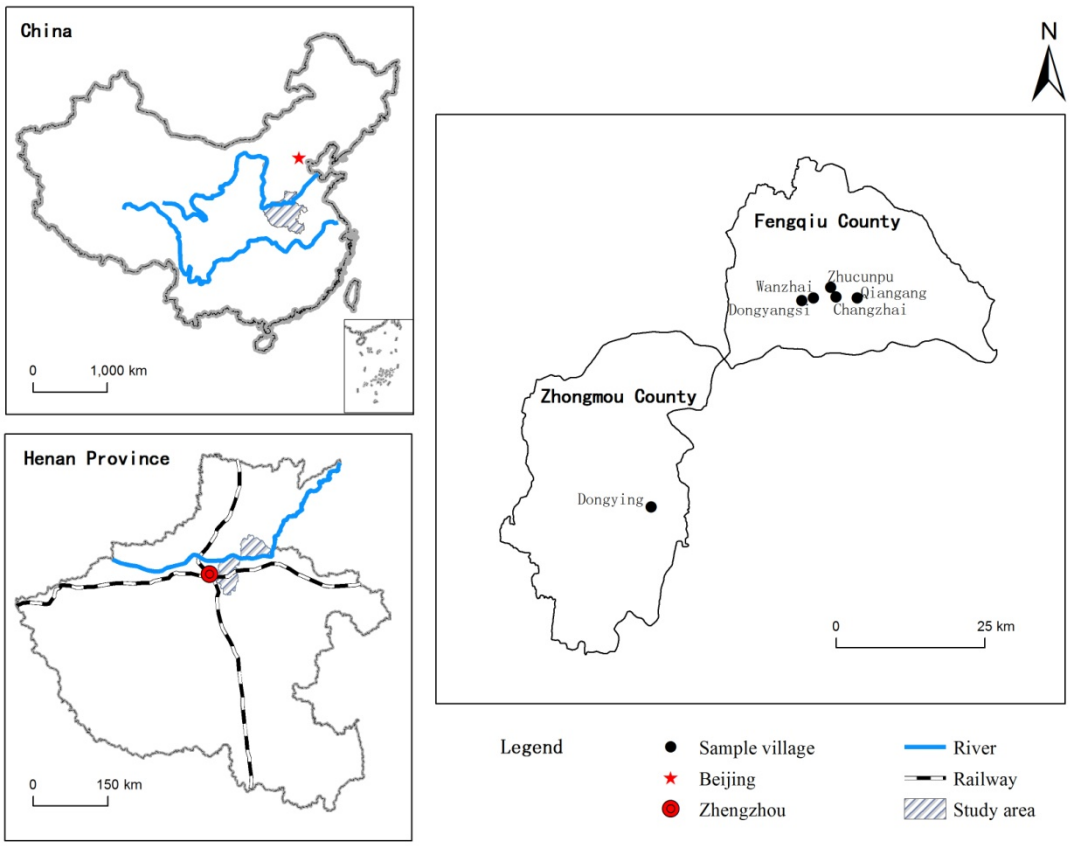


Fig. 1 Map of study area and location of the villages sampled

Six villages were selected within Fengqiu County, Xinxiang City and Zhongmou County, Zhengzhou City, Henan Province (Figure 1), located on both the north and south side of the Yellow River, representing three cultivation types.

Henan Province is located in the central-eastern region of China, the largest province of agricultural population and total crop production. Its total crop yield has remained the highest in China for more than a decade, with its 2012 crop yield, including main cereal types such as paddy rice, wheat and maize, reaching 56,386 million tonnes (National Bureau of Statistics 2012b). The productivity and diversity of agriculture in Henan make it suitable for analysing agricultural disturbances on the environment.

This study chose sites in rural areas along the Yellow River in Henan Province. Villages were the unit of study. In comparison with households, which are the basic production unit of Chinese agriculture, villages better reflect stability and representativeness in cultivation patterns. Two groups of three villages (traditional, specified and diverse) were chosen: Zhu-cun-pu and Dong-yang-si (Fengqiu County), representing traditional cultivation; Chang-zhai and Wan-zhai (Fengqiu County), representing diverse cultivation; and Qian-gang (Fengqiu County) and Dong-yin (Zhongmou County), representing specified cultivation. (refer to Chapter two for village selection details)

2.2 Sample collection and processing

Thirty surface soil samples were collected with a shovel (0-20cm) while walking zigzag patterns in the plots; these samples were then crushed, mixed together, and reduced to one kilogram (for each plot) using quartering method (ISO 2006). All sites were GPS coordinated for future reference. Villages were coded in the order they were sampled: 1, Zhu-cun-pu; 2, Chang-zhai; 3, Qian-gang; 4, Dong-ying; 5, Dong-yang-si; 6, Wan-zhai (will later be referred to by village names for clarity).

Samples were then taken back into the laboratory, dried and sieved (0.15 mm) (see Chapter two). Soil digestion (element extraction) was conducted following the Chinese national standard GB/T 17141-1997 (1997) using HCL-HNO3-HF-HCLO4 with hot plate heating (see Supporting document one). The elements Cr, Ni, Cu, Cd, and Pb in the sample solutions were analysed using a Thermo X Series2 ICP-MS (Inductively Coupled Plasma Mass Spectrometry) of the Thermo Fisher Scientific, USA. Zinc was analysed using AA-6601F Atomic Absorption Spectrophotometer (AAS) of the Shimadzu Corporation, Japan. Blank and parallel samples were added in the analytical process (using elements Rh and In standard solutions) for quality control—control recovery rates were between 90%-107%, parallel sample errors≤3%.

2.3 Analytical comparison

A common way of evaluating elemental contamination in soils is the potential risk index proposed by Hakanson (1980). It was a diagnostic tool developed for contamination assessment and control of marine sediment systems in Scandinavian environments. The index was formed by three major parts: the degree of contamination, the toxicity factor (T) and potential ecological risk factor for individual elements (E). Its main function was to examine heavy metal contamination conditions and assess where relevant studies should be prioritized. The original design had both individual indices (E) and joint index (RI) based on eight sediment heavy metal pollutants:

$$RI_j = \sum_{i=1}^{n} E_j^i = \sum_{i=1}^{n} T^i \times C_j^i = \sum_{i=1}^{n} T^i \times c_j^i / c_r^i$$

Where: RI_j is the joint ecological risk index of site j; E_j^i is the individual potential ecological risk index for element i in site j; T^i is toxicity factor for element i—based on Hakanson's research (1980) which set T^{Cd}=30, T^{Pb}=T^{Cu}=T^{Ni}=5, T^{Cr}=2, T^{Zn}=1; C_j^i is the pollution factor of element i at site j; c_j^i is the concentration of element i at site j; c_r^i is the concentration of element i in the reference sample.

Because only six elements are listed in this research, the potential ecological risk levels need to be reassigned. The lowest level of E is the multiplication of non-polluted index (C=1) and the highest elemental toxicity factor (T) in the research, which in this case T^{Cd}=30, so E=30 (level one). The remaining levels are multiplied by a factor of two. The lowest level of RI is the multiplication of non-polluted index (C=1) and the sum of all elements in the research (in this case 48), so RI=48 (round up to 50) with the remaining levels multiplied by a factor of two (Hakanson 1980). (Table 1)

Table 1 Potential Ecological Risk classification adopted in present paper based on Hakanson (1980)

E^a		RI^b		Potential risk
Hakanson'	Here	Hakanson's	Here	level
＜40	＜30	＜150	＜60	Mild
40-80	30-60	150-300	60-120	Moderate
80-160	60-120	300-600	120-240	Strong
160-320	120-240	≥600	≥240	Very strong
≥320	≥240	-	-	Extreme

[a] Individual potential ecological risk

[b] Joint potential ecological risk

Soil reference samples are needed to better understand the risk levels of study sites. Different standards and scales were generally chosen in response to differences with research goals and region such as using soil heavy metal background concentrations from local to global scales (Chen et al. 1991; Holmgren et al. 1993; Ma et al. 1997; Chen et al. 2004; Fan et al. 2011) or sampling local control sites (Jia et al. 2009). This research excluded most non-agricultural disturbances to farmland soil by carefully implementing a range of criteria e.g. considering only management schemes that came into being at approximately the start of 1990s, and using the soil background element concentration of the province for comparisons (Henan Province data, A/surface layer minimal observations; Table 2) (Wei et al. 1990). These data were collected at the end of 1980s and form a baseline of heavy metal concentrations in agricultural soils for the region.

Table 2 Soil element background concentrations in Henan Province (Wei et al. 1990)

Element	Min (mg/kg)	First quartile (mg/kg)	Median (mg/kg)	Third quartile (mg/kg)	Max (mg/kg)	Mean[a] (mg/kg)	St. Dev.* (mg/kg)
Cr[b]	25	53.5	62.9	71.3	109.8	63.8	13.25
Ni	6	22.5	25.8	29	80.5	26.7	5.69
Cu	5.5	16.4	19	22.3	67.5	19.7	4.8
Zn	34.3	50.7	57.3	65.8	221.5	60.1	15.3
Cd	0.039	0.062	0.074	0.084	0.276	0.074	0.0167
Pb	12.5	16.5	19.1	21.8	38.5	19.6	4.62

[a] Arithmetic mean and standard deviation

[b] Including Cr (III and VI)

3 Results

3.1 Surface soil heavy metal contents

Surface heavy metal concentration showed no consistent pattern in individual villages, except for a general increase associated with agricultural practices compared with baseline values (Table 3). Zinc in traditional villages had values lower than that of the background, suggesting lower risk and/or the possible lack of sample points during background surveys. The high eco-toxicity element, Cr, was higher in specified villages, and Cd was higher in diverse villages with concentrations six-fold over those of traditional villages. Comparison over village types (agricultural systems) displayed higher concentrations in specified (chromium, zinc, cadmium, lead) and diverse (chromium, copper, zinc, cadmium) village types. However, compared with highly increased level of agrochemical use (Chapter two), specified and diverse cultivations did not appear to have dramatically changed the heavy metal concentrations of farmland soils. Surface soil properties of all villages complied with the nation's soil environmental standards (State Bureau of Environmental Protection and State Bureau of Quality Technical Supervision 1995) type II classification for general farmland, with soil sample pH range 7.75-8.73. Soil heavy metal concentrations were slightly higher than other agricultural regions. (Wang et al. 2006; Jia et al. 2009)

Table 3 Surface Soil Heavy Metal Mean Concentrations in the Sample Sites (mg/kg)

Villages	Cr	Ni	Cu	Cd	Pb	Zn
1	31.29	18.87	14.28	0.12	28.17	24.02
2	40.36	15.76	16.11	0.75	21.56	47.36
3	44.03	15.86	10.83	0.15	25.83	39.79
4	54.03	17.84	6.79	0.70	32.63	36.74
5	47.14	16.60	8.29	0.09	20.63	28.09
6	42.40	18.56	13.23	0.62	23.04	34.07
Traditional*	39.22	17.74	11.29	0.11	24.40	26.05
Specified*	49.03	16.85	8.81	0.43	29.23	38.27
Diverse*	41.38	17.16	14.67	0.68	22.30	40.72
Background	25	6	5.5	0.039	12.5	34.3

* Averaged over two villages

Background refers to heavy metal concentrations used for comparison (Wei et al. 1990)

Specified cultivation appeared to have some impact on heavy metal concentrations, especially with chromium, zinc and cadmium in Dong-ying (Table 3), likely attributed to the high agrochemical demand (Chapter two) of garlic mono-cropping. Herbicide reduction caused by honeysuckle sensitivity seemed to have reduced the level of cadmium in Qian-gang, but some other elemental concentrations were still higher than those of traditional villages, likely made up by large amounts of pesticide. Diverse cultivation involves larger amounts of agrochemicals (Chapter two), but there were no other issues regarding toxic metals (high toxicity ones) other than cadmium.

3.2 Potential ecological risk evaluation of surface soils

Table 4 Potential Ecological Risk indices of sample sites

	Element	Zhu-cun-pu	Dong-yang-si	Qian-gang	Dong-ying	Chang-zhai	Wan-zhai
E^a	Cr	2.50	3.77	3.52	4.32	3.23	3.39
	Ni	15.73	13.83	13.22	14.87	13.13	15.47
	Cu	12.98	7.54	9.85	6.17	14.65	12.03
	Cd	92.31	69.23	115.38	538.46	576.92	476.92
	Pb	11.27	8.25	10.33	13.05	8.62	9.22
	Zn	0.70	0.82	1.16	1.07	1.38	0.99
	RI^b	135.49	153.46	617.94	577.95	103.44	518.02

[a] Individual potential ecological risk

[b] Joint potential ecological risk

Results show that element cadmium has the highest potential risks in all villages (Table 4) and especially with diverse villages and specified Dong-ying (contributed to 93% of the total risk RI for Chang-zhai, 93% for Dong-ying, and 92% for Wan-zhai). This could be attributed to agrochemical input (Chapter two). Cadmium potential ecological risks in the three villages exceeded the maximum standard and classified as extremely strong; its potential risks for the rest three villages are strong. All other elements are in the mild category. Diverse villages had the highest RIs. The lower RI in Qian-gang could be caused by lack of herbicide input due to honeysuckle sensitivity (Chapter two). Traditional villages had the lowest RIs, with Zhu-cun-pu at moderate risk and Dong-yang-si at mild risk.

The comparisons of RIs clearly indicate a rise of heavy metal pollution in relation to specified and diverse specialization but this effect could be reduced by the selection of specific cash crops. This increases soil contamination by heavy metals and threatens local agriculture sustainability.

4 Discussion

The lower RIs in traditional villages points to the sustainable nature of conventional cultivation methods. This is under pressure from the policy changes involving the release of agricultural labour, increase of yield requirements and permission of land circulation (trading of farmland). Under such conditions, even fewer people would be left in rural areas (less than 100 million) to manage China’s 120 million hectares of farmland. Extensive monoculture would likely replace the current traditional villages by grouping circulated lands into big plots, eliminating non-field landscapes in the vicinity, and applying agrochemicals at the larger scale. These features of extensive monoculture will damage ecosystem properties even more. Whether or not these changes cause more heavy metal pollution than the alternative methods in rural areas remains to be tested.

Both alternative methods increased metallic elements in the soil. These elevated

individual risks of some metals (such as cadmium) and the total RIs of the villages. Elements such as cadmium and copper can be found in many fertilizers, pesticides, and herbicides either as part of the main component or in residual trace amount (Zhou et al. 2000; Alam et al. 2003). The general study region is agriculturally focused with minimal industry presence, but it is still influenced by atmospheric heavy metal deposits from vehicle exhausts, tyre residuals and, especially, ground water which is the source of irrigation in all Huang-huai-hai alluvial plain agricultural regions and is threatened with heavy metal pollution (Ministry of Environmental Protection et al. 2013).

When comparing conservation potential of the alternative methods of agricultural production, diverse cultivation's poly-cropping could be beneficial in reducing concentrations. Increased floral diversity (Chapter four) has the potential to reduce heavy metal pollution damage in agricultural lands through the phytoextraction capabilities of plant species (Bhargava et al. 2012). Phytoextraction of Cu elements by maize and paddy rice, and abilities of Fabaceae species (e.g. soybean, Glycine *max*) to absorb Zn elements (Murakami and Ae 2009) and Cd elements (Leita et al. 1993; Arthur et al. 2000), may play a role in this regard. Hence, the high variety of crop types found in diverse cultivation fields (including Poaceae, Fabaceae and Brassicaceae) could lower agrochemical residues. Specified mono-culture systems, depending on market values, could be based on cash crops that are sensitive to agrochemicals thereby reducing input (village Qian-gang), but this effect is unstable and larger scale adoptation of it would have similar effects to that of any extensive monoculture.

5 Conclusion

Heavy metal concentration in agricultural soils is related to changes made in cultivation and management. In Chinese traditional cultivation there is a close-to-sustainable production system resulting from centuries of balancing inputs and productivity. Changes induced by new agricultural policies, urbanization and

market economies threaten the existence of the latter sustainable practices. Larger scale production might result in more agrochemicals input, with damage to ecological factors such as biodiversity, reducing regulatory functions in natural ecosystems.

Diverse cultivation, on the other hand, promotes small and large scale landscape heterogeneity (Chapter four) and supports potentially higher biodiversity in farmlands. Its impact on heavy metal concentrations in soils is higher than that of traditional cultivation but this damage is likely to be alleviated through changes in agrochemical inputs (i.e. using more manure instead of industrial fertilizers) and heavy metal phytoextraction by more arable weed species. The high economic revenue created by diverse cultivation systems is especially appealing for farmers and, therefore, requires minimal policy levers to be widely implemented. This could create much needed species and habitat conservations in a region that is possibly shifting towards a highly monotonic landscape.

Specified cultivations can do just as much damage to the soil properties as diverse cultivations depending on the crop type and individual requirements, but it is even more of a mono-culture than traditional cultivation and low in diversities (Chapter two). Its limitations (high demand in manual labour and agrochemicals, and potential market saturation) make it less likely to be implemented on a large scale. Longer ecological impact of specified cultivation awaits further analysis.

This study compared soil element concentrations at village level. A historical record of soil element concentration in this region is lacking so that temporal responses in heavy metal concentrations to agricultural practices could not be quantified. These results, however, can serve as a baseline for future studies. As policy levers drastically change the pattern of agri-industry in China, agricultural practices should be planned in such a way that regional biodiversity can be maintained while meeting high production targets. Conservation and production studies are required on both

small (village) and large (regional) scales.

Chapter 4 Diverse cultivation benefits floral diversity in Chinese rural areas

Abstract: Agricultural practices affect biodiversity, especially flora communities which play important roles in ecosystem stability. Studies focused on environmentally friendly agriculture schemes have found mixed effects on biodiversity by these conservation efforts. However, these practices in agriculturally intensive areas in developing countries such as China where food production is a priority have not been closely examined. This study integrated floral distribution and agricultural inputs in six geographically similar villages with traditional and alternative cultivation methods in a Chinese traditional rural area in an attempt to determine their effects on biodiversity using similarity analyses and linear regression models. Village type significantly affected floral distribution ($p<0.001$) and the influence was more effective at the village scale compared with individual land types. Diverse cultivation was related to increased floral diversity, likely due to heterogeneity created by abundant crop types, and high manual labour input balancing agrochemical requirements. Spatial replication of such methods is recommended to produce definite results regarding optimal effects. Long-term empirical evidence is required to demonstrate sustainable effects. In high demand agricultural regions, diverse cultivation might prove to be a unique way of preserving biodiversity.

Key words: agriculture, floral diversity, management schemes, diverse cultivation

1 Introduction

Agricultural practices[2] are the most basic and fundamental human activities greatly affecting biodiversity worldwide (Tilman et al. 2001; Benton 2007; Sutherland et al. 2009). Conservation actions such as European Union's Agri-Environmental Schemes, US's Conservation Reserve Program and Australia's Landcare Program

[2] This paper defines agriculture only as the cropping practices on farmlands. It does not include forestry, aquaculture (pond fishery) or pastoral (grazed livestock) production.

(Curtis and de Lacy 1998; Johnson and Clark 2001; Directorate General for Agriculture and Rural Development 2010) represent ways to tackle this issue through adopting alternative environmentally friendly methods such as organic farming. Since their implementation, researchers have examined the effectiveness of such actions based on their ability to protect biodiversity (Kleijn et al. 2001; Henle et al. 2008; Gabriel et al. 2010; Smith et al. 2010; Winqvist et al. 2012; Gabriel et al. 2013).

Alternative farming methods have mixed effects on biodiversity. Species react both positively and negatively to changes in land management (Kleijn et al. 2001; Kleijn and Sutherland 2003; Feehan et al. 2005; Kleijn et al. 2006; Kleijn et al. 2011). Positive effects may manifest differently with variation in field or crop types (Bengtsson et al. 2005; Feehan et al. 2005; Hole et al. 2005; Blomqvist et al. 2009; Gabriel et al. 2013). Plants, and solitary animal species such as most farmland insects, benefit from changes in management practices (Hald 1999; Hole et al. 2005); Mobile species, such as birds and some pollinators, likely respond to factors other than those related to the farmlands (Benton et al. 2002; Chamberlain et al. 2010). As such, farmland conservation should incorporate multiple management scales on a case-specific basis (Gabriel et al. 2010).

In farmland regions, floral[3] species play a crucial role in maintaining the functions and structural stability of agricultural ecosystems (Altieri 1991; McLaughlin and Mineau 1995; Swanton and Murphy 1996). Plants provide necessary habitats and refuges for ground insects and pollinators (Hooper and Vitousek 1997; Altieri 1999; Brose 2003; Duffy 2009). As agriculture intensifies, ecological regulations by natural environmental elements (such as plants) have been replaced slowly by anthropogenic regulators such as agrochemicals. This has increasingly affected farmland ecosystems and endangered the natural habitat of plant species (Matson et al. 1997; Butler et al. 2007)

[3] This paper referrers to farmland plants as non-crop species

Floral response to agri-environmental management has been extensively studied (Hole et al. 2005; Blomqvist et al. 2009; Hawes et al. 2010), but most are based on cases of environmental friendly management practices implemented specifically for conservation. This has limited importance in agricultural areas where food production is paramount, such as China, where adopting such measures can be problematic due to decreased yields (Seufert et al. 2012). Therefore, conservation efforts in these regions need to focus on alternative means of cultivation.

China has one of the largest agricultural productions in the world (Food and Agriculture Organization 2013). There is extremely strong emphasis on agricultural production but much interest has been attached to monitoring the response of agriculture to a series of social and political policy reforms, the latest of which being the Household Contract system (Hong and Tao 2002). This contracts collectively-owned farmland to individual households, based on capita and the fast growth of manufacturing and tertiary industries in rural areas. These reforms result in a more fragmented agricultural landscape in rural areas (Li and Wang 2003). Current agriculture development in China involves the formation of specialized villages with most households in a village committed to one or a chain of production type, making this the primary source of revenue (Li et al. 2009). At the end of 2010, China has 51486 specialized villages, with an average village income 15.56% higher than others in the country whilst that of participating households is 25.82% higher than farmers in other villages (Ministry of Agriculture 2011). These villages often choose high value cash crops involving large amount of input. Therefore, this calls into question the environmental impact of such management, especially that on the already threatened floral diversity.

Chinese studies have focused on the ecological functions and services of floral diversity in agricultural landscapes (Wu et al. 1998; Chen et al. 2000) but insufficient attention has been paid to comparing biodiversity with regard to

management changes, likely due to lack of a national farmland conservation plan. By obtaining detailed data at the village level, this research examines how socio-economic factors and on-site cultivation practices affect floral diversity in the study area. In doing so, I try to answer the following questions:

1. Do changes in village scale agricultural practices affect floral species distribution?
2. If so, how are they affecting floral diversity within and between villages?
3. What are the main agricultural-input factors affecting floral diversity?
4. What changes would the development of alternative cultivation methods bring upon the regional floral diversity conditions?

2 Area and methods

Six villages were selected within Fengqiu County, Xinxiang City and Zhongmou County, Zhengzhou City, Henan Province (Figure 1), located on both the north and south side of the Yellow River, representing three main types of newly formed cultivation types.

Henan Province is located in the central-eastern region of China, and is the province with the greatest agricultural population and total crop production. Its total crop yield has remained the highest for more than a decade with its 2012 crop yield, including main cereal types such as paddy rice, wheat and maize, reaching 56,386 million tonnes (National Bureau of Statistics 2012b) thus making Henan very suitable for analysing agricultural disturbances on the environment.

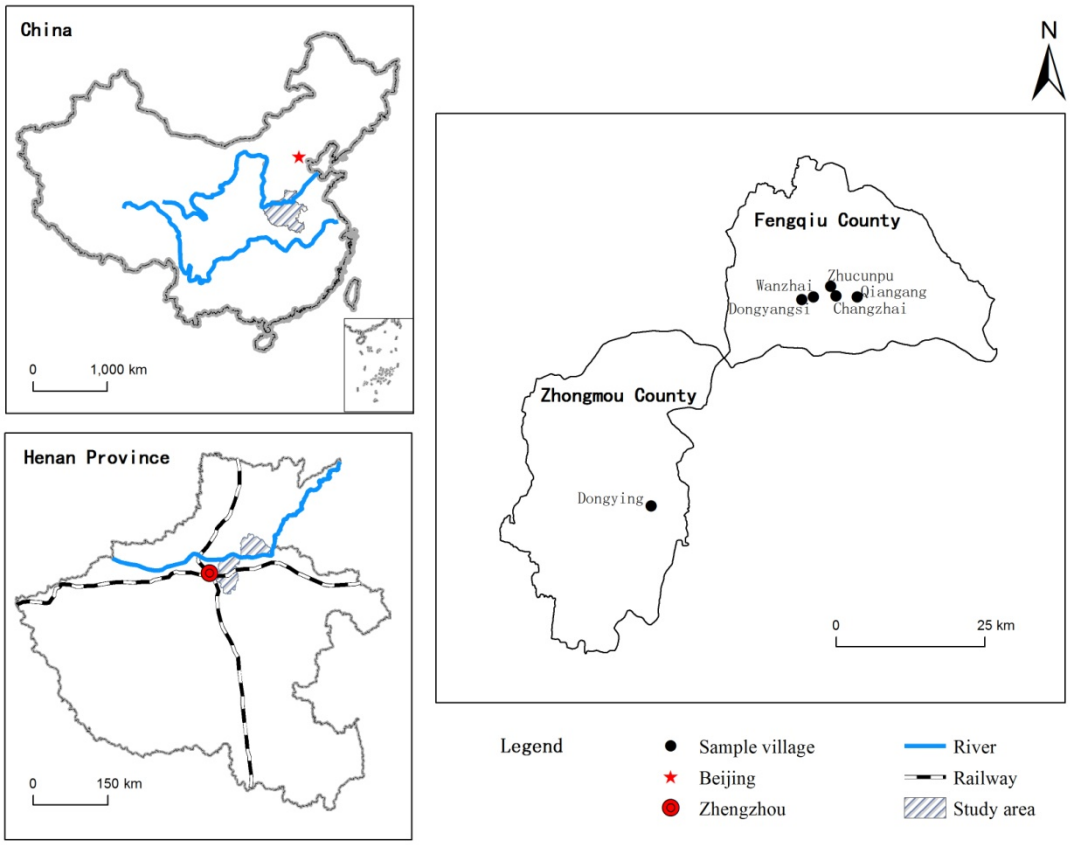


Figure 1 Map of the study area and location of the villages sampled

2.1 Floral survey

Vegetation surveys were conducted in two consecutive years: 2012 summer (August), 2013 spring (April, coded 201304), and 2013 summer (August, coded 201308). Due to accessibility at the time, villages were coded in the order they were sampled: 1, Zhu-cun-pu; 2, Chang-zhai; 3, Qian-gang; 4, Dong-ying; 5, Dong-yang-si; 6, Wan-zhai (will later be referred to by village names for clarity and comparison).

Surveys used a wooden quadrat (with dimensions 0.5 m×0.5 m), and recorded plant species using the Braun-Blanquet cover-abundance scale (Braun-Blanquet 1932; Southwood and Henderson 2009). Classification was based on the species catalogues of Henan Province (Ding and Wang 1998). Data covered four land types in rural villages: farmland (farm-plots with representative crops, e.g. wheat/maize for traditional), roadside (dirt access roads within farmlands), ditch (old irrigation ducts or field boundary ditches), and abandoned (uncultivated plots or patches planted with trees). Farmland plots and abandoned sites were surveyed in a zigzag pattern. Roadsides and ditches were surveyed while walking random number of steps (using randomly generated numbers) along selected roads. Number of quadrats was predetermined using species accumulation curves.

2.2 Floral statistics

Diversity indices were calculated for each site, including: number of taxa; coverage, mean coverage within sample sites based on a 0.25 m^2 quadrat; Margalef's Richness (Margalef 1958; Southwood and Henderson 2009), which accounts for sample size; Shannon-Wiener Diversity Index (SHDI) (Shannon 2001; Southwood and Henderson 2009); Simpson's dominance index (Simpson 1949; Southwood and Henderson 2009); and evenness index E_{var} (Smith and Wilson 1996; Beisel et al. 2003). Measure of species evenness E_{var} was selected to reflect changes of main floral species groups across sites, while being less sensitive to the changes in the rare and sometimes dominant species (Smith and Wilson 1996; Beisel et al. 2003),

which in this case consisted of only three types of species and therefore highly susceptible to change.

$$E_{\text{var}} = 1 - 2/\pi \arctan\left\{\sum_{x=1}^{s}\left(\ln(x_s) - \sum_{t=1}^{S}\ln(x_t)/S\right)^2 / S\right\}$$

Where x_s and x_t are the number of individuals in species s and t respectively, and S is the total number of species in the particular sample.

2.3 Analysis of similarity and ordination

ANOSIM (Analysis of Similarities) with both one-way and two-way crossed design were performed to test and compare the village type and land type factors (with Bray-Curtis dissimilarity as the measure of distance) (Clarke 1993). A one-way analysis was performed based on factor time (2012summer, 2013spring, 2013summer) to test if there was apparent separation of the data. Then two-way crossed analysis was performed with village type and land type for comparison.

To best utilize benefits of non-Euclidean distance comparison measures, constrained ordination (redundancy analysis, RDA) was performed on Hellinger-transformed floral data (Legendre and Gallagher 2001; Legendre and Legendre 2012) based on the factors village type and land type, grouped by time. The increase along the gradient (arrow in the figure) roughly translates to increasing levels of input (from traditional to specified to diverse), so point positions (scaling=3) of sites can better reflect the subjected influence.

2.4 Data modelling

Regression models were calculated to analyse response of floral composition various agricultural inputs. Generalized linear model options were tested first using residual analysis, to ensure whether results were normally distributed. The classical linear model was chosen after this initial analysis. Due to a high frequency of empty cells (zeros in data) in sample sites, floral data averaged over land types were used as dependent variables. Species number did not contain enough variance across

samples, and, therefore, failed to produce significant model results. Floral coverage was selected instead to represent dynamic changes of plant species growth conditions. Independent variables included: pesticide (litres per ha, including major types such as chlorpyrifos, omethoate, and beta-cypermethrin) herbicide (litres per ha, including major types such acetochlor, napropamide, and dibutralin), manual labour (man-hours per ha), agricultural machinery (hours per ha, including irrigation, tillage, and harvest machines), and fertilizers (kg/ha, compound, nitrogen, phosphor, and potassium) (Table S4). Pesticide and herbicide showed interactions during initial assessment, and their interaction was included as an independent variable in the model. Fertilizer inputs were not observed to be related to other independent variables, so they were analysed using a second regression model. Fit of regression models were tested by normal Q-Q plots and distribution histograms (Figures S1-4) with Jarque-Bera statistics (Jarque and Bera 1980; Jarque and Bera 1987).

3 Results

3.1 Flora statistics

The samples contained 105 plant species in total, belonging to 86 genera and 34 families. Of those, 52 species were only found in the summer, six in the spring. Three families were also exclusive to spring: namely, Plantaginaceae, Brassicaceae, and Caryophyllaceae.

Nineteen species dominated the various types of land in the villages; 20 species were found to be in the main group; and 61 in the rare group. The dominant group overlapped highly with the main and therefore were analysed together (Table S1a-S1c). Compositae, which was only found in summer, had the highest number of species.

The species *Humulus scandens* was the most abundant in the overall mean coverage of all six villages, followed by: *Eleusine indica* (L.) Gaertn., *Cucumis melo* L. var. agrestis Naud., *Amaranthus retroflexus* L., *Setaria viridis* (L.) Beauv., *Cardamine*

lyrata, *Polygonum hydropiper* L., and *Cynodon dactylon* (L.) Pers. *Humulus scandens* flourishes in ditches and abandoned fields in all sample seasons. *Eleusine indica* dominates roadsides and fields in the summer, with only two records in spring 2013. *Cucumis melo* grows only in the summer in fields and field-adjacent roadsides, demonstrating a rather high tolerance to the frequent disturbance.

Floral abundances were higher in abandoned sites and ditches and lower in field and roads. This trend was less pronounced in specified and diverse villages than traditional villages. Exceptionally, Dong-yang-si had more diversity in the fields than road and abandoned sites (ditch was not present), probably attributed to the farmers being reluctant to put in much work as there were a high percentage of villager migrant working for a better pay. Specified and diverse villages did not display increased floral diversity in any single land types, but the overall diversities of villages were higher than that of traditional villages (Table 1).

Table 1 Seasonal (spring and summer) taxonomic difference (number of species) between villages

Time	Zhu-cun-pu	Dong-yang-si	Qian-gang	Dong-ying	Chang-zhai	Wan-zhai
Spring	32	27	30	9	35	21
Summer	49	51	50	35	47	64
Total	67	56	58	39	67	67

The highest differences of species coverage (e.g. species *Eleusine indica*, *Setaria viridis*, *Humulus scandens*) occurred in 2013 between villages. Broad-leaved species (e.g. *Polygonum aviculare* of the family Polygonaceae) showed some variation between different types of villages being higher in traditional, and lower in diverse systems (Tables S2a-c). However, this was not apparent for other families such as Fabaceae and Brassicaceae which were more sensitive to agricultural disturbance. This suggests a slightly reduced level of agrochemical disturbance in diverse villages.

3.2 Differences in floral distribution

One-way ANOSIM showed significant global results and further pair-wise tests showed significant separation between groups 2012 and 2013spring (0.643), and 2013spring and 2013summer (0.714). 2012 and 2013summer had high similarities.

Two-way ANOSIM results based on factors village type and land type showed significant global statistic (0.536) between land types in summer data. Pair-wise test of land types revealed significant dissimilarities (number in brackets) in a descending order: field and abandoned (0.86), road and abandoned (0.747), field and ditch (0.73), road and ditch (0.479), field and road (0.358), ditch and abandoned (0.244) ($P<0.05$). Statistics of spring floral groups showed similar results but non-significant levels. (Table S3b)

A significant global result was also observed for the effects of village type in summer data ($p<0.001$) though this was relatively smaller than the effects of land type. Pair-wise results of village types 1, 2 and 2, 3 showed significant differences: 0.279 and 0.369 respectively.

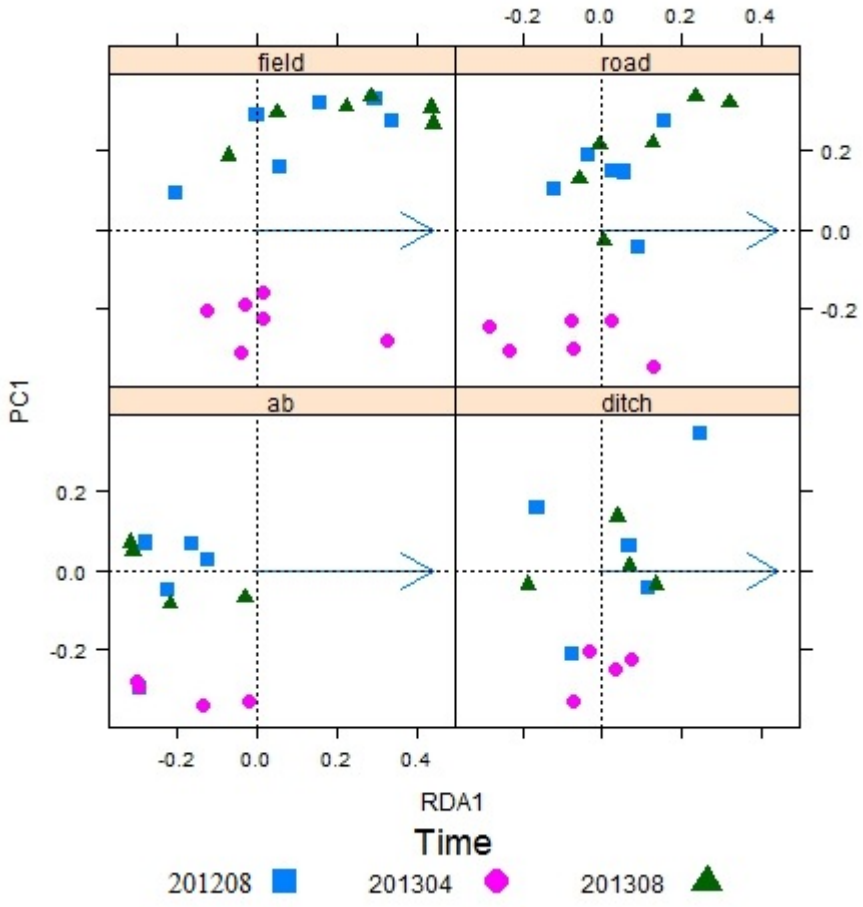


Figure 2 Ordination plot (redundancy analysis, scaling = 3) of Hellinger-transformed floral data on village type; displayed by factor land type and grouped by time; Increase along the gradient (blue arrow) roughly translates to increasing levels of input (from traditional to specified to diverse). Figure shows distribution of 201208 and 201308 samples (blue and green points) more affected by land-type factor compared with 201304 samples; changes caused by village differences are more apparent in field and road land-types as is suggested by more dispersed points.

Visual representation of site distribution suggests that factor village type had more influence with field and road sample sites (Figure 2): with field sites more susceptible to change. Differences caused by village types were close to consistent across various land types. Distribution of abandoned sample sites were more grouped in all seasons, and falls on the left of gradient, which means abandoned sites were relatively resilient to changes caused by village types. Ditch sample sites are not as grouped; changes are present, although minimal. Separation of sample sites on the plot between summer and spring supported earlier findings. Village type also displayed higher influence on site distributions for summer groups.

3.3 Modelling effects of agricultural practices on floral community

Table 2 Regression results of floral coverage with agriculture input (control variables excluded)

	Model one		**Model two**	
	Coverage	Standardized coefficient	Coverage	Standardized coefficient
Herbicide (L/ha)	-46.76**	-47.23**		
	(14.84)	(14.99)		
Pesticide (L/ha)	-6.30**	-11.68**		
	(2.07)	(3.84)		
Herbicide^Pesticide	2.39**	13.10**		
	(0.77)	(4.23)		
Manual labour	0.003*	-2.34*		
(man×hour/ha)	(0.001)	(1.06)		
Machinery (hour/ha)	-0.34*	1.46*		
	(0.15)	(0.55)		
Compound fertilizer			0.008*	2.17*
(Kg/ha)			(0.003)	(0.98)
Nitrogen fertilizer (Kg/ha)			-0.11*	-36.76*
			(0.05)	(18.17)
Phosphorous fertilizer			0.23*	37.33*
(Kg/ha)			(0.12)	(18.37)
Potassium fertilizer (Kg/ha)			0.23*	8.08*
			(0.12)	(4.09)
R^2	0.5658	0.5658	0.1548	0.1548
F	8.63**	8.63**	2.61*	2.61*

Models 1and 2 contain different explanatory variables for the same dependent variables; coverage was the mean floral coverage for specific land types, std. coef. are standardized β values of coverage;

* Significant at 0.05 level ** Significant at 0.01 level

^ Interaction between two variables; for standardized coefficients, interaction were calculated after standardization;

Herbicide had the highest significant negative correlation with floral coverage. However, pesticides were also correlated negatively with coverage regardless of differences in active ingredients. The interaction between herbicide and pesticide (translates to partial derivatives of individual correlation coefficients) was significant, but this result is likely to be coincidental given the lack of theoretical basis, and the interaction of pesticides and herbicides may be a result of confounding due to general application methods. Manual labour input was significantly correlated with floral coverage increase and had a small standard covariance caused by coverage data being averaged over whole sample types. Machinery time input was negatively correlated with floral coverage. This model had a moderate goodness of fit (coefficient of determination 0.5658) representing variations in floral coverage differences. However, this might be a good representation of data variation given that regression was based on spatial data rather than temporal datasets.

Phosphorous fertilizers had a significant positive correlation with floral coverage. Nitrogen fertilizers had a significant negative correlation. Potassium and compound fertilizers had significant but weaker positive correlations. Fertilizers accounted for only a small proportion of variations in floral coverage. These correlations do not imply direct causation, but the two models covered all main factors affecting floral differences in villages sampled so they indicate factors important for maintaining floral diversity amongst those actually observed.

4 Discussion

The considerable differences displayed in ANOSIM results between field/road and abandoned sites (Table S3b) suggests that abandonment (plots left uncultivated or planted with trees for timber) had large impacts on biodiversity, and created local diversity refuges as evident by increasing diversity and richness levels (Tables S2a-c). In traditional Chinese rural areas, agricultural landscapes tend to be mono-cultural yet fragmented (Zhang et al. 2004; Fu et al. 2006), limiting large-scale landscape factors that could be beneficial to biodiversity (Ewers and

Didham 2008; Gabriel et al. 2010; Banks-Leite et al. 2011) and reducing species rich sites with re-colonization capabilities. Abandoned sites and ditches, relatively, have the lowest disturbance levels in farmlands as they do not receive agrochemicals directly and were not subjected to constant manual interference. This results in high similarities between these two groups, and also made them possible sources for floral species in nearby patches. However, although some abandoned sites may exist for more than a year (such as Zhu-cun-pu), others do not (such as Dong-ying). Ditches were also poorly maintained and often absorbed by nearby plot owners for crop production.

High similarities between field and road suggest spill-over of farmland disturbances and possibly of floral species (Brudvig et al. 2009; Gabriel et al. 2010). The high level of agro-chemical input in the farmland plots right next to the roads, which were mostly dirt paths maintained for access to the farmland and due to the high fragmentation of fields located in the mosaics of farmlands, affected not just the plots, but caused changes to the surrounding roads as well.

4.1 Village factors affect floral distribution

Village type had less but still significant influence on the distribution of floral species in sample sites compared to effects of land type, which is regarded as the main source of plant species diversity variations in farmlands (Marshall and Moonen 2002; Roschewitz et al. 2005; Zihua et al. 2010; Fahrig et al. 2011). These influences, as expected, had the highest impact in fields (Figure 2). Its impact on the floral diversity in road sites point to the high level of spill-over of agricultural disturbances to the plot adjacent land types. It also explains the overall lack of diversity and richness in field and road sample sites (Tables S2a-c). Ditch sample sites, though often not far from farmland plots, were partly sheltered from the disturbances by their physical features. This also made their species composition unique: most ditch sites were dominated by *Humulus scandens*, a species, though common, rarely found in dominance in other land types. The floral distribution of

abandoned sites was almost completely unaffected by the village type. Since most abandoned sites were still under a moderate level of disturbance (limited grazing, fire, or occasional plantation), similarities among different villages likely points to the high rate of re-colonization in farmland areas.

The differences between different land types across villages were consistent but quite small (Figure 2; Tables S2a-c, S3b). However, overall species richness was quite distinguishable between village types. The overall species number was highest in diverse villages in summer data and lowest in specified villages. This is probably due to the small species turnover between land types in traditional villages but this increased in specified villages due to the mono-cultural landscape features in comparison with higher rates of turnover in diverse villages. Diverse villages have, on average, lower species diversity in each land type, but higher total diversity on the village scale.

The diverse cultivation method utilizes intercropping to its maximum potential, with up to a dozen crops planted in a single plot (supporting document two). Crops are regularly replaced with new ones when they mature, creating a highly diverse condition at the farmland scale. Plants benefit from the diverse factors at this level (Gabriel et al. 2010; Gabriel et al. 2013). This effect may not be evident at the small scale in individual land types but differences within plots collectively contributed to the overall diversity within the village. While traditional and specified villages have large numbers of similar plots creating a simple village-scale landscape, the landscapes in diverse villages contained more variation and complexity, which provide more resources and potential niches, supporting higher biological diversity levels (Bazzaz 1975; Dufour et al. 2006; Rundlöf et al. 2008).

Though village scale factors in traditional Chinese rural areas are still quite small compared with general landscape elements that would influence biodiversity (Gabriel et al. 2010). The spatial replication of diverse villages within a particular

region may eventually reach such a threshold. The present results point to the potential of diverse cultivation method in promoting conservation.

4.2 Agricultural input factors affecting floral diversity

Pesticide and herbicide application and general factors accounted for a high proportion of observed variation in floral coverage. Regression results suggest that the benefits of diverse-cultivation in promoting plant species richness can largely be attributed to its relatively lower herbicide inputs and high levels of manual labour. Diverse cultivation restricts herbicide input because of unpredicted responses of different cash crops. With control using agrochemicals is replaced by manual labour. Specified cultivation is just as mono-cultural as traditional systems, which is associated with high use of agrochemicals (chapter two).

Diverse cultivation has many features closely resembling traditional practices in comparison with other types of agricultural systems. They are mainly characterized by meticulous, plot-level management of crops and agrochemicals and is more likely to preserve some of the environmental-friendly features of traditional practices (Rosset et al. 1999; Altieri et al. 2012). Regardless of floral diversity in particular farm plots, overall diversity might still be maintained.

The regression analyses show a correlation between reduced floral coverage and nitrogen fertilizer input similar to those found in grassland communities (e.g. Gough et al. 2000; Stevens et al. 2004; Crawley et al. 2005; Silvertown et al. 2006; Harpole and Tilman 2007; Mozumdera and Berrens 2007; Clark and Tilman 2008). This points to the possibilities of reduced niche dimensions caused by eutrophication in agricultural ecosystems in a similar fashion. Loss of plant species diversity has been widely observed in grassland areas where the deposition of nitrogen (and other nutrients) accumulates, even with increased primary productivity. Whether agricultural ecosystems display similar symptoms, is unknown. In grassland communities, this has been largely attributed to the reduction of light to understory

plant species (Hautier et al. 2009). During floral surveys, similar conditions were found in non-field land types. Vegetation patches with higher overstory plants (such as species from genera *Artemisia*, *Chenopodium*, etc.) usually had lower understory species (*Cyperus*, *Digitaria*, *Humulus*, etc.) cover, leading to lower coverage overalls. Patches without dominant overstory species were found to have high understory coverage and sometimes resulted in total coverage ratios above 100%. This occurs because patches with level-five coverage on the Braun-Blanquet scale rarely occur in high canopies. This suggests that in agricultural ecosystems, nutrient eutrophication may similarly reduce floral diversity, but whether or not light deprivation is the main cause, requires more empirical evidence.

5 Conclusion

In Rural China agricultural practices affect floral communities in the farmlands. Diverse cultivation promoted arable weed species diversity in the villages by balancing manual labour with carefully managed agrochemicals, and creating landscape heterogeneity both at small and larger scales. These reduce disturbance frequencies and intensities, and are likely to provide more niches for species and support higher diversity. At a larger scale, villages as such can serve as species refuges in a mono-cultural region. Also, the high economic revenue associated with this cultivation type is especially appealing for farmers and, therefore, requires minimal policy levers for adaptation in other areas. This could create much needed species habitat scattered in the general landscape to boost regional biodiversity.

The traditional method of cultivation, resulting from a historical balance between production and environmental burden, is threatened by changes in agricultural policies, urbanization trends and market economies. Such examples include the rural land circulation and reallocation, which is one of the new policies in China introduced in 2009. It provides farmers with legal grounds to trade their farmland rights and obligations. This policy will drastically change agricultural practices in Chinese rural areas: first economic levers will transfer farmland from those who

prefer other means of income to those who continue in cultivation. Mass production with more agro-chemical input on homogeneous land will become optimal with less human labour required. This means mono-cropping over contiguous patches of fields with minimal alternative land types (e.g. margins, ditches, abandoned sites). Intensive monoculture reduces the overall patch/habitat heterogeneity and diversity, which will potentially reduce available habitats in a landscape. This could decrease local floral diversity even more.

Specified villages' monotonic context prevents this from having higher conservation importance. Its agrochemical input, depending on cash-crop types, could cause a decline in floral communities. However, due to some restrictions of cash crops, such as that demonstrated in Qian-gang, floral species could thrive in some circumstances. The long-term impact of this cultivation method needs to be investigated with more case studies.

This study compared floral communities' statistics in different villages in relation to differences in cultivation type and land use change. However, temporal comparisons and floral response to agricultural practices could not be established due to lack of historical data. Floral response to specific input factors and nutrient eutrophication in agricultural ecosystems require long-term empirical data to be fully understood. However, these results set up a baseline for similar analyses, especially when China's new policy brings about dramatic changes in rural agricultural patterns. Agriculture management plans in such regions should take into account the abilities of these alternative schemes to contribute to conservation of biological diversity, both at small and large scales, to achieve sustainable farming.

Chapter 5 Agricultural management changes affecting faunal communities in Chinese rural areas

Abstract: Agricultural intensification has affected faunal biodiversity in farmlands. Studies examining faunal responses to changes in agricultural management have found mixed effects, but the alternative farming schemes in high-demand agricultural regions have largely been overlooked. This study compares faunal communities from representative villages in Chinese traditional rural area to examine the impact of agricultural systems on faunal diversity. Using analysis of similarity and linear regression models, it was found that village (agricultural systems) type nested within soil depth, significantly affected floral distribution ($p<0.001$). Faunal groups responded to changes differently, with *Acari* being taxonomically diverse and *Collembola* with high densities. Agrochemicals mostly had negative effects on faunal communities whilst increase in manual labour possibly had positive effects which could reduce the level of agrochemicals used. If extensive monoculture thrives in the region, alternative management might represent a unique way of preserving fauna diversity.

Key words: soil fauna, agricultural management, diverse cultivation, agricultural intensification

1 Introduction

Agricultural practice[4] is one of the main factors affecting biodiversity condition in farmland regions (Gall and Orians 1992; Benton et al. 2002; Benton 2007; Sutherland et al. 2009). World conservation efforts have increased at the start of the 21st century, but the decline in diversity has continued. The underlying basis of this decline has attracted worldwide attention (Benton et al. 2002; Kleijn et al. 2009; Kleijn et al. 2010; Kleijn et al. 2011).

[4] This paper defines agriculture only as the cropping practices on farmlands. It does not include forestry, aquaculture or pastoral (grazed livestock) production.

Conservation of biodiversity in Chinese farming regions has been approached with a range of different measures, namely: enhancing farmland biodiversity by lowering overall intensity, and/or restricting agrochemical application and creating heterogeneity by adding extra features supporting biodiversity in agricultural landscapes. These steps have been widely used in some developed countries through voluntary or subsidized actions (Curtis and De Lacy 1996; Giller 1996; Curtis and de Lacy 1998; Johnson and Clark 2001; Abensperg-Traun et al. 2004), usually involving financial incentives. Attempts to understand these changes and their impact on the farmland biodiversity conditions have been well documented (Kleijn et al. 2001; Henle et al. 2008; Gabriel et al. 2010; Smith et al. 2010; Winqvist et al. 2012; Gabriel et al. 2013). Despite mixed effects (Kleijn et al. 2001; Kleijn and Sutherland 2003; Feehan et al. 2005; Kleijn et al. 2006; Blomqvist et al. 2009; Kleijn et al. 2011; Gabriel et al. 2013), it is generally believed that alternative managements such as organic farming benefit biodiversity. Because agricultural production covers a large area, species requiring different ecosystem conditions and ecological resources, respond differently to management efforts. While most invertebrate species benefited from changes in management (Hald 1999; Hole et al. 2005); other species responded differently depending on their individual niches (Benton et al. 2002; Chamberlain et al. 2010).

Soil fauna are resilient to environmental disturbances and can be found in large numbers in most soil types across different ecosystems (Giller 1996). Because of their importance in maintaining biological, physiological, and chemical processes in soil, the study of soil fauna response to agricultural disturbance is vital in protecting biodiversity and farmland ecosystems.

Even though some studies indicate the conservation benefits of environmentally friendly management schemes, most focus on comparisons between traditional and specifically designed agricultural practices in low intensity farmlands (Kleijn et al. 2001; Kleijn and Sutherland 2003; Zechmeister et al. 2003; Bengtsson et al. 2005).

The general application of such practices is limited in highly intensive agricultural regions such as China—notwithstanding the fact that these studies often produce mix results themselves. (Kleijn and Sutherland 2003; Kleijn et al. 2006; Blomqvist et al. 2009)

In China, the basic unit in traditional agricultural practices has been the household (Lin 1992; Li and Wang 2003). Farmers learn from each other within the village, so changes in cultivation occurred between villages rather than within. Therefore, comparisons of environmental impact caused by cultivation and management differences are best performed at the village scale. Village level specialization represents such change. This was created when a large number of households in a village committed to a single or chain of productions or services, making it the village's primary revenue (Li et al. 2009). These changes emerged out of the need for elevated economic benefits for the farmers themselves and, therefore, reflect current trends. The main differences among villages are the farming practices characterized by their choice of cultivation, such as: type of crop, number of different crops in total, agrochemical input, irrigation and manual labour required for the crops in question. These changes in farming practices, while maintaining a relatively high output (yield and/or income), often involve higher input of agrochemicals. The evaluation of the impact of these chemicals on biodiversity, therefore, is crucial in managing conservation efforts in such regions.

This paper identifies representative villages for these new management schemes, and by utilizing data from village level, examines how socio-economic factors and cultivation patterns affect faunal diversity in the study area. In doing so, I address the following questions:

5. Do changes in village scale agricultural practices affect faunal species distribution?
6. If so, how are they affecting faunal diversity within and between villages?
7. What are the main agricultural-input factors affecting faunal diversity?

8. What changes will the development of alternative cultivation methods bring upon the regional faunal communities?

2 Area and method

Six villages were selected from Fengqiu County, Xinxiang City and Zhongmou County, Zhengzhou City, Henan Province (Figure 1), located on both the north and south side of the Yellow River, representing three main types of newly formed cultivation types (chapter two).

Henan Province is located in the central-eastern region of China, and is the largest province of agricultural population and total crop production. Its total crop yield has remained the highest in China for more than a decade, with its 2012 crop yield, including main cereal types such as paddy rice, wheat and maize, reaching 56,386 million tonnes (National Bureau of Statistics 2012b). These make it suitable for analysing agricultural disturbances on the environment where production is prioritized.

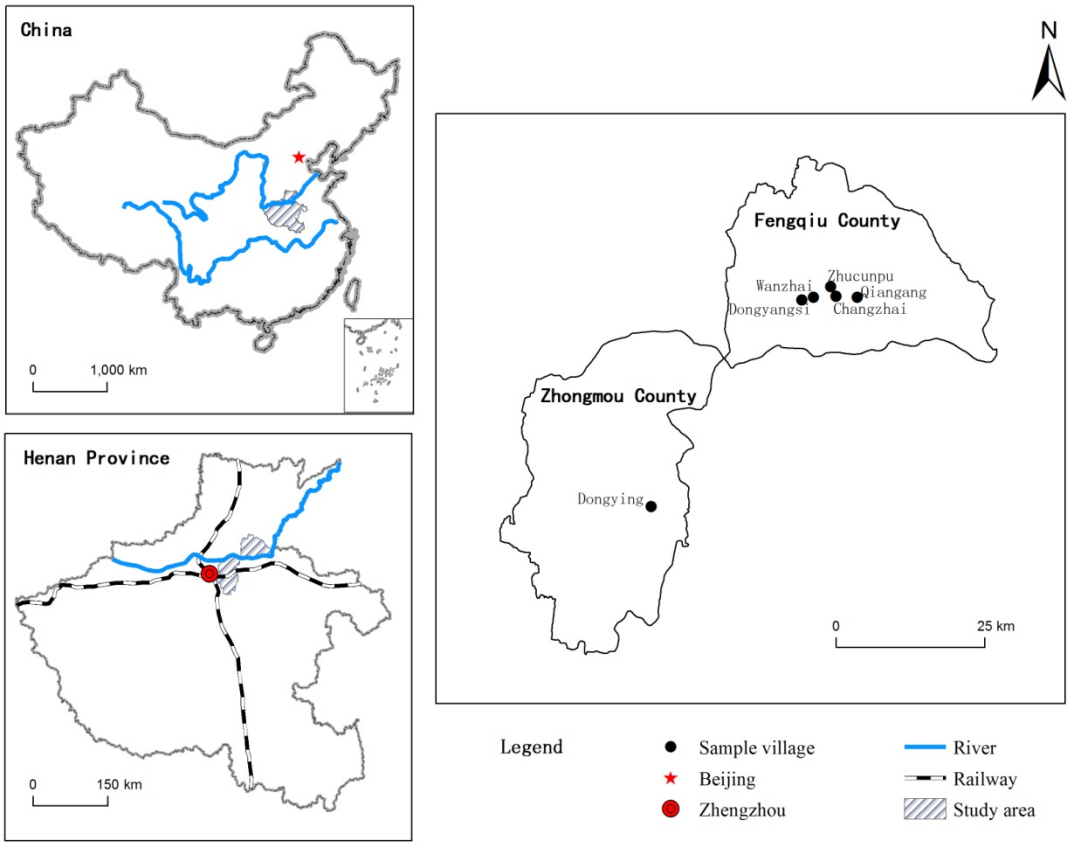


Figure 1 Map of the study area and locations of the villages sampled

2.1 Fauna sample collection

Soil fauna samples were collected in 2012 in two groups. The first was marked H for hand-picked: samples were collected for each layer of soil in the site for a volume of 0.009 m^3 (0.3 m×0.3 m×0.1 m). The second method was marked T for funnel extraction. Samples were collected using soil sample rings with a volume of 7.854E-4 m^3 (0.05 m Ø, 0.1 m length) and then extracted using Tulgren Funnels (Southwood and Henderson 2009). Each sample was marked using five reference codes: Village-Field-Plot-H(T)-Layer; with Zhu-cun-pu Village as 01, Chang-zhai Village as 02, Qian-gang Village as 03, Dong-ying Village as 04, Dong-yang-si Village as 05, Wan-zhai Village as 06 (original sample coding). They were then taken back to the lab for extraction and classification. Extraction was done using Tulgren Funnel setup with 24hour duration (samples were left for a further 24 hours to ensure extraction rate, and proved that 24 hours was enough). Species identification followed the guidelines laid out by Yin Wenying (Yin et al. 1998; Yin 2000).

2.2 Faunal statistics

Faunal species abundance was classified into three categories: 1, rare group, species abundance not greater than the 10^{th} percentile of all species; 2, common group, species abundance between the 10^{th} and 90^{th} percentile; 3, main group, species abundance not smaller than the 90^{th} percentile (percentiles of site average numbers, see Table S5, S6 for details).

Diversity indices were calculated for each site, layer (also referred to as depth) and in general, including: number of taxa; density, number of specimens per cubic meters; Margalef's Richness (Margalef 1958; Southwood and Henderson 2009), which accounts for sample size; Shannon-Wiener Diversity Index (SHDI) (Shannon 2001; Southwood and Henderson 2009); Simpson's dominance index (Simpson 1949; Southwood and Henderson 2009); and evenness index E_{var} (Smith and Wilson 1996; Beisel et al. 2003). The measure of species evenness E_{var} was selected to reflect changes of main faunal species groups across sites, while being less sensitive to the

changes in the rare groups (Smith and Wilson 1996; Beisel et al. 2003), which consisted of only three types of species and, therefore, highly susceptible to change.

$$E_{\text{var}} = 1 - 2/\pi \arctan\left\{\sum_{x=1}^{s}\left(\ln(x_s) - \sum_{t=1}^{S}\ln(x_t)/S\right)^2 / S\right\}$$

Where x_s and x_t are the number of individuals in species s and t respectively, and S is the total number of species in the particular sample.

2.3 Ordination and analysis of similarity

A Non-Metric Multidimensional Scaling (NMDS) (Legendre and Legendre 2012) of species and sample sites was performed to plot the distances with Bray-Curtis dissimilarity distances (Clarke 1993); the influence of village as a factor was investigated by fitting an ellipse hull with standard deviation of point scores.

ANOSIM (Analysis of Similarities)—both one-way, two-way crossed and nested—were then performed to test and compare the influences of village and layer factors: layer was an individual factor, layer and village both treated as main factors, and village nested within layer as a joint factor (with Bray-Curtis dissimilarity as the measure of distance) (Clarke 1993).

2.4 Data modelling

Due to the high frequency of zeros in data cells in samples suggesting an over-dispersed (high turn-over rate of species across samples) condition of faunal species, analyses using data from selected faunal groups would likely diminish the effects of independent factors in regression models. Therefore, faunal data at the village level (species number and density) were used to model the effects of agricultural cultivation practices. Data (square root and log-transformed) were all tested to account for possible exponential responses to environment factors. Independent explanatory variables of agricultural input included agrochemicals: pesticide (litres per ha, including major types such as chlorpyrifos, omethoate, and beta-cypermethrin), herbicide (litres per ha, including major types such acetochlor,

napropamide, and dibutralin) and fertilizer (kg/ha, compound, nitrogen, phosphorus, and potassium); and the general variables including manual labour (man-hour/ha) and machinery (hour/ha, including irrigation and harvest) (Table S7). Irrigation was treated as an explanatory variable after showing collinearity with agrochemicals and agricultural machinery. Root transformed number of taxonomic units was used in the end as reference variables, as other indices did not return satisfactory results based on the number of significant explanatory variables found, and the total goodness of fit.

Initially model two was chosen between the two models containing all twenty four observations (Tables S7 and S8). Model one had a lower Akaike's information criterion (Yamaoka et al. 1978) but a higher Bayesian information criterion (Schwarz 1978). Since following Akaike's would possibly lead to including more non-significant variables, and a residual test for model two had a Jarque-Bera statistic of 1.14 ($p=0.56$), making it acceptable, therefore model two was chosen. Also, limited explanatory-variable entries available meant that the number of variables needed to be reduced. A test was done for combined variables manual labour, depth two and three, which returned a non-significant $F=1.64$ ($p=0.22$). In model two, while surface layer displayed differences, layer two and three were statistically similar to layer four (null hypothesis not rejected, Table S8); therefore these factors were excluded from the final version. Faunal data from layer one was taken out and modelled independently with the explanatory variables that remained.

Fit of regression models were tested using Q-Q plots and distribution histograms (Figures S6-S11). Residuals of models meet the requirements.

3 Results

3.1 Faunal statistics

In the study area of six villages, 8882 specimens were collected. Due to some of the specimens being too damaged to perform detailed classification, they were identified

as 109 families, 12 orders and 1 subclass: Helminthomorpha; belonging to 34 orders and 1 subclass.

Most species were of phylum Arthropoda (arthropods), with a few belonging to phyla Annelida, Nematoda, and Gastropoda. Within arthropods, arachnids (e.g., acari, mites and tickes; spiders) and insects (e.g., beetles and flies) were most common. Collembola (springtails) had the highest density in most samples. Invertebrate pollinators such as those found in Homoptera (butterflies and moths), Hymenoptera (ants, bees, wasps and sawflies), and Lepidoptera (butterflies and moths) were scarce, likely due to the combined effect of high agrochemical input and the adaptations of self-pollinated crops (Table S5).

Different taxonomic groups responded differently to village agricultural systems and layers (depth). Acari had the most taxa units, and higher diversity and density in specified villages. Beetles and flies were equally diverse, showing more units in traditional villages. General pollinators had the lowest diversity level and density and earthworms (mostly of the order Opisthopora) showed slightly higher diversity in diverse and specified villages. Collembola had the highest density level, even though its diversity was rather low, in all villages (Figure 2; Table S6).

Simpson's dominance was slightly higher in specified and diverse villages. However, E_{var}, adjusting for rare and dominant species, showed a rather consistent evenness level with all villages. Since agrochemical input is high across the board, it likely reduced the number of individuals in the dominant and main groups of species in the farmland, diminishing the differences among various fauna groups, leading to a decline in dominance and more evenness in the area (Table S6).

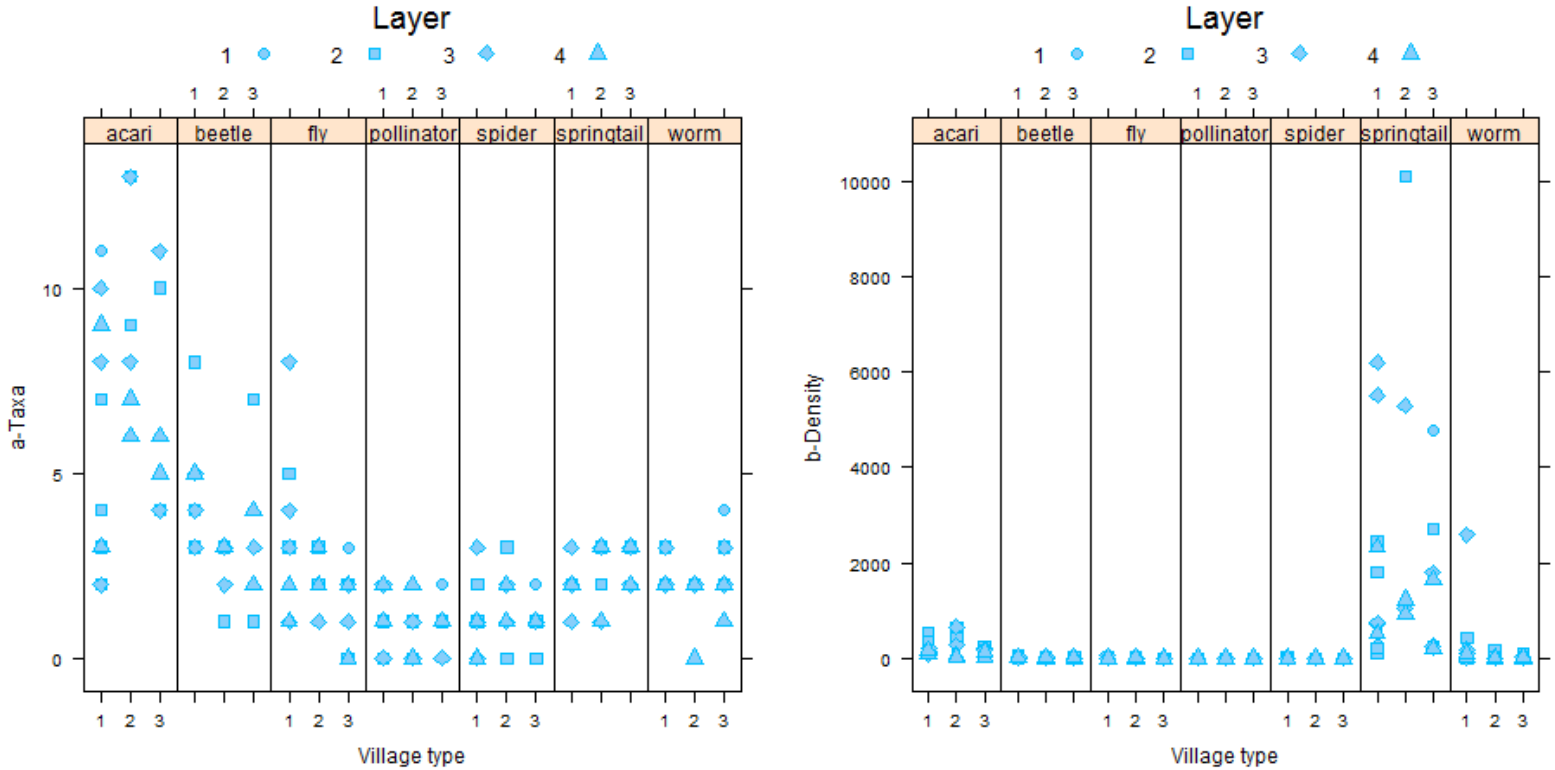


Figure 2 Faunal distribution of different species groups by cultivation systems (x axis 1=traditional, 2=specified, 3=diverse) and layers (1-4 as demonstrated in legends)
Left figure (a) taxa distribution; right figure (b), density distribution

There were seven dominant families (units classified) in all samples (Table S6; numbers can be referred to Table S5 for taxa group names); twenty three in the main group (identification No. 1, 2, 3, 9, 15, 18, 26, 31, 35, 39, 42, 57, 59, 67, 70, 74, 80, 90, 91, 92, 110, 111, 115; Table S5); thirty nine in the rare group (identification No. 4, 10, 12, 19, 20, 30, 32, 39, 41, 43, 46, 54, 55, 56, 58, 63, 66, 74, 77, 79, 84, 86, 87, 89, 90, 94, 95, 96, 97, 99, 100, 101, 103, 104, 108, 110, 117, 120, 121; Table S5).

Dominant species units were found to be consistent between different layers and villages; species from the families Onychiuridae and Isotomidae from the order Collembola, and Zetorchestoid mites from the order Oribatida were widely dominant in various sample sites (Table S6; numbers can be referred to Table S5 for taxa names). Rare fauna group has the least overlap among different sample sites. Taxonomic differences (at the order level) exist mainly across villages, not layers of soil.

Number of faunal taxa decreases with increasing soil depth in all villages (Table S6); this trend is less obvious in traditional villages (Zhu-cun-pu and Dong-yang-si) and more evident in specified and diverse villages (Chang-zhai and Wan-zhai). Margalef's richness, which accounted for sampling effort, displays a similar pattern. Traditional villages hold lower species densities, which generally peak at layer three with the exception of village Dong-yang-si. This is likely due to the conditions of the field during sampling: Zhu-cun-pu was sampled after corn was harvested and Dong-yang-si was sampled at the same time frame but the corn fields were mostly untouched. Specified and diverse villages (aside from Dong-ying) had higher density in the surface layer, suggesting a relatively lower disturbance level. SHDI show higher levels in specified and diverse villages, and generally in mid layers within each village. Mean dominance is higher in traditional villages and lower in diverse villages. E_{var} differs little among layers within or among villages. The combination of richness and density data suggest that high input provides abundant resources in the surface soil supporting more diversity while the related disturbance

in traditional villages diminishes the overall numbers. Less resources in the deep layer support fewer numbers in both richness and density (Table S6).

3.2 Controlling factors for faunal distribution

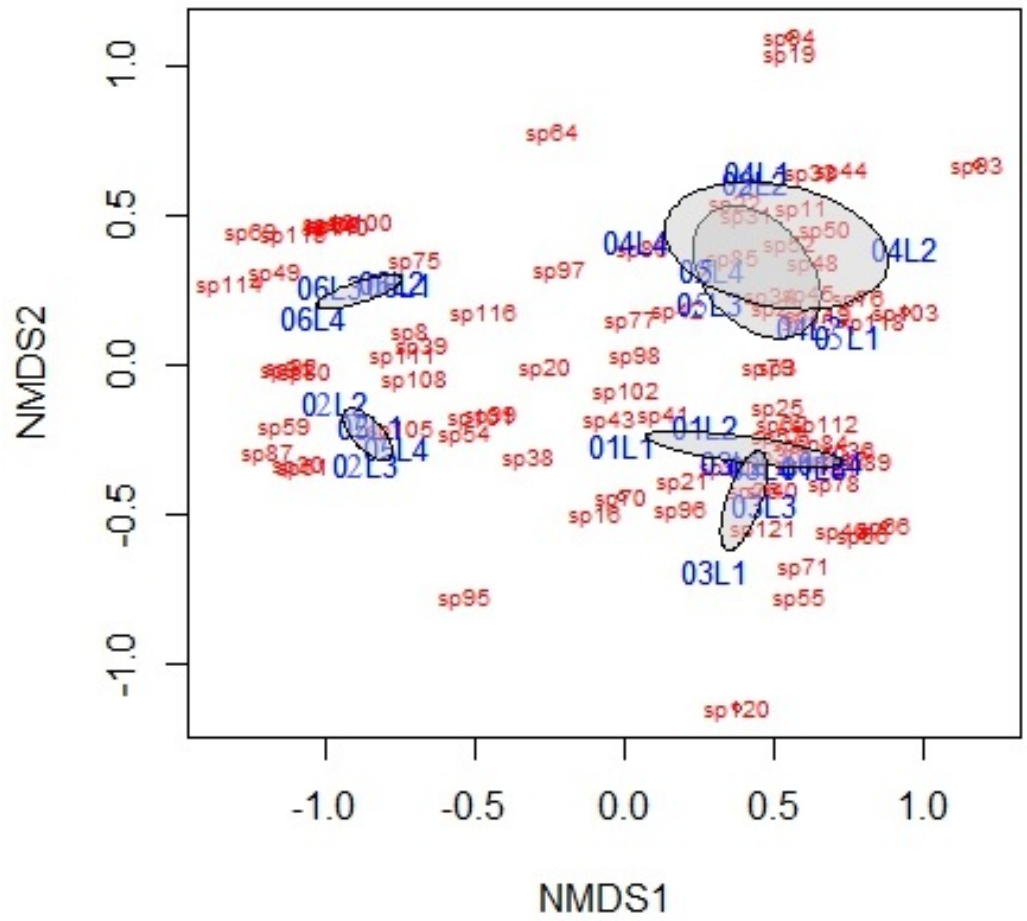


Figure 3 Ordination (NMDS) plot of fauna species with fitted ellipse for village effects (suggest range of effect); Ellipse showing centred village factor influences

(Square root transformation; Wisconsin double standardization; Bray-Curtis distance; dimensions=3, stress=0.1210, iterations=200; see Figure S7 for stress plot)

Villages Zhu-cun-pu (01) and Qian-gang (03) overlap; Dong-ying (04) and Chang-zhai (05) overlap

Partial ordination (NMDS) of the species over sample sites showed inconsistent effects of village factors (Figure 3; see Figure S7 for ordination stress plot). The distribution of dominant and rare species groups (Tables S5, S6) among sample sites appeared unaffected by the village and depth factors. Distribution of main species displayed a slight trend towards the village factors, suggesting some influence.

Table 1 Comparison of ANOSIM results of faunal data with factors village and layer (one-way with layer, two-way crossed with both, and two-way village nested within layer)

	One-way	Two-way crossed	Two-way nested
Factor	Layer	Layer	Layer
Global statistic	0.504	0.438	0.975
Significance level	0.1%	1.6%	0.1%
Number ≥observed	0	15	0

Log-transformed, Bray-Curtis Distance; All statistics based on 999 permutations

Number ≥observed (matching significance) suggests observation not-rejecting the null

Village factor not displayed individually for lack of significance

Result show moderate global representation with first two analyses, and high global representation with nested analyses

The influence of layer (depth) as an individual factor and as a parallel factor with village was both significant, but the moderate global statistic (Table 1) suggested lower representation of all observed changes in the samples. The global statistic of two-way nested analysis, however, showed significant high representation of all observed changes (0.975) when incorporating village as a nested factor within layer. This suggested that village factor had an important role in influencing faunal distribution.

3.3 Modelling fauna distribution with agricultural input

Table 2 Regression results of root faunal taxonomic units with non-fertilizer agrochemicals and general factors (two parts of explanatory variables for the same dependent variables)

	Model I		Model II	
	Root taxonomic units	Standardized coefficient	Root taxonomic units	Standardized coefficient
Herbicide (L/ha)	3.84*	24.83*		
	(0.10)	(0.62)		
Pesticide (L/ha)	0.43*	4.37*		
	(0.01)	(0.13)		
Herbicide^Pesticide	-0.19*	-6.28*		
	(0.005)	(0.16)		
Manual labour	0.00015*	0.38*		
(man×hour/ha)	(0.0000)	(0.03)		
Compound fertilizer			-0.002*	-3.65*
(Kg/ha)			(0.000)	(0.13)
Nitrogen fertilizer (Kg/ha)			0.018*	36.92*
			(0.001)	(2.39)
Phosphor fertilizer (Kg/ha)			-0.138*	-37.45*
			(0.009)	(2.48)
Potassium fertilizer (Kg/ha)			-0.034*	-7.42*
			(0.003)	(0.58)
R^2	0.9999	0.9999	0.9998	0.9998
F	1840.87*	1840.87*	1136.52*	1136.52*

* Significant at 5% level ** Significant at 1% level

^ Interaction between two variables; standardized coefficient are standardizations of coverage β values; for interactions, values were calculated after standardization;

Numbers in brackets are standard deviations

Regression results (Table 2) suggest that joint interaction between herbicide and pesticide is significantly correlated with the explanatory variable root number of fauna taxonomic units. Manual labour also significantly correlated positively with root number of fauna taxonomic units. Most fertilizers, except nitrogen ones, had negative correlations (Table 2).

4 Discussion

Overall results were similar to empirical data collected in other long-term cultivation farmlands such as in Shaanxi and Jilin Provinces, and the Xinjiang Uygur Autonomous Region (Lin et al. 2010), but different from data collected at experimental sites where less disturbance led to increased soil faunal diversity, especially Oligochaeta species (Lin et al. 2005).

Since early site selection used parameters excluding soil type, which is considered one of the main confounding factors of faunal distribution (Irmler 2003), it can be assumed that the variations in faunal diversity between villages resulted mainly from cultivation differences.

Village influence on the distribution of faunal species was more obscure (Figure 3) compared with that on floral species (refer to Chapter four). This is probably caused by complex interactions of agricultural input with various taxonomic groups both within plots and villages. Layer is a traditional factor affecting fauna communities, but this can only explain part of the observed trend in the data. The high global statistic of the nested analysis (Table 1) suggested that the variation in taxa abundance were caused by the combined influence of layer and village.

4.1 Conservation benefits of alternative cultivation

Faunal richness and density of all sites peaked in top soil layers (Table S6), likely due to the abundant resources brought about by agricultural input. Species in traditional villages displayed patterns typical in agricultural lands, i.e. decreasing

diversity with greater depth and higher density in middle layers (Baker 1998; Wang et al. 2002). By comparison, the faunal distribution in specified and diverse villages displayed high diversity and richness in the surface layer. Diverse villages also had slightly higher worm diversity, likely caused by the extensive use of organic fertilizers (animal manure) in farmlands. Diverse villages, unlike traditional and specified villages which require set intervals of tillage, had high level and frequency of disturbance such as harvesting, planting and removing arable weeds manually. These factors often affected faunal communities negatively (Berry and Karlen 1993; Czarnecki and Paprocki 1997; Bedano et al. 2006). Thus the diversity and density levels indicate that diverse villages have the potential to support more faunal species in its farmlands. Specified villages had the highest density of Collembola, which suggests a lower level of general disturbance (Heisler 1991). This is further supported by the elevated density of Collembola in specified villages which respond to soil disturbances (Heisler 1991). However, they failed to show advantages in species diversity except Acari. These findings point to a higher conservation potential of diverse villages.

Diverse cultivation involves extensive intercropping, creating a highly diverse plot-scale landscape. Between-plot differences also contributed to the overall diversity within the village. Therefore, the landscapes in diverse villages contained higher complexity, providing more resources and potential niches, supporting higher diversity levels (Anderson 1977; Giller 1996). The abundance in arable weed species in diverse villages (Chapter four) likely also contributed in a similar fashion. These small scale factors in rural areas, although not yet apparent in their influences on biodiversity, can be of high conservation importance when spatial replication of such methods is set in motion.

4.2 Input factors affecting fauna distribution

Faunal distribution patterns in the sample sites resulted from joint interactions between village and soil depth. Therefore, final regression using data from all layers

and villages was likely affected by stochastic factors. Regression results using top layer data suggest that manual labour might have contributed to increased faunal diversity. This might be caused by reduced agrochemical input balanced by manual labour as households with abundant labour tend to substitute purchasing agrochemicals with human management such as weed and pest removal. Fertilizers usually had negative effects on taxa diversity; possibly because increased nutrients led to higher competition and dominance of few highly resilient species. In comparison, traditional villages had higher evenness amongst taxa both within and across sample land types, but with less turn-over. Therefore the total number of species in the entire landscape is less than that of villages with high manual labour (Table S6).

High representativeness of both models is most likely a result of chance given the small observation pool and cross-sectional nature of dataset.

5 Conclusion

Faunal communities reacted differently to changes in village level, agricultural management with increased density, dominance and variability between different soil layers in diverse agricultural systems. The effects were inconsistent among the seven major fauna groups. The positive effect of manual labour (Table 2) suggests that conventional methods might help maintain faunal diversity in agricultural regions. Unfortunately, even traditional cultivation involves massive agrochemicals (Chapter two) to compensate for reduced labour due to migrant working opportunities elsewhere. This will be aggravated by the changing agricultural policy aiming at releasing labour from Chinese rural areas. If so, these alternative methods with high labour requirements represent a chance at maintaining diversity levels with their high income as incentives.

In agricultural regions with similar conditions, long-term exposure to agrochemicals has already decreased faunal diversity. Results here suggest that this effect is

stronger in rural areas in the Huang-huai-hai plain. The resulting lack of variation the in faunal data collected here is the main factor limiting the construction of a model to account for this important change. This could be countered by increasing the number of village samples. Further analysis should focus on establishing spatial as well as temporal replication of comparable villages in rural areas. Identifying faunal responses to environmental variables is better performed focusing on individual or a set of faunal taxa with important ecological functions supporting agricultural ecosystems, such as earthworms or belowground pollinators (larvae). Even though main crops in China do not require the effect of these species, they are important in a larger landscape and serve to maintaining a healthier ecosystem.

Chapter 6 Socio-economic factors affecting agricultural input levels in rural China

Abstract: This paper compares alternative cultivation schemes in rural China, where traditional agricultural practices are exposed to policy and social changes. Agricultural input factors (e.g. pesticide, herbicide, fertilizers) were modelled with socio-economic factors covering household status, factors of production, income structure, and farmers' behaviours (decision made) to determine the factors influencing agricultural input levels in rural China. Results show that fewer plots (less land fragmentation), higher crop number and percentage of cash-crop income are positively associated with the increase in most agricultural input factors. Under national development goals, rural China is likely to be homogenized with large-scale mono-cropping dominating most of the fields. Alternative cultivation systems are likely to be replicated at small scales. Farmers are susceptible to advertisements and promotions, but most cultivation practices in terms of decisions on crops and management are made based on village level leadership. Short-term conservation plans in the region can target individual farmers' behaviour while long-term plans need to focus on rural leadership capacities.

Keywords: agricultural input, conservation, socio-economic factors, household

1 Introduction

Agricultural practices have greatly affected farmland ecosystems (Tilman et al. 2001; Evenson and Gollin 2003), in particular, species biodiversity, ecological functions and ecosystem services. Changes brought forward by growing population and food security are affecting the current balance between production and environmental concerns in most traditional agricultural regions in both developed and developing countries (Gall and Orians 1992). In some developed countries, environmental-friendly agricultural management schemes have been introduced to alleviate such problems (Curtis and de Lacy 1998; Johnson and Clark 2001 ; Yussefi

and Willer 2007). In spite of beneficial and negative reports of effects (Hole et al. 2005; Kleijn et al. 2011), these programs have generally reported enhanced biodiversity in response to changes made in on-site managements (Tuomisto et al. 2012). Research programs in developing countries which focus on sustainable agriculture, such as experimental sites in India and Ethiopia coordinated by the CIMMYT (International Maize and Wheat Improvement Centre, see CIMMYT website) (Frédéric Baudron 2013) lack strong biodiversity goals due to lack of a systematic themes promoting biodiversity conservation. The environmental impact of agricultural development in these regions warrants more attention.

Recent studies have explored the role of socio-economic factors in influencing cultivation practices, especially agrochemical inputs (amount and cost). Household differences caused by behavioural variations can lead to different input levels (Grossman 1992; Burleigh et al. 1998; Huang et al. 2008), and positive associations with agrochemicals have been found for farmland size, lower economic status, education levels, capital and distance between farmlands and household residents (Khanna 2001; Bekele and Drake 2003; Rahman 2003). Negative associations have been found between agrochemical input levels and crop price (Khanna 2001). Input levels are also affected by regional agrochemical policies, advertisements, technical assistance and farming experiences (Thrupp 1990; Mbaga-Semgalawe and Folmer 2000). However, whether these effects are still present and/or significant in affecting agrochemical input in villages in China with different managements is unknown.

Chinese agri-industry retains most of the major characteristics of a developing country. High demand, small production scale, fragmented landscapes, and increasing pressure from socio-economic changes are apparent (Xu et al. 1992; Li and Wang 2003), but also contains peculiarities such as the basic unit in traditional agricultural practices which has been the household due to the Household Contract System (Lin 1992; Li and Wang 2003) ever since the end of 1970s. Changes in cultivation patterns occur at the village scale, however, and a good representation of

this is village level specialization where a large number of households commit to a single or chain of production or services, making it the village's primary source of revenue (Li et al. 2009). Specialized agricultural income was considerably higher, therefore, this system has attracted attention and support from the Chinese government (Ministry of Agriculture 2011).

While researchers have examined the formation specialized villages and explored the possibilities of its spatial expansion (Li et al. 2009), much less has been done on understanding the environmental impact of these villages in relation to changes in agrochemical inputs. These alternative management schemes are not formed on conservation plans or policy but rather from market mechanisms, and the socio-economic factors of the households. The latter include living conditions (e.g. income level, residential condition), agricultural awareness (e.g. education level and conservation awareness), and cultivation behaviour (number and type of plots and crops, access to farmlands). These may affect agrochemical inputs. As agri-industries change in China and other regions, it is important to ascertain the main factors that support future agri-conservation planning in these areas. This study examines the factors influencing agricultural input levels in rural China by modelling village scale agricultural input data and detailed household socio-economic data. We attempt to identify factors of significance in conservation planning under the current policy and social reforms in China.

2 Study Area and Methods

2.1 Study area

Six villages were selected within Fengqiu County, Xinxiang City and Zhongmou County, Zhengzhou City, Henan Province (Figure 1), located on both the north and south side of the Yellow River, representing three main types of newly formed cultivation types. Henan Province is located in the central-eastern region of China. Its total crop yield has been the highest in China for more than a decade, with its 2012 crop yield, including main cereal types such as paddy rice, wheat and maize,

reaching 56,386 million tonnes (National Bureau of Statistics 2012b).

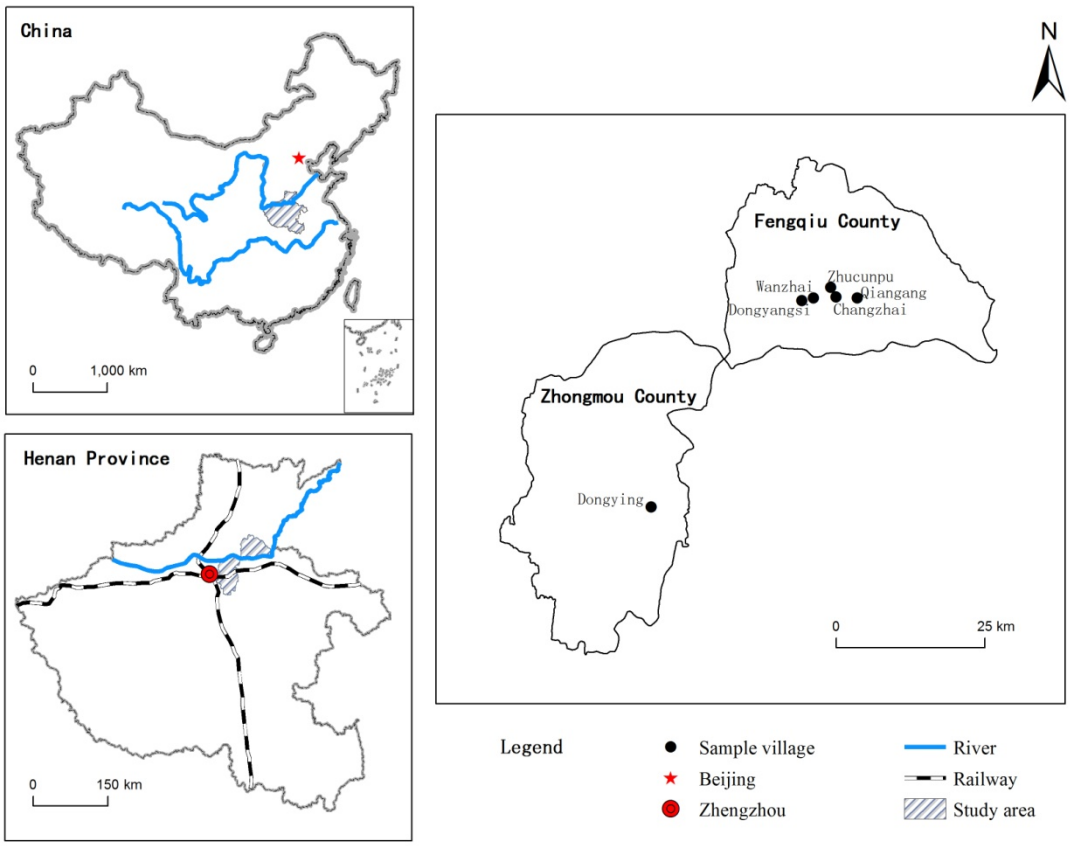


Figure 1 Map of the study area and locations of the villages sampled

2.2 Theoretical framework of the study

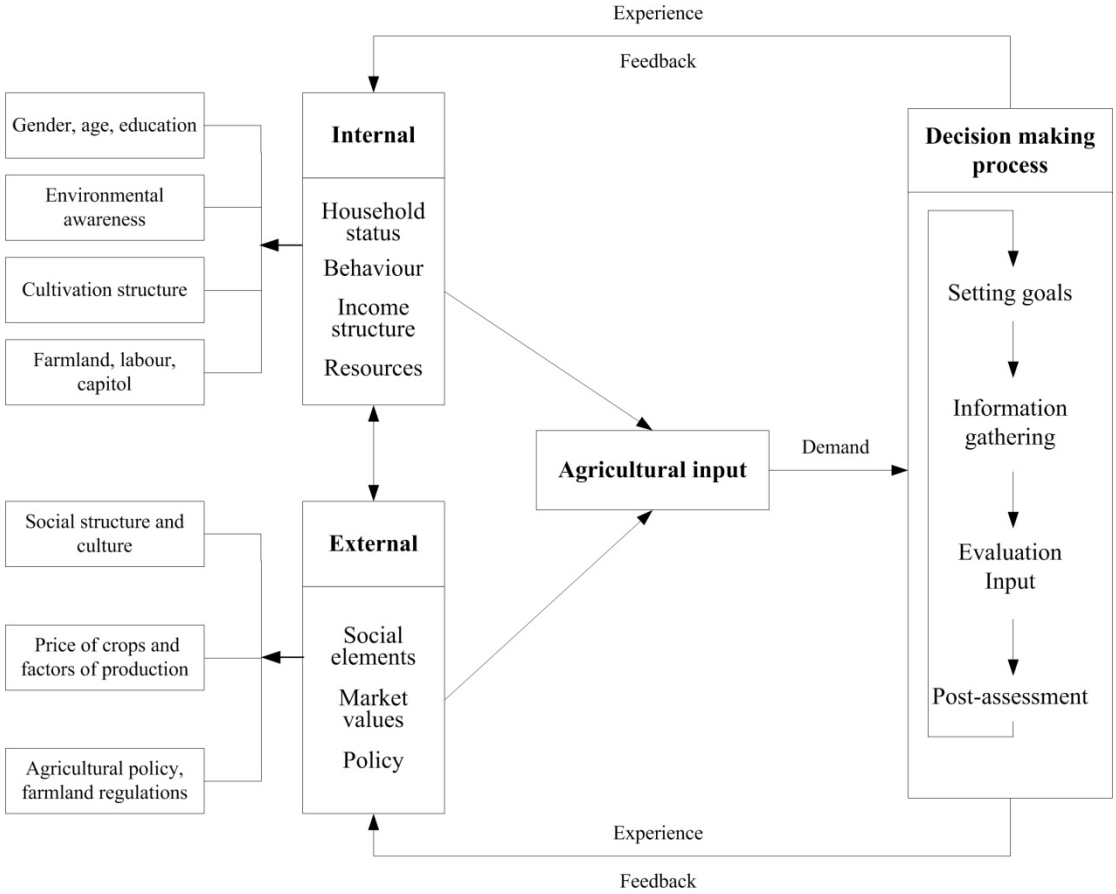


Figure 2 Theoretical framework of this study

Households have been the basic units of agricultural production in China ever since late 1970s (Lin 1992; Li and Wang 2003). They directly influence cultivation methods and input choices which are, in turn, influenced by household socio-economic and behavioural factors (Figure 2).

In a market economy, household choices are rationalized by profit (Figure 2) but, due to indirect participation and asymmetric information available, which is the case in most developing countries, rationalization is based on a limited set of internal and external factors (Figure 2). Internal factors support and limit agricultural choices, which include capital, labour, available farmland and geographical resources. External factors stimulate and steer agricultural choices. These include changes in culture and policy, accessibility of information, technology, subsidies and related products such as agrochemicals. While they collectively affect household choices, the latter occasionally supersedes the former. On this basis, the socio-economic questionnaires in this study collected the following groups of data (see Supporting document three for social survey questionnaires).

Household status: in Chinese rural areas, household owners are the decision makers. Their age, gender and education etc. affect cultivation behaviours. For instance, age can have controversial effects, being older could limit labour intensity and household-owner's ability to take in new information making cultivation more conservative. On the other hand, old age could translate to more experience in both farming and acceptance of change, making them more adaptive (Li et al. 2009). Educational status functions by bridging gaps between household owners and current developments (e.g. market trends).

Household factors of production: This includes farmland, labour, and capital. Farmland is the most crucial factor in agriculture. Its quality directly affects crop types and yields, fertilizer requirement and income. The spatial distribution of plots translates to accessibility, which limits fertilizer and irrigation input. Labour

availability determines all input levels. There is a trade-off between labour and agrochemicals as abundant labour leads to a manual approach to tillage and management which reduces chemical inputs, whereas lack of labour is compensated by use of more chemicals. Hence, this factor regulates changes in agricultural management. Household capital, like labour, limits a household's ability to adopt new crop types and agrochemicals.

Agricultural income structure: Agricultural income can be divided into food (wheat and maize in this case) and cash crop incomes. The ratio of food crops to cash crop income represents a household's cultivation focus, and thus is the major factor that separates villages according to their cultivation types.

Behavioural characteristics: This includes farmers' agri-environmental awareness, food-safety consciousness, and attitude towards adopting new schemes. Current legal and policy frameworks in China place little emphasize on the farmers' responsibility in maintaining the environment. Farmers are the sole decision making body in this regard. For example, their choices of which kind of pesticide (cheaper but damaging or *vice versa*) will have considerable impact on the environment. Due to lack of higher education and access to current market information, most farmers in rural China base their decisions on others people's experiences and opinions. This makes them susceptible to all forms of promotions and/or advertisements. Local regulations and policies pertinent to agriculture (e.g. land circulation, food safety, and agricultural subsidies) can also influence cultivation decisions.

2.3 Data collection and analysis

Socio-economic data were collected in the form of social questionnaires (supporting document three). Face-to-face interviews of individual households were carried out in August and September 2011. One hundred households were randomly selected in each village matching pre-determined criteria (household cultivation pattern matches the village type). Data covering all aspects of agricultural practice were collected

during the interviews. This includes cultivation (e.g., number of plots, size of plots, crop types); agriculture input frequency and amount/volume (e.g., fertilizers, agrochemicals, irrigation); spatial characteristics (e.g., distance from plots; distance from roads); household status (e.g., income, living condition); education (e.g., level, environmental awareness) (supporting document three). Data were pre-processed and rid of ineffective entries afterwards—questionnaires within which considerable inconsistencies were found (e.g. inconsistencies between income level and living status).

2.4 Variable selection

The major dependent variables in the dataset include pesticides (litres per ha, including major types such as chlorpyrifos, omethoate, and beta-cypermethrin); herbicides (litres per ha, including major types such acetochlor, napropamide, and dibutralin); fertilizers (kg/ha): compound, nitrogen, phosphorous and potassium; irrigation (hours of irrigation pumping/ha), agricultural machinery (hours/ha), and human labour (man-hours/ha). Irrigation and machinery showed confounding patterns when tested: irrigation showed collinearity with all agrochemicals (especially with fertilizers), this was caused by the farmers' way of applying agrochemicals when irrigating to save time. Machinery (mainly pumps for irrigation) was problematic for similar reasons. Because of these reasons, irrigation and agricultural machinery have been excluded from the final modelling process. Rather, their effect will be represented by the village dummy variables (as they are basically caused by cultivation differences). To establish comparability and eliminate differences between different kinds (brands and types) of agrochemicals, pesticide and herbicide were transformed to emergy (available energy) units (Odum et al. 2000; Odum and Odum 2000). All four fertilizers were grouped together and transformed to total emergy units based on their specific types.

2.5 Model estimation

Model was estimated based on selected variables to determine the effects of

different factors in agricultural input:

$$input_i = \beta_0 + \beta_1 Edu_i + \beta_2 Hous_i + \beta_3 Perland_i + \beta_4 Plotnum_i + \beta_5 Cropnum_i + \beta_6 Cashper_i + \beta_7 Envdum_i + \beta_8 Chgdum_i + \beta_9 Villdum_i + u_i$$

where $input_i$ is the agricultural input (agrochemicals, manual labour) of household i.

Table 1 lists the independent variable definitions.

Table 1 Independent variable definitions (abbreviations used in the model, data unit and definition of categorical variables)

Variable explanation (abbr.)	Definition
Edu	Education level of the household owner: 1—uneducated; 2—elementary; 3—secondary; 4—higher
Hous	Household living status (house type): 1—rammed earth; 2—brick; 3—brick-concrete; 4—concrete
Perland	Household farmland per capita (categorical): 1—larger than 0.067 ha; 0—smaller than 0.067 ha
Plotnum	Household total number of plots
Cropnum	Household total number of crops
Cashper	Percentage of cash-crop income (in total cultivation income)
Envdum	Presence of environmental promotions: 1—present; 0—absent
Chgdum	Household willingness to change cultivation patterns: 1—yes; 0—no
Villdum	Village dummy variable: 1 if household is of a particular village

Household living status (categorical) was used to represent the economic conditions instead of per capita income levels. This was because interviewees tended to mask their true level of income by giving lower numbers (concluded based on general comparison and village level census data). Due to cultural reasons, residential construction has long been linked to social status in rural areas, so using this factor better reflected actual conditions. Cash-crop income percentage was calculated through gathering plot number, crop types and average produce prices.

3 Results and discussion

3.1 Characteristics of the villages

Table 2 Socio-economic description of the villages sampled (geographical, social and economic characteristics influential on agricultural input levels)

Village	Zhu-cun-pu (traditional)	Dong-yang-si (traditional)	Qian-gang (specified)	Dong-ying (specified)	Chang-zhai (diverse)	Wan-zhai (diverse)
Distance from county seat (km)	5	4	6	13	5	5
Crop type	Traditional		Specified		Diverse	
Household number	228	190	310	285	230	192
Population	952	804	1500	1450	927	872
Average education level[a]	2.46	2.42	2.44	2.72	2.64	2.62
Average income (Chinese RMB)	5929	5860	9599	15259	11555	9932
Arable land (ha)	114	120	93.33	133.33	68.93	147
Plot number per capita	2.378	2.168	1.797	1.875	2.123	2.014
Land per capita (ha)	0.097	0.149	0.069	0.104	0.069	0.168
Average number of crops	3.044	2.946	2.864	3.036	6.099	5.974
Cash crop percentage (total agricultural income)	30.78%	30.58%	53.68%	90.80%	87.76%	85.35%
Fertilizer input (seJ[b]/ha)	9.329E16	9.473E15	3.822E15	1.373E16	2.155E16	5.592E15
Manual labour (man hour/ha)	971.097	1041.512	4216.995	1268.027	3188.798	3012.411
Pesticide input (L/ha)	8.288	22.3	29.006	18.270	15.718	19.02

Herbicide input (L/ha)	2.588	3.138	0.908	10.909	3.335	3.133
Percentage willing to change	68.9%	67%	13.56%	20.45%	25%	29%
Percentage participated in promotions	71.11%	72.24%	64.41%	63.64%	50%	52.35%

[a] Categorical variable: 1 uneducated; 2 elementary; 3 secondary; 4 high-school;

[b] Emergy (solar equivalent Joules);

All data calculated from sampled households included in regression models

Zhu-cun-pu and Dong-yang-si are both traditional villages (Table 2). Their wheat and maize double-cropping remained unchanged; but manual labour was substituted with agrochemicals and mechanization. Conventional food crops (now hybridized species) are less susceptible to diseases and pests and, therefore, require relatively less pesticide input (Huang et al. 2002). Higher percentages of households in both villages showed interest in changing cultivation patterns including crop types and total area of farmland plots.

Chang-zhai and Wan-zhai are diverse villages poly cropping vegetables such as sweet potato, garlic, onion, etc. Chang-zhai has the lowest per capita arable land in all sample villages and one of the highest cultivation intensities in the region. Wan-zhai started following Chang-zhai's examples a decade ago. Most households sampled were content with their income level and were reluctant, therefore, to change cultivation patterns (current environmental law does not support direct intervention).

Qian-gang and Dong-ying villages specialize in honeysuckle and garlic plantation respectively. Honeysuckle plantation, due to its unique medicinal use—traditionally used to prevent and/or treat fever, headache, cough, etc. (Song et al. 2001)—is supported by local pharmaceutical companies. Garlic produced in Dong-ying village is mostly exported from of the east coast of China. Income in these two villages, however, fluctuated with market values but was quite high, so farmers were less likely to change cultivation patterns.

3.2 Factors influencing agrochemical and manual labour input

Table 3 Regression results of agricultural input levels as explained by socio-economic variables (each input utilizes an individual model)

Variable	Model 1 (Pesticide)	Model 2 (Herbicide)	Model 3 (Fertilizer)	Model 4 (Manual labour)
Edu	-0.028	0.222	-0.565	-38.972
	（1.138）	(0.415)	(0.613)	(151.890)
Hous	0.278	-0.264	0.308	-209.423
	（1.184）	(0.432)	(0.638)	(158.001)
Perland	-0.993	0.223	-2.579*	-241.070
	（2.473）	(0.902)	(1.332)	(185.752)
Plotnum	-4.510***	-0.501	-2.719***	-157.999
	（1.391）	(0.508)	(0.750)	(185.752)
Cropnum	3.289***	0.627**	2.019***	211.695**
	（0.779）	(0.284)	(0.420)	(104.025)
Cshper	0.026	-0.041**	0.027	19.614***
	（0.050）	(0.018)	(0.027)	(6.740)
Envdum	5.560**	1.523*	0.732	8.143
	（2.158）	(0.788)	(1.163)	(288.048)
Chgdum	3.875	-1.642*	-0.597	-113.791
	（2.711）	(0.989)	(1.461)	(361.878)
N	317	317	317	317
R^2	0.214	0.300	0.357	0.274
adjR^2	0.186	0.275	0.333	0.248
F	7.589	11.909	15.412	10.493

***, **, * represent significance at 0.01, 0.05, and 0.1 level respectively

Individual models were established for each four of the input categories

Standard deviations within brackets

Variables were described in table one

Household status: education level displayed non-significant relationships with all input factors. This differs from studies where education influenced agricultural sustainability (e.g. Phillips 1994; Thiam et al. 2001; Van Passel et al. 2009; Picazo-Tadeo et al. 2011). In rural China where villages are the collective bodies of agricultural production, and farmers learn from each other thereby reducing the effect of educational differences within villages. Between village differences are too small to display any significant impact (Table 3). Village level specialization has been found to arise out of leadership capacities of individual farmers with access to new technology or up-to-date information (Li et al. 2009). Village leadership plays a vital role in determining collective choices (e.g. crop types, irrigation, machinery input). Conservation strategies aiming at household level actions may achieve a better outcome by working through village leaders rather than wide-scale agri-environmental promotions.

Household factors of production: household living status displayed non-significant correlations with all agricultural input levels. However, its effect on agrochemicals coincided with early assumptions in this study. Richer households more likely participated in cash crop cultivations, and cash crops require large amounts of fertilizer and pesticide input (chapter two). Descriptive statistics show that households made of concrete structures (type four) have an average cash-crop income percentage of 74.94%. This number drops to 64.91% for brick-concrete households, 66.57% for brick households, and 46.09% for rammed earth households (houses built using raw materials such as earth and gravel).

Arable land per capita results display similar characteristics. Lack of arable land was the most important reason for intensive mono-culture as farmers attempted to exploit their production potentials to the maximum. Therefore, households with less than 0.067 ha per capita were more likely to have participated in cash crop cultivation, which resulted in more fertilizer, pesticide and manual labour input.

The negative relations displayed by plot number per household (with three significant correlations) reflect Chinese rural conditions since the adoption of Household Responsibility System. As collective farmland was broken up and divided, yet not continuously, to farmers in the village, household plots could easily be separated by being at totally different locations of the village. Households with more fragmented plots, therefore, were less likely to have participated in labour intensive cash crop production. Households with more connected plots, with better accessibility to cultivation, irrigation and fertilizers were more willing to develop

cash crop production. In this case, allowing rural land circulation could reduce farmland fragmentation and create more unified plots.

Agricultural income structure: household crop number was significantly positively correlated with input factors across the board. Descriptive statistics show that for every single increase of crop numbers (controlling for other variables), the associated pesticide increase was 3.289 L/ha, herbicide increase was 0.627 L/ha, fertilizer increase was 2.019E15 seJ/ha, and a manual labour increase of 211.695 manhour/ha. Crops number, therefore, is the most important factor in agricultural input in the study area and likely a causal agent. Factors such as education level and farmland size, which were found to be affecting agrochemical input levels elsewhere (Khanna 2001; Bekele and Drake 2003; Rahman 2003), were not found to be significant in determining input levels.

Percentage of cash-crop income was significantly correlated with the decrease of herbicide input and the increase of manual labour input. On average one percent increase in cash-crop income (controlling for other variables) was associated with a 0.041 L/ha decrease in herbicide input, and a 19.614 manhour/ha increase in manual labour input.

The number and type of cash crops, theoretically, should depend on market mechanisms. However, in rural China changes in these patterns were often observed at the collective scale (Li et al. 2009) as individual farmers may hesitate in venturing into new work patterns. Also, cash crop cultivation is labour intensive, and subject to risks (e.g. changing weather and resource prices). These factors may limit the wider adaptation of specified or diverse cultivation schemes.

Behavioural characteristics: environmental promotion was a significant factor in only two of the input types. These correlations were positive in contrast with initial assumptions that conservation promotions would persuade farmers into using less agrochemicals or switching to less toxic ones. Interviews with local village leaders revealed that most environmental promotions in the region were advertisements supported by the agrochemical industries in promoting new chemicals. Real agri-environmental talks rarely attracted any audiences as farmers perceive they lack direct relevance to their lives. As a result, these promotion events more likely lead to high agrochemical input levels.

Household willingness to change cultivation patterns lacked significant correlations. However, this factor can predict agricultural changes when actual land circulation commences in the region. Traditional villages had on average 65.6% households willing to cultivate more land with only 4.4% wanting less. Diverse villages had only 36.0% households willing to cultivate more whilst 8.1% wanted less. Specified village had 54.35% households willing to cultivate more with 6.7% wanting less. Thus, land circulation would probably expand the area of traditional cultivation in the region. This effect may even spread beyond traditional village with the benefit of large-scale machinery, breaking down current boundaries and creating big farms similar to the USA, Brazil and many countries in Europe. In contrast, diverse cultivations with their labour intensive practices may prohibit large-scale spread. Replication is more likely to occur at the current village-scale and appear as patches in an otherwise uniform mono-cultured landscape. Specified cultivation is hard to predict; despite more than half of households wanting to cultivate more land, market saturation may prevent this.

4 Conclusion

Land fragmentation may have contributed initially to the creation of specialization in rural China. With the current policy and social reforms aiming at promoting urbanization, more agricultural labour will be absorbed into town and/or cities leaving abundant land resources for the remaining farmers. The results of this study suggest that when land circulation gradually concentrates arable land, the result will be a more homogeneous landscape with less crops types and manual labour input, and more efficient agrochemical use. Farmers with access to more land are less likely to adopt alternative, especially diverse, cultivation methods in these regions. However, with the right incentive and leadership, it is possible to promote alternative management schemes in the region but only at smaller scales.

Although, the village and its collective resources ownership may slowly phase out under the new agricultural policies, the roles of village leaders in rural China will

probably remain. Lack of higher education throughout the country makes it hard to target individual farmers for large scale conservation planning at the current stage. Exposing rural leaders to sustainable ideas can be far more effective in introducing and expanding agri-environmental practices.

This analysis also points to the urgent need for conservation campaigns and government measures to support them in rural China. The balance between production and nature achieved by historic agricultural practices in China has long been derailed by intensive agrochemical input. Excessive nutrient input in Chinese agriculture (Vitousek et al. 2009) is not only a regional issue, but also contributes to global environmental change. Producer level environmental awareness, therefore, is essential in any form of conservation action. Although major cultivation choices are consistent, farmers are still susceptible to all forms of advertising. Local authorities could reduce certain harmful outcomes by actively promoting environmentally friendly lower toxicity agrochemicals. However, to support longer-term conservation planning, agricultural input models on a time series need to be established to monitor changes associated with socio-economic differences.

Chapter 7 General discussion

7.1 Main findings of the study

This study concluded that agricultural ecosystems in rural China face unprecedented challenges to conservation. The historic remnant of traditional cultivation is threatened by agrochemical input, increasing food demand, and policy changes towards urbanization. Alternative agricultural managements, which independently arose out of land ownership status and market mechanisms, have mixed effects. Diverse cultivation can potentially support higher biodiversity through creation of highly diverse niches and habitats at various scales (Table 1, chapter 4; Tables S2a-c), but specified cultivation does not have similar benefits for biodiversity. Both alternative managements involve massive agrochemical input (Tables 1 and 2, chapter 2), which causes heavy metal pollution and contamination in farmlands (Tables 3 and 4, chapter 3).

Current national policy and development plans dictate that excess agricultural labour (Carter et al. 1996) is released into towns and/or cities to boost the urbanization process. This would probably lead to relatively abundant land resources distributed to the remaining agricultural communities, reducing the incentives for alternative management schemes in rural areas. To enhance conservation actions in the region, policies should target farmers with leadership capacities in the region instead of actual producers.

7.2 Conservation in high-intensity agricultural China

7.2.1 Alternative cultivation schemes

The Chinese agricultural sector faces the same challenges as most developing countries do. It is challenged by the demand for growing food security and national plans for development (mainly urbanization). Whether China has passed the Lewis turning point (Lewis 1954), where excess labour from subsistence sectors has been fully absorbed, thereby, causing wage increase, is still under debate (Cai 2010; Meiyan 2010; Minami and Ma 2010; Yao and Zhang 2010; Zhang et al. 2011; Cai 2012). The nation’s policy promotes urbanization through releasing excess labour

from the agriculture sector which was estimated to be approximately 270 million people (Lv and Ding 1997), leaving less than 100 million managing more than 120 million hectares of farmland. In this regard, large-scaled mono-cropping will eventually replace the traditional small-scale farming systems in most areas. This will leave only a few traditional, small-scale production villages scattered in the landscapes. This would lead to a steep reduction in landscape heterogeneity in farmlands. The negative environmental effects of such practices (Matson et al. 1997; Tilman 1999) will add to the already threatened biodiversity in farmland landscapes.

Agricultural landscapes are human-dominated, but a balance between the needs of the people and the ecosystem has to be reached for any successful implementation of conservation plans. In high-demand agricultural regions such as China, food security has been given the utmost attention. Conservation, therefore, has to adjust to this reality. Although conservation based agriculture (e.g. no-tillage or strip-tillage farms) has been found to increase corn yield in the USA (Ismail et al. 1994; Triplett and Dick 2008; Palm et al.), and Chinese implementation of such practices has showed environmental improvement in farmlands (He et al. 2009), it is uncertain whether these practices can have similar effects on winter wheat and paddy rice which are food crops designated as 100% self-supporting for China (National Development and Reform Commision 2008). This will be especially challenging with reducing farmland and growing population. A meta-analysis by Seufert et al. (2012) concluded that organic cultivation yields were on average 25% lower than conventional ones. This deficit was even higher for developing countries (43%). There is little empirical evidence to suggest that shifting towards environmentally friendly agriculture will definitely reduce production (Seufert et al. 2012), but the lack of general organic farming techniques and high demand for certain crop types (especially wheat) in developing countries, could halt the progress of a large-scale conservation plans.

However, adopting diverse cultivation and management schemes represents a real chance of tackling the conservation of biodiversity in agricultural ecosystems within the current economic and practical requirements and limitations. Diverse cultivation, as shown in the previous chapters, increases the potential to maintain a higher floral and faunal diversity in agriculture areas. It also increases heterogeneity at both farmland and landscape scale, and offers habitat and refuge for species at multiple levels. In a broader farm region perspective, diverse villages could be viewed as

islands of habitats in a monotonic sea of crops. Floral and soil faunal species in farmlands are generally sedentary (on the farmland scale) and could only re-colonize nearby farmlands, but diverse cultivation could be beneficial for other ambulatory species such as pollinators and birds (Gabriel et al. 2010). This study did not include high proportions of mobile species. The “landscape-moderated conservation effectiveness hypothesis” (Tscharntke et al. 2005; Tscharntke et al. 2012) and the “equilibrium hypothesis” (MacArthur 1967; Whittaker and Fernández-Palacios 2007), however, point to the possibilities that within a certain agricultural landscape, patches of diverse cultivation villages, while supporting higher species diversity, would promote interactions of more vagile species, thereby reducing the risk of these species going extinct completely.

Socio-economic factors also benefit the general development of diverse villages. Diverse cultivation, compared with traditional, increased per capita agricultural income by more than 100% (Chapter 2). Notwithstanding other economic revenue (e.g. migrant work), this creates a strong incentive for farmers. This means that such implementation requires minimal policy levers and government facilitation, and will be met with minimal resistance.

Specified cultivation, another type of specialization similar in input, lacks the potential to support high species diversity. Its crop choice depends highly on domestic markets and is subjected to fluctuations. It is also highly profitable compared with traditional cultivation and, therefore, likely to be adopted by farmers. Long-term monitoring is needed to evaluate the environmental impact and conservation consequences of such a scheme.

Both types of specialization involved large quantities of agrochemical input, degrading soil conditions. Heavy metal accumulation in Chinese agricultural regions has been a long-standing issue (Qiu 2010; Tang et al. 2010). As agriculture intensifies, heavy metal pollution status could deteriorate even more. The effects of this due to leaching and accumulation of underground water, will spread beyond the boundaries of the villages. Diverse cultivation, in this regard, also offers a possible solution to alleviate the heavy metal pollution in farmland soils as increasing floral diversity to include species which could phytoextract the elements and, thus, decrease soil concentrations. More empirical data are needed to support the

application of such a process. As a matter of immediate concern, better soil properties in diverse villages could be sought after by more efficient agrochemical input.

7.2.2 Critical leverage-factors for agri-sustainability

Conservation in rural China has been limited by lack of state support, theoretical knowhow, and a general lack of ecological perception by the farmers. The "ecological high-value agriculture" at the heart of the nation's development strategies (Zhao and Huang 2012), requires more emphasis on the environmental consequences of agricultural management, especially the knowledge and attitude of farmers.

Chinese farmers are usually undereducated, and their attitude towards the environment largely comes from TVs, opinions of neighbours and village consensus. Direct indoctrination of sustainable practices will less likely lead to change and produce the desire results. Conservation planning in rural regions should engage rural leaders to set an example. Farmers are far more likely to copy successful changes in agriculture, be it organic management or government subsidized cultivation, than taking first steps on their own. Long-term strategies require longitudinal studies with relevant empirical data as well as broader socio-economic data for a better understanding of stakeholder interests.

7.3 Shortcomings and future propositions

This study is based on first-hand data (species diversity surveys, soil chemical samples, and face-to-face interviews). While this approach offers the best representation of actual agricultural practices in the study area, the limitations of such an approach such as the lack of village replication and shortage of historic data, limits its overall representativeness.

Due to load of work, only two village-replication groups (three types in each group) were examined, though efforts were made during village selection to ensure comparability by satisfying multiple socio-economic and geographical criteria (Chapter 2). However, the analyses could not account for all stochastic elements involved e.g. effectiveness and impurities of agrochemicals, competence in farming. More replication is needed covering larger agricultural areas in a region to

adequately assess the environmental implications of specialized managements. Because most farmers have not received higher education, socio-economic data can only be gathered by face-to-face interview. A better selection of data and interview method will improve efficiency when a large number of villages is being sampled. Lack of systematic planning for conservation in China means there are insufficient historic data in this field, e.g. only record of flora in the region were from 1979-1998 (Ding and Wang 1998) and these surveys were not focused on agricultural lands. As floral and faunal responses to cultivation are time-based, and soil element concentration is a cumulative process, quantifiable comparisons of environmental impact related to management changes are best analysed along a continuous time gradient. These two factors point to the necessity of a wider evaluation effort dedicated to monitoring the conservation properties of alternative managements in Chinese rural areas. These studies will offer vital knowledge of real-world, agri-environment capabilities in helping nation-wide agricultural conservation schemes come into being.

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Appendices

Table S1a

201208 (August) record of floral species mean coverage of respective land types (villages in post-sample order, groups by style)

	Village	1	1	1	1	2	2	2	3	3	3	3	4	4	4	4	5	5	5	5	6	6	6
	Time	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012
No.	Species	field	road	ditch	ab[a]	field	road	ab	field	road	ditch	ab	field	road	ditch	ab	field	road	Ditch	Ab	field	road	ditch
1	Artemisia argyi													0.032									0.031
2	Imperata cylindrica						0.111					0.053				0.097				0.028			0.125
3	Echinochloa crusgali												0.008	0.113		0.226	0.023	0.040					
4	Bothriospermum chinense.							0.063															
5	Ixeris sonchifolia							0.063															
6	Polygonum aviculare	0.033	0.789	0.095	0.042	0.067	0.056			0.156		0.013			0.156			0.360				0.063	
7	Descurainia sophia					0.033		0.063		0.375											0.067	0.031	0.031
8	Xanthium sibiricum			0.238	0.083									0.032				0.360	0.167	0.111		0.156	**1.375**
9	Plantago asiatica																						
10	Rumex dentatus																						0.031
11	Cirsium setosum.	0.150	0.079		0.083	0.333	0.333	0.063	0.067	0.375		0.132					0.047	0.080		0.083	0.067	0.281	0.406
12	Oxalis pes-caprae											0.237											
13	Calystegia hederacea	0.167	0.289		0.014	0.367	0.278		0.067	0.125		0.039	0.177	0.169		0.161	0.174	0.200	0.083	0.014	0.500	0.500	0.156
14	Rheum palmatum					0.067																	
15	Kochia scoparia				0.056									0.081				0.080					
16	Rehmannia glutinosa				0.111				0.100			0.026		0.032					0.250				
17	Euphorbia humifusa		0.026		0.042		0.167		0.250	0.250		0.039							0.167	0.028	0.067	0.031	
18	Cynanchum thesioides	0.017	0.053		0.028		0.056		0.100			0.171											
19	Lepidium																					0.03	

	apetalum																							1	
20	Stellaria media					0.100																	0.100		
21	Amaranthus retroflexus					0.767	1.028																1.333	0.938	0.219
22	Rorippa globosa																								
23	Trigonotis peduncularis					0.067		0.688								0.065									
24	Setaria viridis	**0.750**	**1.632**	1.095	**1.069**	0.733	0.472		0.267			0.724	0.210	0.371	0.328	1.339	0.081	0.480	0.667	1.139	0.733	0.406	0.625
25	Cynodon dactylon	0.067	0.737	0.071	0.028	1.000	**2.333**	0.031	0.100	0.688	0.200	0.053		**1.177**	0.125	1.226	0.047	0.760	0.583	0.056	0.067	1.313	1.000
26	Lycium chinense	0.033	0.105	0.095	0.028	0.267	0.139	0.125				0.079				0.016		0.240	0.333	0.083			0.063
27	Broussonetia kazinoki				0.056							0.184								0.056			0.031
28	Bidens pilosa			0.095	0.250							0.105								0.056			
29	Eragrostis pilosa																				0.033		
30	Youngia japonica					0.133	0.111														0.400	0.031	0.313
31	Scutellaria baicalensis					0.200																	
32	Chenopodium glaucum	0.067	0.395	0.167	0.278	0.233	0.167	0.156		0.031	0.133	0.132		0.081		0.210	0.151	0.380	**1.917**	0.417	0.233	0.188	0.094
33	Tribulus terrester																		0.083				
34	Equisetum ramosissimum					0.033				0.438										0.056			
35	Setaria glauca												0.008	0.032									
36	Bidens biternata			0.095	0.056							0.026											
37	Helianthus tuberosus											0.079											
38	Alternanthera philoxeroides																						0.500
39	Sonchus oleraceus																						0.031
40	Capsella bursa-pastoris							0.531		0.250													1.250

41	Chenopodium album	0.100		0.119	0.542	0.067		0.375				0.184	0.040		0.031	0.323	0.023	0.360		0.306	0.333	0.031	0.031
42	Eclipta prostrata	0.200	0.026	0.619	0.194	**1.300**	0.833		0.067			0.026	0.032	0.008	0.031	**1.661**	0.302	0.040	0.250	0.472	1.133	0.625	1.000
43	Calystegia sepium								0.067	0.067				0.016									
44	Salvia plebeia.									0.063		0.013											0.188
45	Aster albescens								0.033	0.033		0.026				0.677							
46	Solanum nigrum	0.050		0.095	0.056							0.053				0.226	0.047					0.063	0.063
47	Phragmites australis															0.032							0.344
48	Humulus scandens		0.368	0.738	0.472		0.611	**0.750**		0.063	**1.000**	**1.000**		0.129		0.161		0.280	1.250	**1.722**		1.125	1.000
49	Portulaca oleracea																					0.063	
50	Cucumis melo	0.467	0.342	0.119		0.433	0.361		**0.817**	**0.817**			0.565	0.661	0.844		**1.140**	0.340	0.292	0.056	1.167	0.625	0.094
51	Digitaria sanguinalis	0.067	0.105			0.333	0.361		0.333			0.053	0.718	0.452	0.734	0.323	0.174	0.040		0.056		0.656	0.063
52	Datura stramonium		0.211	0.143																			
53	Phytolacca americana				0.139																		
54	Lactuca tatarica	0.033		0.190								0.053					0.023			0.056			
55	Hemistepta lyrata					0.233	0.139	0.125													0.133		
56	Eleusine indica	0.583	0.474	0.381	0.111	0.633	1.250		0.700	0.063			**0.919**	0.935	**1.656**	0.097	0.302	0.980	0.542	0.097	**2.000**	**1.813**	0.406
57	Cynanchum auriculatum				0.083																		0.125
58	Achyranthes bidentata																	0.080					
59	Veronica didyma					0.333		0.156		0.375	0.067										0.267		0.063
60	Taraxacum mongolicum										0.200												
61	Pharbitis nil	0.167	0.289	0.262	0.056	0.033			0.217			0.026		0.032			0.023	0.200		0.139		0.031	
62	Rubia cordifolia				0.056		0.083					0.105											0.063
63	Abutilon theophrasti	0.067	0.105	0.190	0.194	0.033	0.111					0.026		0.145		0.306		0.300	0.167	0.139	0.067	0.156	0.031

64	Cyperus glomeratus																						0.375
65	Cyperus rotundus	0.100	0.289		0.056	0.167	0.056		0.383			0.823	0.524	0.859	0.113	0.558	0.120	0.083		0.733	0.250	0.656
66	Ixeris denticulata	0.017			0.083				0.267	0.267	0.079								0.042	0.067		
67	Duchesnea indica				0.222																	
68	Ranunculus sceleratus																					0.063
69	Polygonum hydropiper																					0.531
70	Oenanthe javanica																					0.094
71	Galium bungei					0.067														0.033		
72	Conyza sumatrensis			0.143		0.033	0.028													0.167		0.031
73	Physalis alkekengi			0.024	0.083		0.028					0.161	0.016	0.063					0.028	0.067		
74	Rumex acetosa																					0.094
75	Cardamine lyrata																					0.188
76	Carex tristachya															0.070						
77	Erysimum bungei.																					
78	Convolvulus arvensis				0.014	0.367	0.444	0.156	0.033		0.026		0.032			0.093			0.028	0.100		
79	Acalypha australis	0.100	0.105	0.143	0.111	0.300	0.083	0.188	0.133	0.133	0.026	0.153	0.081	0.031		0.105	0.080	0.083	0.083	0.767	0.281	0.031
80	Mazus japonicus																			0.200		0.313
81	Potentilla chinensis					0.067														0.067		
82	Equisetum arvense																					0.500
83	Lagopsis supina					0.767	0.778	0.313												0.267	0.406	**1.375**
84	Amaranthus tricolor	0.383	1.395	**1.262**	0.486				0.433	0.433	0.197	0.266	0.871	0.203		1.047	**1.000**	0.667	0.500		0.031	
85	Typha orientalis																					0.063
86	Conyza bonariensis				0.083						0.197								0.056			

87	Chenopodium serotinum																				
88	Conyza canadensis			0.024	0.167						0.237		0.031	0.387		0.080		0.028			0.063
89	Physalis minima			0.095		0.167													0.533	0.031	0.031
90	Inula japonica																				0.250
91	Commelina communis	0.017			0.028						0.053	0.008									
92	Populus simonii																			0.125	
93	Daucus carota																				
94	Vicia sepium					0.033															
95	Avena fatua								0.063												
96	Leonurus artemisia							0.125										0.139			
97	Artemisia scoparia										0.079			0.161		0.040					
98	Silene gallica																				
99	Poa pratensis																				
100	Euphorbia helioscopia					0.400	0.028														
101	Salsola collina		0.184								0.053			0.032			0.250				
102	Galium aparine								0.313												
103	Corydalis edulis										0.145							0.111	0.033		
104	Potamogeton crispus																				0.125
105	Aster subulatus																				0.531

[a] Abandoned sites

Data represent per quadrat ($0.25m^2$) mean coverage of respective land types with Braun-Blanquet index (0.5-minimal presence, 1-less than 5%, 2-5% to 25%, 3-25% to 50%, 4-50% to 75%, 5-over 75%);

Dominant species for each type are marked in bold;

Table S1b

201304 (April) record of floral species mean coverage of respective land types (villages in post-sample order, groups by style)

	Village	1	1	1	1	2	2	2	3	3	3	3	4	4	5	5	5	5	6	6	6
	time	201304	201304	201304	201304	201304	201304	201304	201304	201304	201304	201304	201304	201304	201304	201304	201304	201304	201304	201304	201304
No.	Name	field	road	ditch	ab[a]	field	road	ab	field	road	ditch	ab	field	road	field	road	ditch	ab	field	road	ditch
1	Artemisia argyi		0.267																		
2	Imperata cylindrica																0.033				
3	Echinochloa crusgali			0.067																	
4	Bothriospermum chinense.							0.063													
5	Ixeris sonchifolia							0.063	0.100		0.133						0.200	0.286			
6	Polygonum aviculare		0.267	0.133			0.143		0.033	0.156						0.133				0.600	0.500
7	Descurainia sophia	0.067	0.333	0.100		0.400	**1.143**	0.063	0.167	0.375						0.067				**0.867**	0.133
8	Xanthium sibiricum																				
9	Plantago asiatica																0.067				
10	Rumex dentatus			0.067													0.200				
11	Cirsium setosum.			0.133	0.133		0.071	0.063	0.600	0.375	0.933	0.133			0.133	0.133		0.238	0.200	0.133	0.500
12	Oxalis pes-caprae																				
13	Calystegia hederacea	**0.733**	0.267			**0.667**	0.286		0.333	0.125	0.133	0.133		0.133	0.333	0.867	0.067	0.190	0.633	0.533	0.067
14	Rheum palmatum																				
15	Kochia scoparia																				
16	Rehmannia glutinosa																				
17	Euphorbia humifusa																				
18	Cynanchum thesioides																				
19	Lepidium apetalum						0.071														
20	Stellaria media						0.071					0.067									0.200
21	Amaranthus retroflexus																				
22	Rorippa globosa			0.467								0.067					0.667				
23	Trigonotis peduncularis		0.067		0.133		0.071	0.688	0.067			0.400				0.200	0.467	0.048		0.067	
24	Setaria viridis																		0.100	0.033	

25	Cynodon dactylon	0.033	0.233	0.533			0.500	0.031		**0.688**	0.200			**0.700**			0.133			0.333	
26	Lycium chinense		**1.200**	0.067	**0.733**		0.214	0.125			0.467	0.533				0.200		0.548		0.200	
27	Broussonetia kazinoki																				
28	Bidens pilosa																				
29	Eragrostis pilosa																				
30	Youngia japonica																				
31	Scutellaria baicalensis																				
32	Chenopodium glaucum	0.333	0.533	0.133	0.333		0.429	0.156	0.200	0.031	0.133	0.167	0.133	0.500	0.067	0.400		0.190	**1.000**	0.267	0.367
33	Tribulus terrester																				
34	Equisetum ramosissimum			1.133						0.438						0.067	0.467				
35	Setaria glauca																				
36	Bidens biternata																				
37	Helianthus tuberosus										0.333										
38	Alternanthera philoxeroides																				
39	Sonchus oleraceus																				
40	Capsella bursa-pastoris		0.467	0.267	0.200	0.067	0.643	0.531	0.200	0.250		**0.600**	0.033	0.467	0.267	0.867		0.333		0.333	0.867
41	Chenopodium album	0.033	0.067		0.333			0.375	0.067			0.400			0.033	0.067					0.067
42	Eclipta prostrata																				
43	Calystegia sepium					0.133	0.071														
44	Salvia plebeia.			0.067						0.063							0.067				
45	Aster albescens			0.900	0.067												0.067				
46	Solanum nigrum																				
47	Phragmites australis																0.067				
48	Humulus scandens		0.333	**1.267**	0.600			**0.750**		0.063	**1.000**	0.400				0.133	0.467	**1.095**		0.200	0.667
49	Portulaca oleracea																				
50	Cucumis melo																				
51	Digitaria sanguinalis																		0.067		0.067
52	Datura stramonium																				

53	Phytolacca americana																			
54	Lactuca tatarica										0.200									
55	Hemistepta lyrata		0.067		0.200			0.125					0.067				0.133	0.133	0.333	0.067	0.067	0.067
56	Eleusine indica						0.143			0.063												
57	Cynanchum auriculatum																			
58	Achyranthes bidentata																			
59	Veronica didyma		1.133				0.357	0.156	**0.733**	0.375	0.067	0.333					0.133	0.133			0.067	**1.000**
60	Taraxacum mongolicum		0.400		0.467						0.200											
61	Pharbitis nil																			
62	Rubia cordifolia																			
63	Abutilon theophrasti																			
64	Cyperus glomeratus																			
65	Cyperus rotundus																			
66	Ixeris denticulata																			
67	Duchesnea indica				0.067															
68	Ranunculus sceleratus			0.600														0.067		
69	Polygonum hydropiper																			
70	Oenanthe javanica																			
71	Galium bungei																			
72	Conyza sumatrensis																			
73	Physalis alkekengi																			
74	Rumex acetosa																			
75	Cardamine lyrata			1.133														1.000		
76	Carex tristachya																			
77	Erysimum bungei.		0.067																	
78	Convolvulus arvensis	0.167						0.156	0.433				0.067	0.033	0.300	0.033	0.533		0.048			0.200
79	Acalypha australis							0.188														
80	Mazus japonicus																			
81	Potentilla chinensis															0.200	0.267					

82	Equisetum arvense																				
83	Lagopsis supina				0.633	0.067	0.357	0.313				0.133						0.190	0.067		0.533
84	Amaranthus tricolor																				
85	Typha orientalis																				
86	Conyza bonariensis																				
87	Chenopodium serotinum												0.167	0.333							
88	Conyza canadensis			0.200	0.067		0.071					0.400		0.067	0.133		0.133				0.133
89	Physalis minima																				
90	Inula japonica																				
91	Commelina communis																				
92	Populus simonii																				
93	Daucus carota			0.200													0.067				
94	Vicia sepium																				
95	Avena fatua		0.067							0.063	0.600						**1.600**				
96	Leonurus artemisia							0.125													
97	Artemisia scoparia																				
98	Silene gallica						0.071		0.267												
99	Poa pratensis		0.067						0.133		0.133			0.067	**0.600**	**1.200**				0.533	0.067
100	Euphorbia helioscopia						0.143										0.067				
101	Salsola collina																	0.095			
102	Galium aparine	0.067	0.067			0.067	0.214		0.200	0.313	0.067	0.333	**1.300**	0.200	0.167	0.133	0.133	0.048		0.067	
103	Corydalis edulis											0.267						0.071			
104	Potamogeton crispus																				
105	Aster subulatus																				

[a] Abandoned sites

Data represent per quadrat ($0.25m^2$) mean coverage of respective land types with Braun-Blanquet index (0.5-minimal presence, 1-less than 5%, 2-5% to 25%, 3-25% to 50%, 4-50% to 75%, 5-over 75%);

Dominant species for each type are marked in bold;

Table S1c

201308 (August) record of floral species mean coverage of respective land types (villages in post-sample order, groups by style)

	village	1	1	1	1	2	2	2	3	3	3	3	4	4	5	5	5	5	6	6	6
	time	201308	201308	201308	201308	201308	201308	201308	201308	201308	201308	201308	201308	201308	201308	201308	201308	201308	201308	201308	201308
No.	Name	field	road	ditch	ab[a]	field	road	ab	field	road	ditch	ab	field	road	field	road	ditch	ab	field	road	ditch
1	Artemisia argyi			0.429													0.136				0.033
2	Imperata cylindrica						0.111	0.188				0.053						0.133			0.133
3	Echinochloa crusgali																				
4	Bothriospermum chinense.																				
5	Ixeris sonchifolia																				
6	Polygonum aviculare		0.263		0.020		0.056			0.156						0.160				0.200	
7	Descurainia sophia									0.375											
8	Xanthium sibiricum			**1.524**												0.160	0.136				1.133
9	Plantago asiatica																				
10	Rumex dentatus																				0.033
11	Cirsium setosum.	0.225	0.053		0.080	0.200	0.333	0.125	0.067	0.375		0.105			0.069			0.233			0.433
12	Oxalis pes-caprae											0.026									
13	Calystegia hederacea	0.225	0.421		0.040	0.500	0.278		0.250	0.125		0.092	0.034		0.483	0.240	0.273	0.033		0.200	0.167
14	Rheum palmatum					0.067															
15	Kochia scoparia				0.080																
16	Rehmannia glutinosa		0.105		0.160				0.100			0.053					0.136				
17	Euphorbia humifusa				0.040		0.167		0.117	0.117		0.026					0.045	0.033			
18	Cynanchum thesioides						0.056		0.100			0.158						0.333			
19	Lepidium apetalum																				
20	Stellaria media					0.100															
21	Amaranthus retroflexus					0.400	1.028														0.233
22	Rorippa globosa																				
23	Trigonotis																				

	peduncularis																				
24	Setaria viridis	**0.825**	**1.421**	0.810	**1.320**	0.533	0.472	0.438	0.267	0.267	**2.750**	**1.724**	0.241	0.400	0.017	0.440	0.409	0.500		0.200	0.400
25	Cynodon dactylon	0.100	0.263	1.238		0.333	**2.333**	0.625	0.100	0.688	0.750	0.026	0.138	0.800	0.034	**1.760**	**1.909**	0.067		0.333	1.600
26	Lycium chinense	0.025			0.040	0.333	0.139									0.080	0.182	0.033			0.067
27	Broussonetia kazinoki																				0.033
28	Bidens pilosa			0.048	0.560			0.313				0.079									
29	Eragrostis pilosa																				
30	Youngia japonica						0.111														0.267
31	Scutellaria baicalensis					0.200															
32	Chenopodium glaucum	0.075	0.105	0.167	0.240		0.167	**1.125**		0.031	0.375	0.289		0.067	0.069	0.320	0.455	0.367			0.100
33	Tribulus terrester																0.045				
34	Equisetum ramosissimum			0.048		0.033				0.438							0.136	0.133			
35	Setaria glauca																				
36	Bidens biternata			0.095	0.080																
37	Helianthus tuberosus																				
38	Alternanthera philoxeroides																				0.267
39	Sonchus oleraceus		0.211									0.026									0.033
40	Capsella bursa-pastoris									0.250											0.833
41	Chenopodium album	0.025			0.840							0.421		0.067	0.034	0.200		0.233			0.033
42	Eclipta prostrata	0.225	0.632	0.429	0.160	**0.600**	0.833		0.033	0.033		0.132			0.224	0.080	0.773	0.133	0.400	0.333	1.033
43	Calystegia sepium								0.033												
44	Salvia plebeia.									0.063											0.200
45	Aster albescens																				
46	Solanum nigrum		0.211									0.053									0.033
47	Phragmites australis			0.095													0.818				0.300
48	Humulus scandens		0.579	**1.524**	0.160		0.611	1.063		0.063	**2.750**	0.579				0.080	1.114	**2.367**			**2.200**
49	Portulaca oleracea																				

50	Cucumis melo	0.625	1.105	0.381		0.233	0.361		**1.117**	**1.117**			**1.690**	**2.133**	**2.000**	0.880	0.023	0.067	**2.400**	1.667	0.100
51	Digitaria sanguinalis	0.100		0.333	0.040	0.267	0.361		0.350			0.118	1.586	1.067	0.138	0.520		0.067		0.133	0.067
52	Datura stramonium																				
53	Phytolacca americana				0.200																
54	Lactuca tatarica														0.034						
55	Hemistepta lyrata						0.139														
56	Eleusine indica	**0.825**	1.211	0.286	0.060	**0.600**	1.361	0.063	0.583	0.063		0.079	**1.690**	1.800	0.397	0.740	0.159		0.800	**3.000**	0.700
57	Cynanchum auriculatum				0.080																0.133
58	Achyranthes bidentata																				
59	Veronica didyma					0.067		0.125		0.375											0.067
60	Taraxacum mongolicum																				
61	Pharbitis nil	0.200	0.263	0.143	0.040				0.100	0.100		0.158				0.080		0.067			
62	Rubia cordifolia				0.200		0.083														0.067
63	Abutilon theophrasti					0.033	0.111	0.125								0.180	0.045	0.067			0.033
64	Cyperus glomeratus																				0.200
65	Cyperus rotundus	0.075	0.026	0.143	0.160	0.333	0.417		0.367		0.250		0.414	0.433	0.690	0.600	0.341		0.467	0.800	0.767
66	Ixeris denticulata				0.120				0.150			0.039						0.167			
67	Duchesnea indica																				
68	Ranunculus sceleratus																				0.033
69	Polygonum hydropiper			1.095				0.875									0.091				0.500
70	Oenanthe javanica																				0.100
71	Galium bungei																				
72	Conyza sumatrensis			0.095			0.028														0.033
73	Physalis alkekengi			0.024			0.028											0.033			
74	Rumex acetosa																				0.100
75	Cardamine lyrata																				0.200
76	Carex tristachya														0.069						

77	Erysimum bungei.																			
78	Convolvulus arvensis					0.333	0.444		0.067		0.026			0.034						
79	Acalypha australis	0.075		0.048		0.267	0.083	0.313	0.100	0.100	0.171	0.103	0.033	0.190	0.120		0.067	0.200		0.033
80	Mazus japonicus																			0.333
81	Potentilla chinensis																			
82	Equisetum arvense																			0.533
83	Lagopsis supina		0.158			0.067	0.444	0.063												1.267
84	Amaranthus tricolor	0.300	0.500	0.429	0.220	0.067			0.217		0.211	0.069	1.133	0.638	0.480	0.045	0.167	0.667	0.267	
85	Typha orientalis																			0.067
86	Conyza bonariensis			0.048	0.080			0.188			0.211					0.045	0.133			
87	Chenopodium serotinum			0.095							0.026						0.067			
88	Conyza canadensis				0.100						0.105				0.080		0.033			0.067
89	Physalis minima		0.105		0.080	0.067												0.267		0.033
90	Inula japonica							0.563								0.182				0.267
91	Commelina communis		0.211		0.040			0.063			0.237									
92	Populus simonii																			
93	Daucus carota																			
94	Vicia sepium																			
95	Avena fatua									0.063										
96	Leonurus artemisia																0.133			
97	Artemisia scoparia										0.079				0.040					
98	Silene gallica																			
99	Poa pratensis																			
100	Euphorbia helioscopia						0.028													
101	Salsola collina															0.136	0.100			
102	Galium aparine									0.313										
103	Corydalis edulis																0.267			
104	Potamogeton crispus																			0.133

105	Aster subulatus	0.375	0.567

[a] Abandoned sites

Data represent per quadrat ($0.25m^2$) mean coverage of respective land types with Braun-Blanquet index (0.5-minimal presence, 1-less than 5%, 2-5% to 25%, 3-25% to 50%, 4-50% to 75%, 5-over 75%);

Dominant species for each type are marked in bold;

Table S2a

201208 (August) floral summary statistics (calculated using mean coverage on the Braun-Blanquet index on respective land types)

Statistics	**Village**					
	Traditional		Specified		Diverse	
	Zhu-cun-pu	Dong-yang-si	Qian-gang	Dong-ying	Chang-zhai	Wan-zhai
Taxa						
Field	22	34	19	13	19	30
Road	21	27	21	24	24	28
Ditch	24	na[a]	5	13	18	48
Abandoned	35	17	37	21	30	na
Coverage[b]						
Field	3.633	10.167	4.433	4.081	4.430	11.733
Road	8.000	10.444	5.375	6.032	6.920	10.281
Ditch	6.500	na	1.600	5.094	7.833	15.063
Abandoned	5.458	3.969	4.750	7.839	6.181	na
Total						
SHDI						
Field	2.546	3.079	2.572	2.064	2.250	2.817
Road	2.556	2.692	2.719	2.445	2.787	2.723
Ditch	2.667	na	1.153	1.925	2.461	3.290
Abandoned	2.996	2.463	2.988	2.478	2.546	na
Total						
Simpson's Dominance						
Field	0.109	0.060	0.098	0.153	0.153	0.082
Road	0.106	0.099	0.080	0.115	0.079	0.088
Ditch	0.100	na	0.431	0.190	0.118	0.050
Abandoned	0.078	0.110	0.086	0.118	0.135	na
Total						
Evar						
Field	0.120	0.211	0.196	0.184	0.141	0.243
Road	0.279	0.242	0.217	0.122	0.228	0.204
Ditch	0.203	na	0.348	0.220	0.385	0.186
Abandoned	0.115	0.202	0.097	0.248	0.119	na
Dominant species						
Field	Setaria viridis (L.) Beauv.	Eclipta prostrata (Linn.) Linn.	Cucumis melo L. var. agrestis Naud.	Eleusine indica (L.) Gaertn.	Cucumis melo L. var. agrestis Naud.	Eleusine indica (L.) Gaertn.
Road	Setaria viridis (L.) Beauv.	Cynodon dactylon (L.) Pers.	Cucumis melo L. var. agrestis Naud.	Cynodon dactylon (L.) Pers.	Chenopodium serotinum Linn.	Eleusine indica (L.) Gaertn.
Ditch	Amaranthus tricolor L.		Humulus scandens (Lour.) Merr.	Eleusine indica (L.) Gaertn.	Chenopodium glaucum	Xanthium sibiricum, Lagopsis supina
Abandoned	Setaria viridis (L.) Beauv.	Humulus scandens (Lour.) Merr.	Humulus scandens (Lour.) Merr.	Eclipta prostrata (Linn.) Linn.	Humulus scandens (Lour.) Merr.	

[a] Missing sample types

[b] Per quadrat ($0.25m^2$) mean coverage

Table S2b

201304 (April) floral summary statistics (calculated using mean coverage on the Braun-Blanquet index on respective land types)

Statistics	Village					
	Zhu-cun-pu	**Dong-yang-si**	**Qian-gang**	**Dong-ying**	**Chang-zhai**	**Wan-zhai**
Taxa						
Field	7	6	14	5	10	7
Road	18	19	14	9	17	15
Ditch	18	na	14	na[a]	22	16
Abandoned	13	17	17	na	14	na
Coverage[b]						
Field	1.433	1.400	3.533	1.667	1.967	2.133
Road	5.900	5.071	3.375	2.767	5.533	4.300
Ditch	7.467	na	4.600	na	6.300	5.433
Abandoned	3.967	3.969	4.500	na	3.714	na
SHDI						
Field	1.393	1.370	2.353	0.783	1.993	1.406
Road	2.468	2.560	2.338	1.969	2.412	2.373
Ditch	2.448	na	2.286	na	2.496	2.406
Abandoned	2.294	2.463	2.620	na	2.243	na
Simpson's Dominance						
Field	0.335	0.324	0.116	0.626	0.169	0.322
Road	0.112	0.104	0.114	0.160	0.120	0.113
Ditch	0.109	Na	0.130	na	0.123	0.110
Abandoned	0.119	0.110	0.083	na	0.144	na
Evar						
Field	0.173	0.237	0.242	0.217	0.192	0.255
Road	0.266	0.231	0.219	0.340	0.278	0.251
Ditch	0.329	na	0.309	na	0.199	0.290
Abandoned	0.303	0.202	0.268	na	0.230	na
Dominance species						
Field	Calystegia hederacea Wall.	Calystegia hederacea Wall.	Veronica didyma Tenore	Galium aparine Linn. var.	Poa pratensis Linn. var. pratensis	Chenopodium glaucum
Road	Lycium chinense Miller	Descurainia sophia (L.) Webb ex Prantl	Cynodon dactylon (L.) Pers.	Cynodon dactylon (L.) Pers.	Poa pratensis Linn. var. pratensis	Descurainia sophia (L.) Webb ex Prantl
Ditch	Humulus scandens (Lour.) Merr.		Humulus scandens (Lour.) Merr.		Avena fatua Linn. var. fatua	Veronica didyma Tenore
Abandoned	Lycium chinense Miller	Humulus scandens (Lour.) Merr.	Capsella bursa-pastoris (Linn.) Medic.		Humulus scandens (Lour.) Merr.	

[a] Missing sample types

[b] Per quadrat ($0.25m^2$) mean coverage

Table S2c

201308 (August) floral summary statistics (calculated using mean coverage on the Braun-Blanquet index on respective land types)

Statistics	Village					
	Zhu-cun-pu	**Dong-yang-si**	**Qian-gang**	**Dong-ying**	**Chang-zhai**	**Wan-zhai**
Taxa						
Field	15	22	18	9	16	7
Road	19	27	20	10	20	10
Ditch	23	na	5	na[a]	23	47
Abandoned	27	17	28	na	27	na
Coverage[b]						
Field	3.925	5.633	4.117	5.966	5.121	5.200
Road	7.842	10.583	5.108	7.933	7.240	7.133
Ditch	9.524	Na	6.875	na	7.636	15.967
Abandoned	5.240	6.625	5.303	na	6.033	na
SHDI						
Field	2.266	2.825	2.443	1.620	2.002	1.599
Road	2.540	2.722	2.578	1.882	2.535	1.734
Ditch	2.582	na	1.254	na	2.522	3.198
Abandoned	2.670	2.483	2.604	na	2.473	na
Simpson's Dominance						
Field	0.135	0.068	0.125	0.239	0.206	0.271
Road	0.102	0.097	0.102	0.178	0.111	0.253
Ditch	0.100	Na	0.336	na	0.119	0.059
Abandoned	0.114	0.103	0.138	na	0.178	na
Evar						
Field	0.204	0.228	0.188	0.436	0.171	0.816
Road	0.346	0.258	0.204	0.605	0.289	0.628
Ditch	0.268	na	0.969	na	0.215	0.192
Abandoned	0.139	0.350	0.127	na	0.146	na
Dominance species						
Field	Eleusine indica (L.) Gaertn.	Eclipta prostrata (Linn.) Linn.	Cucumis melo L. var. agrestis Naud.	Cucumis melo L. var. agrestis Naud., Eleusine indica (L.) Gaertn.	Cucumis melo L. var. agrestis Naud.	Cucumis melo L. var. agrestis Naud.
Road	Setaria viridis (L.) Beauv.	Cynodon dactylon (L.) Pers.	Cucumis melo L. var. agrestis Naud.	Cucumis melo L. var. agrestis Naud.	Cynodon dactylon (L.) Pers.	Eleusine indica (L.) Gaertn.
Ditch	Xanthium sibiricum, Humulus scandens (Lour.) Merr.		Setaria viridis (L.) Beauv., Humulus scandens (Lour.) Merr.		Cynodon dactylon (L.) Pers.	Humulus scandens (Lour.) Merr.
Abandoned	Setaria viridis (L.) Beauv.	Chenopodium glaucum	Setaria viridis (L.) Beauv.		Humulus scandens (Lour.) Merr.	

[a] Missing sample types

[b] Per quadrat ($0.25m^2$) mean coverage

Table S3a

One-way ANOSIM results of floral data based on factor time

	Global	Pairwise		
Factor		2012summer, 2013spring	2012summer, 2013summer	2013spring, 2013summer
Sample statistic	0.431	0.643	-0.013	0.714
Significance level	0.1%	0.1%	62.9%	0.1%
Number ≥observed	0	0	628	0

All statistics based on 999 permutations

Log(x+1) transformed floral data, Bray-Curtis Distance

Table S3b

Two-way ANOSIM results of floral data based on factors village type and land type

	Global	Pairwise						Global	Pairwise		
Factor	Land type	Field, road	Field, ditch	Field, abandoned	Road, ditch	Road, abandoned	Ditch, abandoned	Village type	1, 3	1, 2	2, 3
Sample statistic	0.536	0.358	0.73	0.86	0.479	0.747	0.244	0.246	0.097	0.279	0.369
Significance level	0.1%	1.5%	0.1%	0.1%	0.1%	0.2%	9.7%	0.1%	19.4 %	0.8%	0.2%
Number ≥observed	0	14	0	0	0	1	96	0	193	7	1
Sample statistic	0.419	0.333[a]	0.5[a]	0.226[a]	0.637[a]	1[a]	0[b]	-0.009	-0.174[c]	0.197	0.086[b]
Significance level	1.8%	18.5 %[a]	14.8 %[a]	37%[a]	3.7%[a]	3.7%[a]	66.7[b]	52.9%	81.5 %[c]	25.9%[b]	55.6%[b]
Number ≥observed	17	5[a]	4[a]	10[a]	1[a]	1[a]	6[b]	528	66[c]	7[b]	15[b]

Log(x+1) transformed floral data, Bray-Curtis Distance

[a] Based on twenty seven permutations;

[b] Based on nine permutations;

[c] Based on eighty one permutations;

If unspecified, based on 999 permutations;

Table S4

Regression variables used for flora data (villages in post-sample orders—grouped by cultivation style)

Village	Mean coverage	Land type*	Time*	Pesticide (L/ha)	Herbicide (L/ha)	Manual labor (man×hour /ha)	Machinery (hour/ha)	Compound fertilizer (Kg/ha)	Nitrogen fertilizer (Kg/ha)	Phosphor fertilizer (Kg/ha)	Potassium fertilizer (Kg/ha)
1	8.0000	Road	2012	8.2900	2.5883	971.0961	47.8043	1196.3556	1441.3333	266.7911	73.7778
1	6.5000	Ditch	2012	8.2900	2.5883	971.0961	47.8043	1196.3556	1441.3333	266.7911	73.7778
1	3.6333	Field	2012	8.2900	2.5883	971.0961	47.8043	1196.3556	1441.3333	266.7911	73.7778
1	5.4583	Abandoned	2012	8.2900	2.5883	971.0961	47.8043	1196.3556	1441.3333	266.7911	73.7778
2	10.4444	Road	2012	22.3000	3.1384	1041.5124	51.3252	2341.1353	1391.1234	251.0928	68.3241
2	10.1667	Field	2012	22.3000	3.1384	1041.5124	51.3252	2341.1353	1391.1234	251.0928	68.3241
2	3.9688	Abandoned	2012	22.3000	3.1384	1041.5124	51.3252	2341.1353	1391.1234	251.0928	68.3241
3	5.3750	Road	2012	24.1200	0.9083	4216.9953	23.5421	1396.3560	1063.0227	177.3333	200.5333
3	4.7500	Abandoned	2012	24.1200	0.9083	4216.9953	23.5421	1396.3560	1063.0227	177.3333	200.5333
3	4.4333	Field	2012	24.1200	0.9083	4216.9953	23.5421	1396.3560	1063.0227	177.3333	200.5333
3	1.6000	Ditch	2012	24.1200	0.9083	4216.9953	23.5421	1396.3560	1063.0227	177.3333	200.5333
4	6.0323	Road	2012	20.3000	10.9045	1261.8032	94.5452	3515.5056	1036.8539	101.8427	393.7079
4	7.8387	Abandoned	2012	20.3000	10.9045	1261.8032	94.5452	3515.5056	1036.8539	101.8427	393.7079
4	4.0806	Field	2012	20.3000	10.9045	1261.8032	94.5452	3515.5056	1036.8539	101.8427	393.7079
4	5.0938	Ditch	2012	20.3000	10.9045	1261.8032	94.5452	3515.5056	1036.8539	101.8427	393.7079
5	6.9200	Road	2012	18.3700	3.3232	3222.2890	60.5975	2937.5422	3378.4096	467.0843	196.8193
5	7.8333	Ditch	2012	18.3700	3.3232	3222.2890	60.5975	2937.5422	3378.4096	467.0843	196.8193
5	4.4302	Field	2012	18.3700	3.3232	3222.2890	60.5975	2937.5422	3378.4096	467.0843	196.8193
5	6.1806	Abandoned	2012	18.3700	3.3232	3222.2890	60.5975	2937.5422	3378.4096	467.0843	196.8193
6	15.0625	Ditch	2012	19.0200	3.1328	3012.4109	55.1254	2823.2352	3243.3532	451.3214	201.2414
6	11.7333	Field	2012	19.0200	3.1328	3012.4109	55.1254	2823.2352	3243.3532	451.3214	201.2414
6	10.2813	Road	2012	19.0200	3.1328	3012.4109	55.1254	2823.2352	3243.3532	451.3214	201.2414

1	5.9000	Road	201304	8.2900	2.5883	971.0961	47.8043	1196.3556	1441.3333	266.7911	73.7778
1	7.4667	Ditch	201304	8.2900	2.5883	971.0961	47.8043	1196.3556	1441.3333	266.7911	73.7778
1	1.4333	Field	201304	8.2900	2.5883	971.0961	47.8043	1196.3556	1441.3333	266.7911	73.7778
1	3.9667	Abandoned	201304	8.2900	2.5883	971.0961	47.8043	1196.3556	1441.3333	266.7911	73.7778
2	5.0714	Road	201304	22.3000	3.1384	1041.5124	51.3252	2341.1353	1391.1234	251.0928	68.3241
2	1.4000	Field	201304	22.3000	3.1384	1041.5124	51.3252	2341.1353	1391.1234	251.0928	68.3241
2	3.9688	Abandoned	201304	22.3000	3.1384	1041.5124	51.3252	2341.1353	1391.1234	251.0928	68.3241
3	3.3750	Road	201304	24.1200	0.9083	4216.9953	23.5421	1396.3560	1063.0227	177.3333	200.5333
3	4.5000	Abandoned	201304	24.1200	0.9083	4216.9953	23.5421	1396.3560	1063.0227	177.3333	200.5333
3	3.5333	Field	201304	24.1200	0.9083	4216.9953	23.5421	1396.3560	1063.0227	177.3333	200.5333
3	4.6000	Ditch	201304	24.1200	0.9083	4216.9953	23.5421	1396.3560	1063.0227	177.3333	200.5333
4	2.7667	Road	201304	20.3000	10.9045	1261.8032	94.5452	3515.5056	1036.8539	101.8427	393.7079
4	1.6667	Field	201304	20.3000	10.9045	1261.8032	94.5452	3515.5056	1036.8539	101.8427	393.7079
5	5.5333	Road	201304	18.3700	3.3232	3222.2890	60.5975	2937.5422	3378.4096	467.0843	196.8193
5	6.3000	Ditch	201304	18.3700	3.3232	3222.2890	60.5975	2937.5422	3378.4096	467.0843	196.8193
5	1.9667	Field	201304	18.3700	3.3232	3222.2890	60.5975	2937.5422	3378.4096	467.0843	196.8193
5	3.7143	Abandoned	201304	18.3700	3.3232	3222.2890	60.5975	2937.5422	3378.4096	467.0843	196.8193
6	5.4333	Ditch	201304	19.0200	3.1328	3012.4109	55.1254	2823.2352	3243.3532	451.3214	201.2414
6	2.1333	Field	201304	19.0200	3.1328	3012.4109	55.1254	2823.2352	3243.3532	451.3214	201.2414
6	4.3000	Road	201304	19.0200	3.1328	3012.4109	55.1254	2823.2352	3243.3532	451.3214	201.2414
1	7.8421	Road	201308	8.2900	2.5883	971.0961	47.8043	1196.3556	1441.3333	266.7911	73.7778
1	9.5238	Ditch	201308	8.2900	2.5883	971.0961	47.8043	1196.3556	1441.3333	266.7911	73.7778
1	3.9250	Field	201308	8.2900	2.5883	971.0961	47.8043	1196.3556	1441.3333	266.7911	73.7778
1	5.2400	Abandoned	201308	8.2900	2.5883	971.0961	47.8043	1196.3556	1441.3333	266.7911	73.7778
2	10.5833	Road	201308	22.3000	3.1384	1041.5124	51.3252	2341.1353	1391.1234	251.0928	68.3241
2	5.6333	Field	201308	22.3000	3.1384	1041.5124	51.3252	2341.1353	1391.1234	251.0928	68.3241
2	6.6250	Abandoned	201308	22.3000	3.1384	1041.5124	51.3252	2341.1353	1391.1234	251.0928	68.3241

3	5.1083	Road	201308	24.1200	0.9083	4216.9953	23.5421	1396.3560	1063.0227	177.3333	200.5333
3	5.3026	Abandoned	201308	24.1200	0.9083	4216.9953	23.5421	1396.3560	1063.0227	177.3333	200.5333
3	4.1167	Field	201308	24.1200	0.9083	4216.9953	23.5421	1396.3560	1063.0227	177.3333	200.5333
3	6.8750	Ditch	201308	24.1200	0.9083	4216.9953	23.5421	1396.3560	1063.0227	177.3333	200.5333
4	7.9333	Road	201308	20.3000	10.9045	1261.8032	94.5452	3515.5056	1036.8539	101.8427	393.7079
4	5.9655	Field	201308	20.3000	10.9045	1261.8032	94.5452	3515.5056	1036.8539	101.8427	393.7079
5	7.2400	Road	201308	18.3700	3.3232	3222.2890	60.5975	2937.5422	3378.4096	467.0843	196.8193
5	7.6364	Ditch	201308	18.3700	3.3232	3222.2890	60.5975	2937.5422	3378.4096	467.0843	196.8193
5	5.1207	Field	201308	18.3700	3.3232	3222.2890	60.5975	2937.5422	3378.4096	467.0843	196.8193
5	6.0333	Abandoned	201308	18.3700	3.3232	3222.2890	60.5975	2937.5422	3378.4096	467.0843	196.8193
6	15.9667	Ditch	201308	19.0200	3.1328	3012.4109	55.1254	2823.2352	3243.3532	451.3214	201.2414
6	5.2000	Field	201308	19.0200	3.1328	3012.4109	55.1254	2823.2352	3243.3532	451.3214	201.2414
6	7.1333	Road	201308	19.0200	3.1328	3012.4109	55.1254	2823.2352	3243.3532	451.3214	201.2414

* Used as dummy control variables in the regression

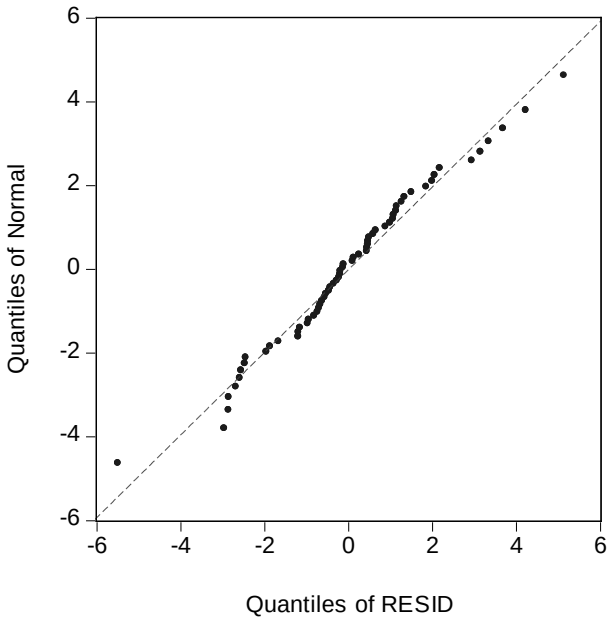


Figure S1 Plotted residuals of floral coverage regression with non-fertilizer agrochemicals and general factors

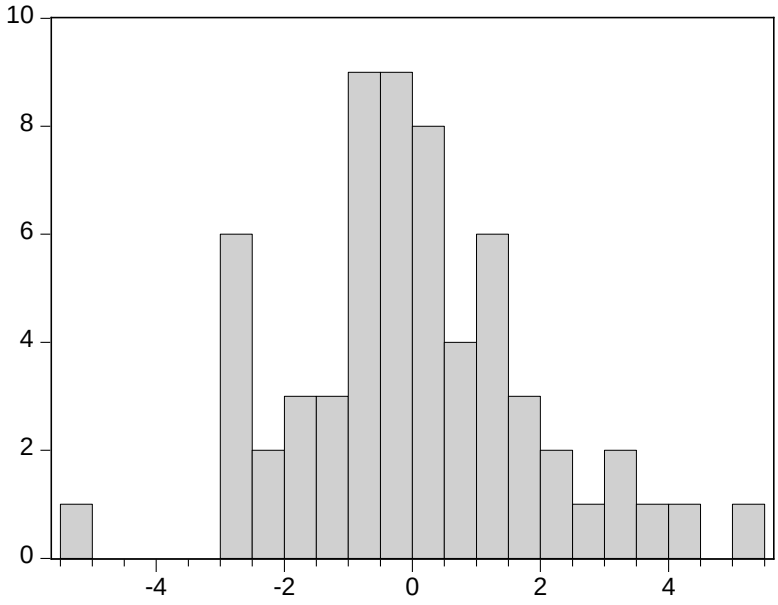


Figure S2 Residual histogram of floral coverage regression with non-fertilizer agrochemicals and general factors (Skewness =0.13; Kurtosis=3.59; JB=1.07, P=0.58, normal hypothesis not rejected)

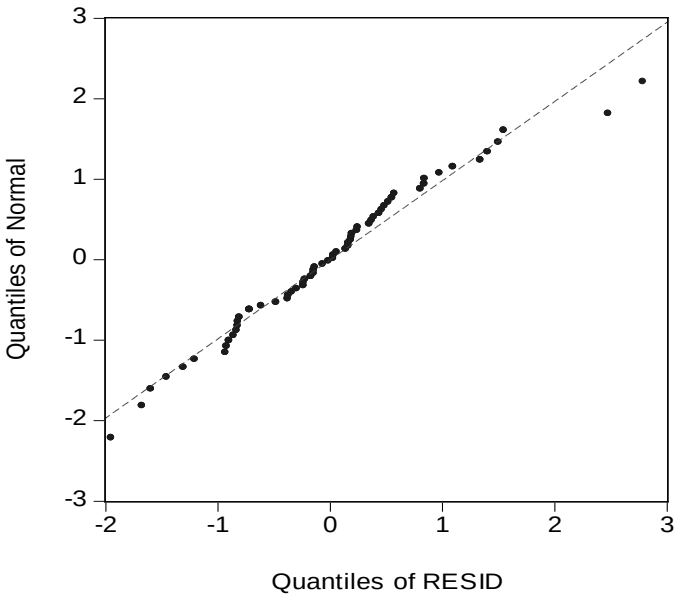


Figure S3
Plotted residuals (Q-Q plot) of floral coverage regression with fertilizers

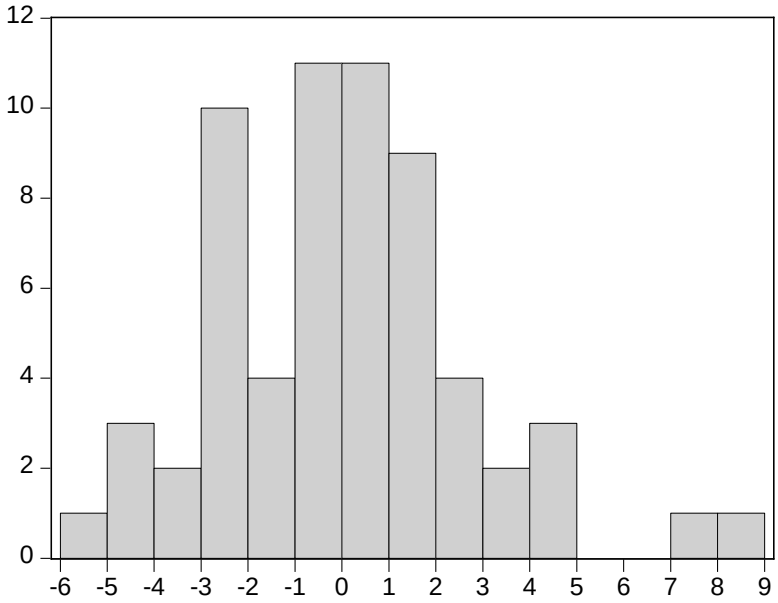


Figure S4
Residual histogram of floral coverage regression with fertilizers (Skewness =0.52; Kurtosis=3.82; JB=4.48, P=0.11, normal hypothesis of residuals not rejected

Table S5

Recorded mean faunal density (per m^3) of sample sites (villages in post-sample orders—grouped by cultivation style)

Order	Group	No.	01 L1	02 L1	03 L1	04 L1	05 L1	06 L1	01 L2	02 L2	03 L2	04 L2	05 L2	06 L2	01 L3	02 L3	03 L3	04 L3	05 L3	06 L3	01 L4	02 L4	03 L4	04 L4	05 L4	06 L4
Oribatida	Otocepheoid mites	1			743		424				2440	849			127		849	1528			446		212			
Oribatida	Anderemaeoid mites	2	141		743				141		4775	424			127		1167	3692	106		191		318	212		
Oribatida	Oppioid mites	3	849		318	106	743		1273		5730	106	2122		191		2865	1783	2971		382		212	212	106	
Psocomorpha	Hemipsocidae	4			19																					
Lepidoptera	Hepialidae	5																			22					
Diptera	Keroplatidae	6							11																	
Blattaria	Eupolyphaga	7																								
Coleoptera	Carabidae	8		154	37			406	12	49				311	22				212	141	33					225
Isopoda	Oniscidae	9	12																							
Hemiptera	Pentatomidae	10												12												
Coleoptera	Throscidae	11										106						382						106		
Homoptera	Fulgoridae	12					19																			
Oribatida	Macropyline oribatid mites	13					11																			
Oribatida	Galumnoid mites	14																127								
Collembola	Isotomidae	15	1839		2971	36500	4244		17118		7746	69179	5942		38516		7215	31704	9337		16234		6366	8594	10398	
Geophilomorpha	Geophilomorpha	16	74	12	37				25						33	83	37	22			11	37				
Collembola	Neelidae	17			106																					
Coleoptera	Polyphaga	18	12																							
Homoptera	Delphacidae	19											19													
Coleoptera	Geotrupidae	20		12			93	136						25	11						11	83			19	
Diptera	Scatopsidae	21	141						141																	
Acariformes	Raphignathoidea	22																							106	
Acariformes	Tarsonemidae	23	71			37	231		141		212		318		266				955		64				106	
Diplura	Parajapygidae	24																								
Araneida	Liocranidae	25	37		56		93		12		19				22		19	67	19		22		19	19	19	

Opisthopora	Opisthopora	26	185		15555	254	37		49		1111		37		22		19		37		100			37									
Parasitiformes	Pachylaelapidae	27																127															
Coleoptera	Cicindelidae	28																			64												
Hemiptera	Anthocoridae	29																															
Julida	Julidae	30		12				12		37						74							25										
Collembola	Onychiuridae	31	283		1910	6843	29197	10481	141		106	1379	12945	354				1655	2796	71	64		19		1061								
Haplotaxida	Acanthodrilidae	32					19																										
Parasitiformes	Parasitidae	33				106	106					106	212					255	106						106								
Diplura	Japygidae	34				212			141			106						255			329		318	531	424								
Oribatida	Ceratozetoid mites	35	1273		955	318					2122						1061	2801	106		64		212										
Diptera	Sciaridae	36			106		212																										
Diptera	Therevidae	37			11																												
Coleoptera	Scarabaeoidea	38	37	111	352		19	62		111	167			182	44	25	130			49	33	37	111				12						
Parasitiformes	Macrochelidae	39	71	1061	106		106	1839	71	2617		318	424	2405		2688		1401	424	1698		4315			212	849							
Isopoda	Armadillidiidae	40							62						22																		
Coleoptera	Elateridae	41								12					11		56		37			25	19		37								
Oribatida	Nothroid mites	42	1485	141	1061	2228	318	2617	71		2016	5623	424	424			531	4456	212	141	191	141	106	424		354								
Araneida	Zoridae	43						12			19																						
Oribatida	Liacaroid mites	44					318						106																				
Moniligastridae	Moniligastridae	45	74		19	19	56		25			162	74		22		19	22	56														
Lepidoptera	Lepidoptera	46																			22		19										
Isopoda	Tylidae	47													22																		
Oribatida	Eremaeidae	48			212	212	212					318	106		127						127			212								
Araneida	Agelenidae	49						160		37				99						74							49						
Oribatida	Lohmannioid mites	50	141			424	637		141		106	3820	955				106	1783	318					106									
Oribatida	Gymnodamaeoid mites	51	141																														
Acariformes	Caeculidae	52										106			64									106									

Diptera	Plecia	53			56																										
Diptera	Tabanidae	54	71					495	71	71	106						95							12							
Araneida	Linyphiidae	55																19													
Hymenoptera	Hymenoptera	56													11																
Parasitiformes	Ascidae	57	1379						2900		743		212		1910		1061		382	531		1019		212		318					
Siphonaptera	Scraptiidae	58			19																										
Collembola	Pseudanurophorus	59		354						920			71		1061								849				495				
Coleoptera	Coccinellidae	60									11						11														
Araneida	Gnapphosidae	61		71																											
Polydesmida	Paradoxosomatidae	62			106														127	106				106							
Coleoptera	Lucanidae	63						49					12																		
Coleoptera	Coleoptera	64				56							71																		
Collembola	Hypogastruridae	65					11																								
Psocomorpha	Sphaeropsocidae	66																				11									
Araneida	Theridiosomatidae	67	12																												
Coleoptera	LeiodidaeFleming	68	71																												
Dermaptera	Labiduridae	69																			71										
Acariformes	Trombidiidae	70	12																												
Diplopoda*	Helminthomorpha	71			37						74				22		130					11		37							
Oribatida	Oribatuloid mites	72				106																									
Oribatida	Eremuloid mites	73				106																									
Archaeognatha	Machilidae	74						12					12																		
Lithobiomorpha	Lithobiomorpha	75					19	71		71			141							19	71				37						
Diptera	Aslidae	76																	22												
Diptera	Diptera	77	148	12	74	74		62	49		37		74	11						93	12			37	143	37					
Diptera	Ephydridae	78			106		106																								

Coleoptera	Scydmaenidae	79			19	19						19																					
Oribatida	Zetorchestoidmites	80	283	14147				2759		7286			212	1698		3183				3042		212						2264					
Araneida	Salticidae	81			11																												
Hemiptera	Cydnidae	82						11																									
Acariformes	Microdispidae	83										106																					
Opisthopora	Microchaetidae	84					19		12							11																	
Parasitiformes	Uropodoidea	85																		106													
Diptera	Culicidae	86								12																			125				
Stylommatophora	Fruticicolidae	87								71							12																
Scolopendra	Scolopendra	88																															
Diptera	Empididae	89										19			11		37																
Orthoptera	Grylloidea	90							12																								
Aphelenchina	Aphelenchoides	91		141				1485		212				71		495				141		424						354					
Tubificida	Enchytraediae	92		212				2064		354				283		707				141		212						141					
Acariformes	Eupalosellidae	93										106																					
Coleoptera	LathridiidaeEricHson	94				19																											
Diptera	Bolitophilidae	95			19											12																	
Homoptera	Aphidinae	96			19		19								11	12																	
Coleoptera	Histeridae	97				19																12											
Symphyla	Scutigerellidae	98				106							106		64		106					424											
Coleoptera	Chrysomeloidea	99						37	25							12																	
Coleoptera	PselaphidaeLatreille	100						25						12						25					19		12						
Hymenoptera	Formicidae	101		12	37				12	12	19			25		25	19					12	19		19	71							
Coleoptera	Staphylinidae	102	157	12	546	74	355	647	320	37	236		125	95	546	320	19	22	19		44	83	19	106		12							
Thysanoptera	Thysanoptera	103					19																										
Araneida	Pholcidae	104			19																												
Diptera	Rhagionidae	105	71	71			106	71		212						71																	

Collembola	Sminthuridae	106						11																								
Coleoptera	Silphidae	107							25																							
Diptera	Phoridae	108	37	25	19				25	12						37		37					37		37			19				
Diptera	Mycetophilidae	109				531																										
Diptera	Hesperinidae	110							12																							
Collembola	Orchesellidae	111			424				2193		637	106		106		1203		4173			3692	424	1698		2829	19		19		849		
Acariformes	Stigmaeidae	112				212		318				212	212							212	127	106				106						
Diptera	Dolichopodidae	113				212				12		318	106				75							64		106	19					
Oribatida	Ptychoid oribatid mites	114																												495		
Acariformes	Acariformes	115							2405							2688							707							141		
Opisthopora	Lumbricidae	116	136	12	19	444		494		185	19	74	37	333		420		22	19	136	11	444		74	19	37						
Araneida	Araneida	117						19																	19							
Parasitiformes	Phytoseiidae	118					106					106			191			637				64										
Clitellata	Clitellata	119			1698	125	1061		71		212	1910	637				212	509	212					318		212						
Polyzoniida	Hirudisomatidae	120			19																											
Araneida	Trochanteriidae	121									19																					

*Diplopoda is a class;
Number refers to the order they were recorded/classified, also to specific taxa groups in the main text when numbers are used instead of names;
Data are mean species density per metric meters averaged over two sample quadrats for each type;

Table S6

Faunal summary statistics of villages and layers

Statistics	Village						
	Zhu-cun-pu	Dong-yang-si	Qian-gang	Dong-ying	Chang-zhai	Wan-zhai	Total
Taxa							
L1	29	19	37	24	29	27	82
L2	27	19	26	22	20	24	66
L3	28	19	22	26	25	17	63
L4	26	19	23	18	18	16	65
Total	54	30	51	45	46	33	
Density							
L1	9246	16999	29067	48512	39122	28656	171603
L2	23064	12943	28686	85243	25119	10638	185694
L3	42514	13507	15885	57601	19326	8256	157088
L4	19634	10216	8928	10976	13342	6361	69455
Total	94458	53664	82565	20233	96908	53910	
Margalef's Richness							
L1	3.066	1.848	3.503	2.132	2.648	2.533	11.032
L2	2.588	1.901	2.436	1.850	1.875	2.481	8.759
L3	2.533	1.893	2.171	2.281	2.432	1.774	8.547
L4	2.529	1.950	2.418	1.827	1.790	1.713	8.388
Total	7.857	4.693	7.563	5.861	6.646	5.174	
SHDI							
L1	2.501	0.800	1.914	0.965	1.133	2.183	2.347
L2	1.052	1.494	2.147	0.863	1.584	2.200	2.018
L3	0.503	1.884	1.847	1.813	1.815	1.822	2.011
L4	0.883	1.74	1.367	1.044	1.002	2.065	1.892
Total	1.257	1.714	2.318	1.315	1.646	2.387	
Simpson’s Dominance							
L1	0.120	0.698	0.310	0.588	0.571	0.178	0.834
L2	0.570	0.367	0.161	0.666	0.332	0.159	0.692
L3	0.823	0.203	0.258	0.324	0.283	0.230	0.680
L4	0.688	0.269	0.515	0.619	0.616	0.183	0.628
Total	0.568	0.282	0.157	0.529	0.326	0.123	
Evar							
L1	0.030	0.037	0.029	0.027	0.028	0.025	0.025
L2	0.037	0.031	0.024	0.021	0.023	0.030	0.023
L3	0.042	0.029	0.028	0.019	0.027	0.029	0.022
L4	0.037	0.031	0.036	0.033	0.033	0.029	0.024
Total	0.031	0.025	0.025	0.021	0.024	0.021	
Dominance species							
L1	31	80	26	15	31	31	31
L2	15	80	15	15	31	115	15
L3	15	111	15	15	15	80	15
L4	15	39	15	15	15	80	15
Total	15	80	15	15	31	31	

Taxa refers to number of different species groups classified;
Density refers to number of individuals per cubic metre

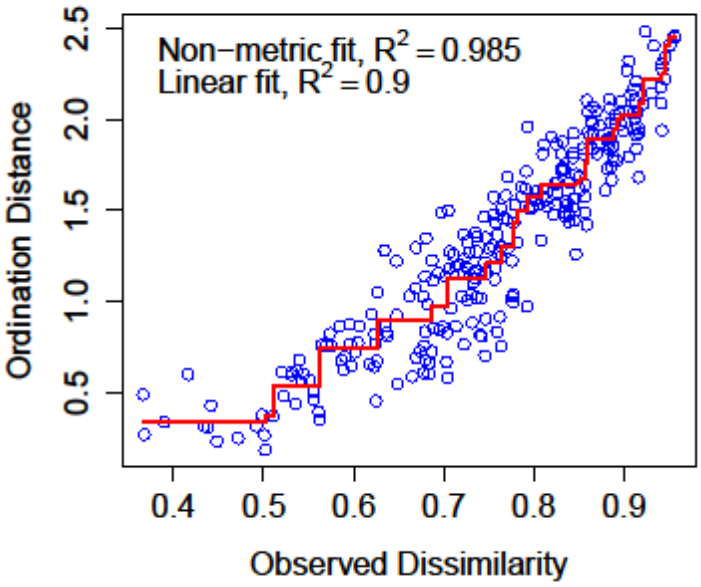


Figure S5 Sheppard plot (stress plot) of fauna NMDS results (Bray-Curtis distance; Reduced dimensions=3, stress=0.1210, iterations=200)

Table S7

Regression variables for fauna data (villages in post-sample orders—grouped by cultivation style)

Village	Density (per m^3)	Number of units	Layer *	Pesticide (L/ha)	Herbicide (L/ha)	Manual labor (man×hour/ha)	Machinery (hour/ha)	Compound fertilizer (Kg/ha)	Nitrogen fertilizer (Kg/ha)	Phosphor fertilizer (Kg/ha)	Potassium fertilizer (Kg/ha)
1	9246.35	29	1	8.2900	2.5883	971.0961	47.8043	1196.3556	1441.3333	266.7911	73.7778
2	16998.9	19	1	22.3000	3.1384	1041.5124	51.3252	2341.1353	1391.1234	251.0928	68.3241
3	29067.1	37	1	24.1200	0.9083	4216.9953	23.5421	1396.3560	1063.0227	177.3333	200.5333
4	48512.3	24	1	20.3000	10.9045	1261.8032	94.5452	3515.5056	1036.8539	101.8427	393.7079
5	39121.6	29	1	18.3700	3.3232	3222.2890	60.5975	2937.5422	3378.4096	467.0843	196.8193
6	28656.3	27	1	19.0200	3.1328	3012.4109	55.1254	2823.2352	3243.3532	451.3214	201.2414
1	23064.1	27	2	8.2900	2.5883	971.0961	47.8043	1196.3556	1441.3333	266.7911	73.7778
2	12943.3	19	2	22.3000	3.1384	1041.5124	51.3252	2341.1353	1391.1234	251.0928	68.3241
3	28686	26	2	24.1200	0.9083	4216.9953	23.5421	1396.3560	1063.0227	177.3333	200.5333
4	85243	22	2	20.3000	10.9045	1261.8032	94.5452	3515.5056	1036.8539	101.8427	393.7079
5	25119.5	20	2	18.3700	3.3232	3222.2890	60.5975	2937.5422	3378.4096	467.0843	196.8193
6	10638	24	2	19.0200	3.1328	3012.4109	55.1254	2823.2352	3243.3532	451.3214	201.2414
1	42513.9	28	3	8.2900	2.5883	971.0961	47.8043	1196.3556	1441.3333	266.7911	73.7778
2	13506.8	19	3	22.3000	3.1384	1041.5124	51.3252	2341.1353	1391.1234	251.0928	68.3241
3	15885	22	3	24.1200	0.9083	4216.9953	23.5421	1396.3560	1063.0227	177.3333	200.5333
4	57600.9	26	3	20.3000	10.9045	1261.8032	94.5452	3515.5056	1036.8539	101.8427	393.7079
5	19325.8	25	3	18.3700	3.3232	3222.2890	60.5975	2937.5422	3378.4096	467.0843	196.8193
6	8255.71	17	3	19.0200	3.1328	3012.4109	55.1254	2823.2352	3243.3532	451.3214	201.2414
1	19634	26	4	8.2900	2.5883	971.0961	47.8043	1196.3556	1441.3333	266.7911	73.7778
2	10216	19	4	22.3000	3.1384	1041.5124	51.3252	2341.1353	1391.1234	251.0928	68.3241
3	8927.7	23	4	24.1200	0.9083	4216.9953	23.5421	1396.3560	1063.0227	177.3333	200.5333
4	10975.7	18	4	20.3000	10.9045	1261.8032	94.5452	3515.5056	1036.8539	101.8427	393.7079
5	13342	18	4	18.3700	3.3232	3222.2890	60.5975	2937.5422	3378.4096	467.0843	196.8193
6	6360.53	16	4	19.0200	3.1328	3012.4109	55.1254	2823.2352	3243.3532	451.3214	201.2414

* Used as dummy control variable in the regression

Table S8 Initial regression results containing twenty four observations (four layers)

	Root number of unit (model one)	Root number of unit (model two)	Standardized coefficient
Pesticide (L/ha)	0.41**	0.29**	2.98**
	(0.14)	(0.09)	(0.91)
Herbicide (L/ha)	3.59**	2.74**	17.74**
	(1.06)	(0.76)	(4.91)
Pesticide^herbicide	-0.18**	-0.13**	-4.48**
	(0.05)	(0.04)	(1.23)
Manual labor (man×hour/ha)	-0.00012	—	—
	(0.00011)		
Depth 1	0.76**	0.55**	1.09**
	(0.19)	(0.16)	(0.32)
Depth 2	0.33	—	—
	(0.19)		
Depth 3	0.30	—	—
	(0.19)		
Constant	-3.87	-1.58	—
	(2.63)	(0.1.90)	
R^2	0.7042	0.6130	0.6130
F	5.44**	7.52**	7.52**
AIC	0.87	0.89	
SC	1.27	1.14	
JB	1.06(p=0.59)	1.16(p=0.56)	

* Significant at 5% level ** Significant at 1% level

^ Interaction between two variables; for standardized coefficient, interaction calculated after standardization;

Numbers in brackets are standard deviations; changes from model one to two reflect part of the variable selection process

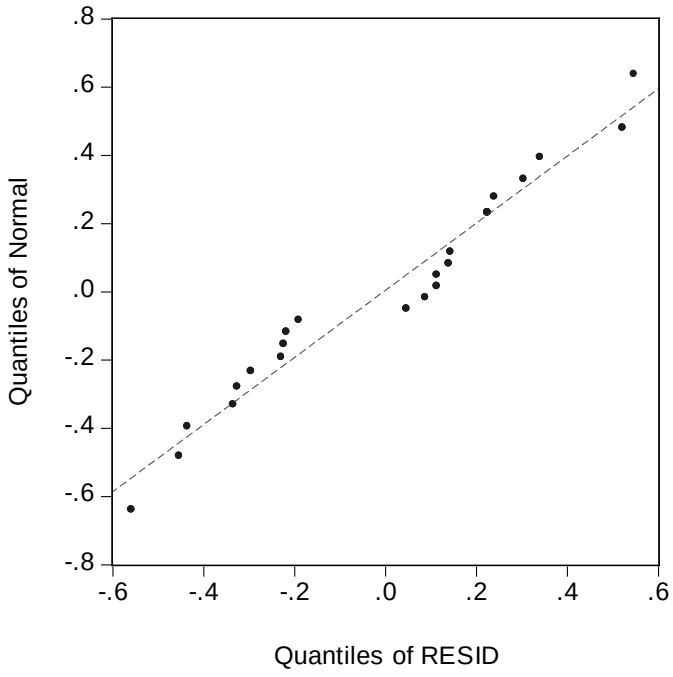


Figure S6 Plotted residuals (Q-Q plot) of fauna root number-of-unit regression with

non-fertilizer agrochemicals and general factors using twenty four observations

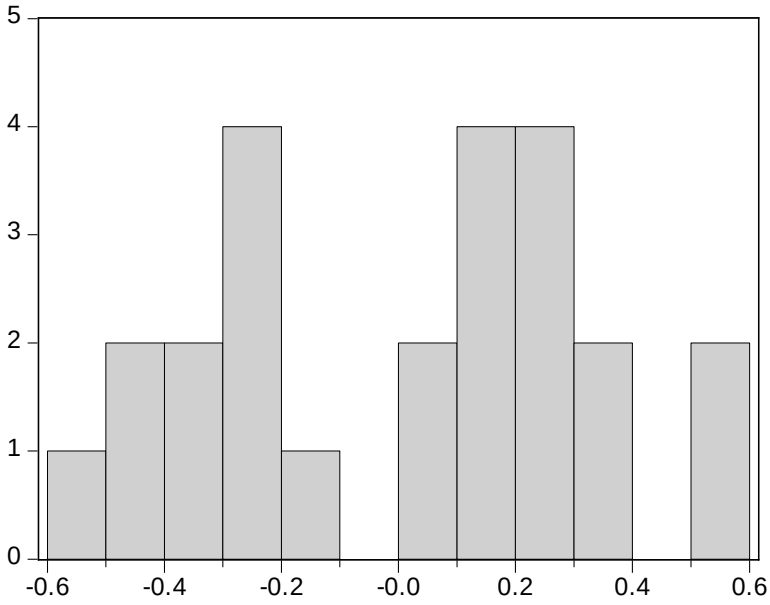


Figure S7 Residual histogram of fauna root number-of-unit regression with non-fertilizer agrochemicals and general factors with twenty four observations (Skewness =-0.08; Kurtosis=1.94; JB=1.16, P=0.56, normal hypothesis not rejected)

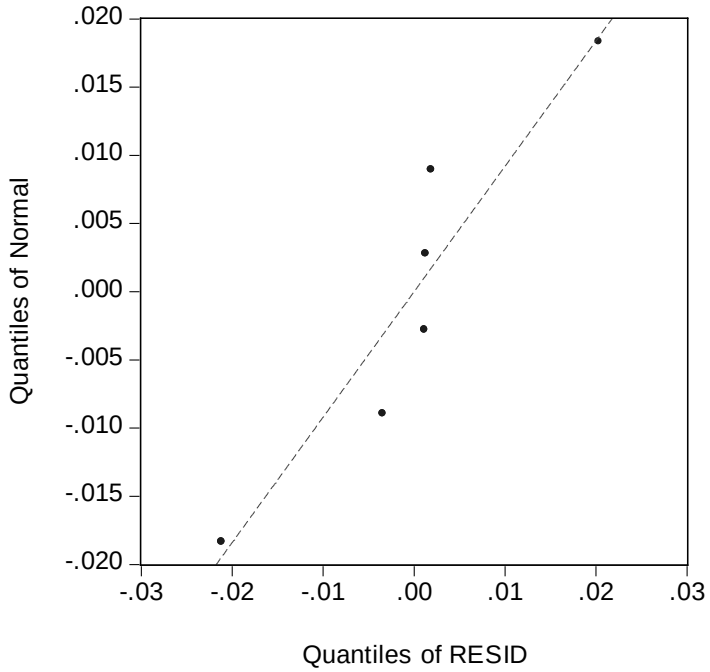


Figure S8 Plotted residuals (Q-Q plot) of fauna root number-of-unit regression with non-fertilizer agrochemicals and general factors using six observations

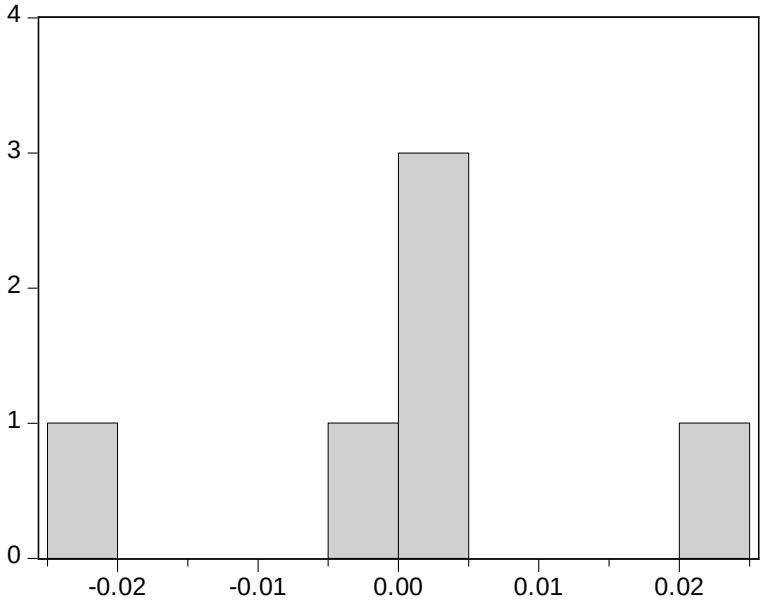


Figure S9 Residual histogram of fauna root number-of-unit regression with non-fertilizer agrochemicals and general factors with six observations (Skewness =-0.11; Kurtosis=2.88; JB=0.02, P=0.99, normal hypothesis not rejected)

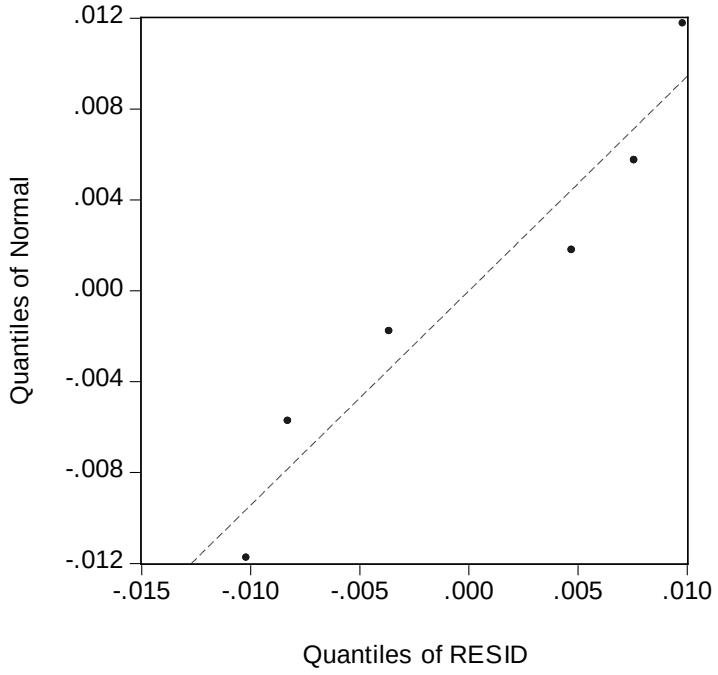


Figure S10 Plotted residuals (Q-Q plot) of fauna root number-of-unit regression with fertilizers using six observations

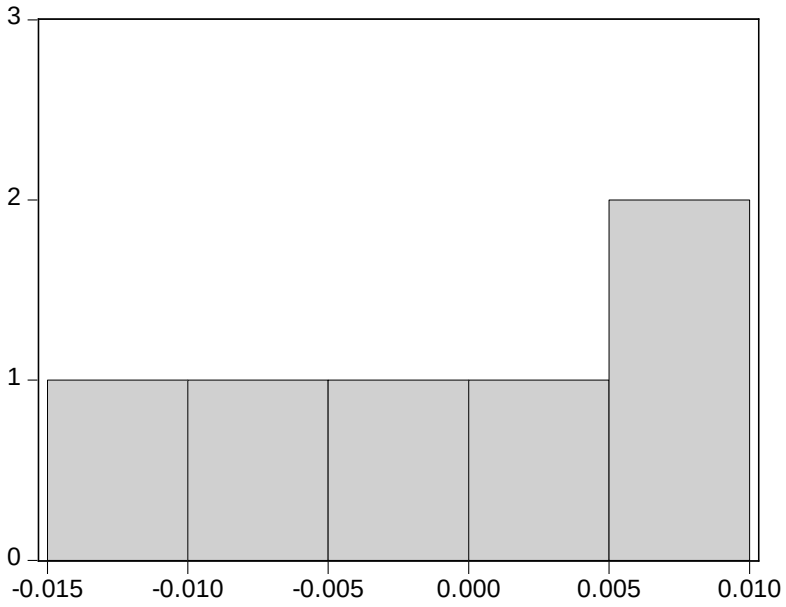


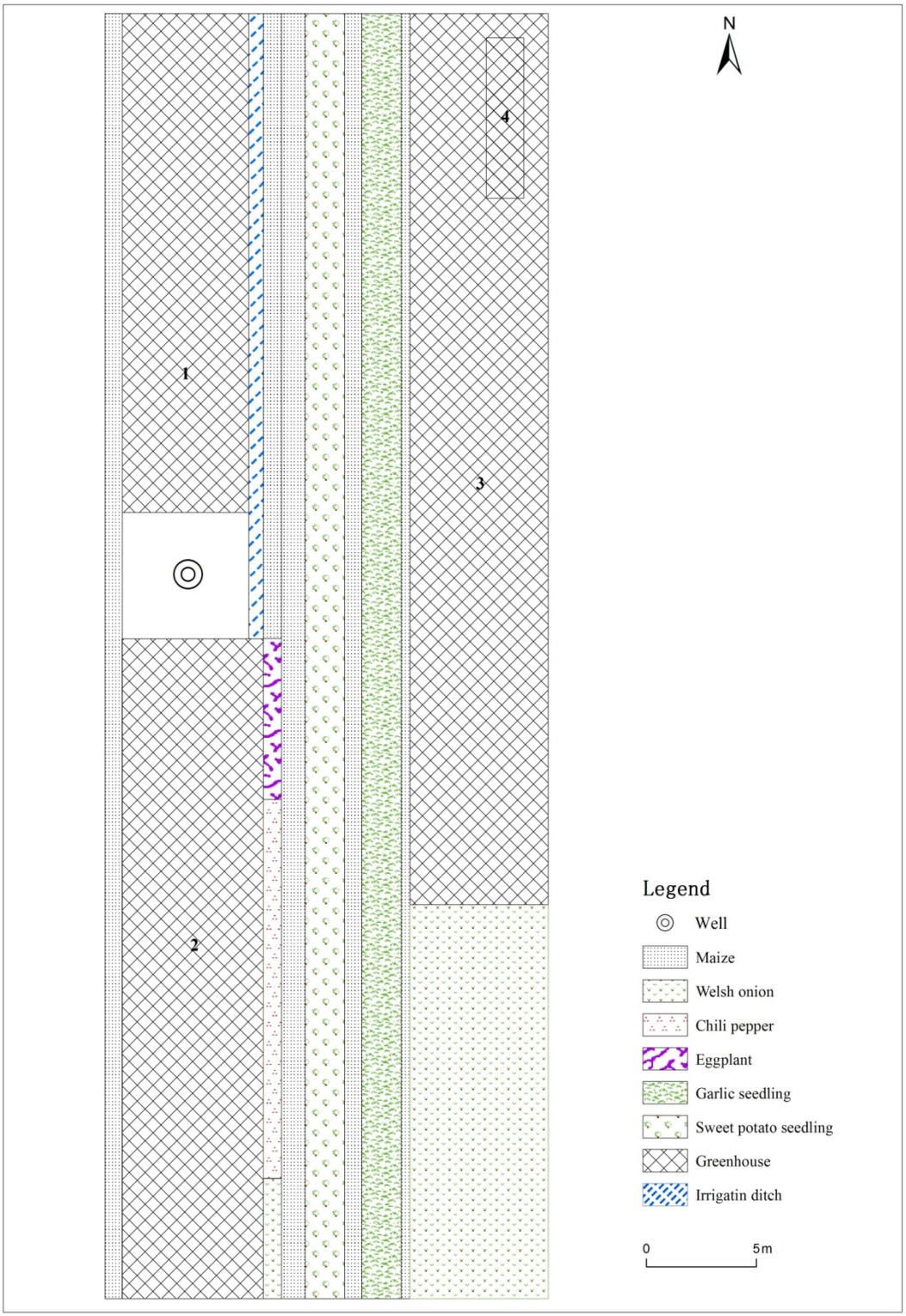
Figure S11 Residual histogram of fauna root number-of-unit regression with fertilizers with six observations (Skewness =-0.07; Kurtosis=1.32; JB=0.71, P=0.70, normal hypothesis not rejected)

Supporting document one
Heavy metal element extraction method; part of the original document of Chinese government standard GB/T 17141-1997)

Materials: (the Guaranteed Reagent level is equivalent to IUPAC level E)
Hydrochloric acid (HCL): ρ = 1.19g/mL, guaranteed reagent;
Nitric acid (HNO_3): ρ = 1.42g/mL, guaranteed reagent;
HNO_3 1:1 solution: equal volume ratio solution of HNO_3 and deionized water
Hydrofluoric acid (HF): ρ = 1.49g/mL, guaranteed reagent;
Lanthanum nitrate [$La(NO_3)\cdot 6H_2O$] solution: mass fraction 5%;

Element extraction: weigh 0.2-0.5g (accurate to 0.0002g) soil samples and place in PTFE crucibles; wet with deionized water, then add 10mL HCL; heat at low temperature (approximately 100°C) on electric heating board under fume hood to break down samples preliminarily until about 3mL remain. Cool down samples, and then add 5mL HNO_3, 5mL HF, 3mL $HCLO_4$, close lid and heat at moderate temperature (180-200°C) for an hour. Open lid and continue heating to remove silicon—for better results stir occasionally. When white smoke starts to come out, close lid and continue heating until black organic carbon residues disappear on the side of crucibles; then open lid and heat until sample fluid show viscosity (depending on sample condition, repeat measure can be taken by adding 3mL HNO_3, 3mL HF, and 1mL $HCLO_4$). Remove crucibles and cool down; wash lid and inside walls with deionized water; and add 1mL 1:1 HNO_3 solution to dissolve sample fluid. Then transfer sample fluid into 50mL volumetric flasks; add 5mL standard lanthanum nitrate solution to each flask, and add deionized water to correct volume at room temp (20°C), invert to thoroughly mix solution.

Supporting document two
Figure representing a typical diverse cultivated field)



1 Greenhouse, Indian lettuce (*Lactuca indica*) and chili pepper (*Capsicum chinense*) double-cropping
2 Greenhouse, sweet potato (*Ipomoea batatas*) seedling and garlic (*Allium sativum*) seasonal rotation
3 Greenhouse, garlic seedling, Chinese leaf (*Brassica chinensis*), cauliflower (*Brassica oleracea*)

Supporting document three

Social survey questionnaire

Number: City____ County____ Village____ Household leader: Household type: Rich/Moderate/Poor Time: 2011/ / Interviewer:

1. Basic information

	Sex	Age	Education level	Main source of income
Interviewee				
Spouse				
Father				
Mother				
Children				
Others (specify):				
Note		Calendar Year	1.Uneducated 2.Elementary 3.Middle school 4.High School 5.Higher	1.Food crop 2.Cash crop 3.Livestock 4.Migrant work 5.Other(specify) 6.No income

2. Economic status

Main income	Food crop (CNY)	Cash crop (CNY)	Livestock (CNY)	Subsidies (CNY)	Migrant work (CNY)	House type (Rammed earth/Brick/Brick-concrete/Concrete)	Other (specify)
2010							

3. Land use

Total plot number: Farmland per capita (*mu*): increased/decreased farmland area in 2010: (*mu*)

	Plot	1	2	3	4	5	6	Note
Basic info	Size (*mu*)							
	Cultivation type							Representative plots
	Tillage							If no-till, specify time

	Cultivation duration							Year
	Distance to road (m)							Above county level
	Distance to residence(m)							

	Plot	1	2	3	4	5	6	Note
Agricultural input in 2010	Seed							Type, amount, time
	Irrigation							Type (River/underground); amount, time
	Direct manual labour:1Tillage 2Seeding 3Fertilizing 4Irrigation 5Weed removal 6Pest removal 7 Harvest							Man-hour; time
	Indirect manual labour							Man-hour; time
	No-till percentage							
	Manure							Type (human/cattle/swine/avian); amount; time
	Machinery							Type (tillage/seed/irrigation/harvest); amount(hours); time
	Electricity							Amount; cost (CNY, and time)
	Animal power							Type (cattle/horse); amount (hours); time

	Fertilizer							Type; amount (kg); time
	Pesticide							Type; amount (L); time
	Herbicide							Type; amount (L); time

	Plot	1	2	3	4	5	6	Note
Production data	2009 yield							Main crops
	2010 yield							Main crops
	2011 yield							Main crops
	2010 tillage							Main crops

4. Household awareness

① Is education important for cultivation? 1 Not 2Does not matter 3 Some 4 Very

② Are you satisfied with current living status? 1 Strongly disagree 2Disagree 3 Does not matter 4 Agree 5 Strongly agree; any improvements needed:

③ Are you willing to change current cultivation status: 1 No 2 Yes Specify:

④ Are you satisfied with the environment (air, water, living): 1 Strongly disagree 2 Disagree 3 Does not matter 4 Agree 5 Strongly agree; any improvements needed:

⑤ Do weed species affect cultivation: 1 Yes, negatively 2 No 3 Yes, positively Should they be protected: Yes/No

⑥ Are fauna (e.g. earth worms, bees) important for cultivation: 1 Strongly disagree 2 Disagree 3 Does not matter 4 Agree 5 Strongly agree; Should they be protected: Yes/No

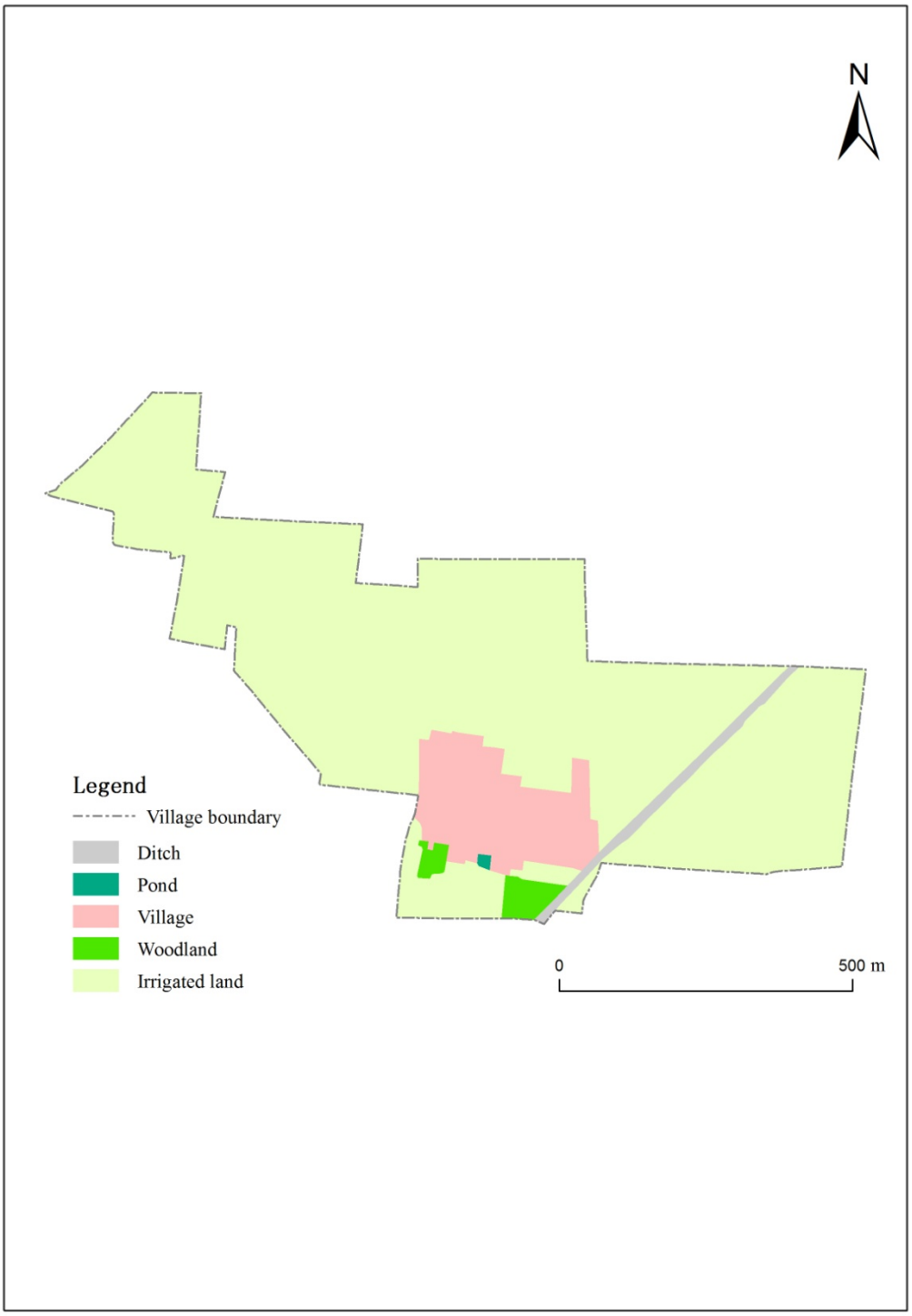
⑦ Are there any environmental promotions/advertisements: Yes/No If yes, how often does it happen: 1 More than one year 2 Yearly 3 Half a year 4 Quarterly 5 Monthly; what contents:

⑧ Compared to raising yield, is environmental-friendly agriculture important: 1 Strongly disagree 2 Disagree 3 Does not matter 4 Agree 5 Strongly agree

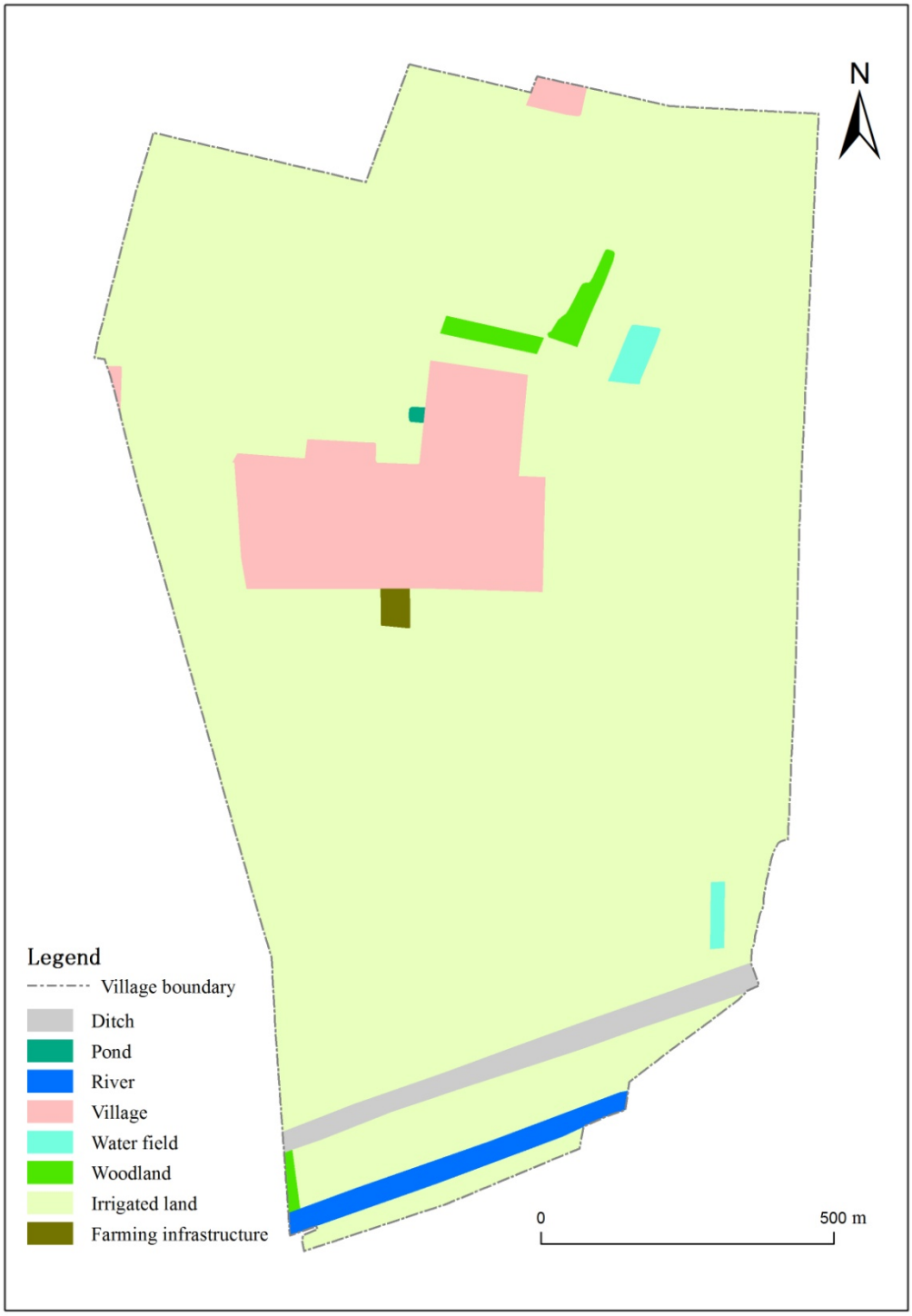
⑨ With agricultural income set at the score of 10, how important is sustainability: environment: future production:

⑩ If land circulation is in place, what would you do: 1 Maintain current status 2 Cultivate less 3 Cultivate more If 2 or 3, how much land (*mu*): Crop type and reason:

Supporting document four
Land use map of the sampled villages



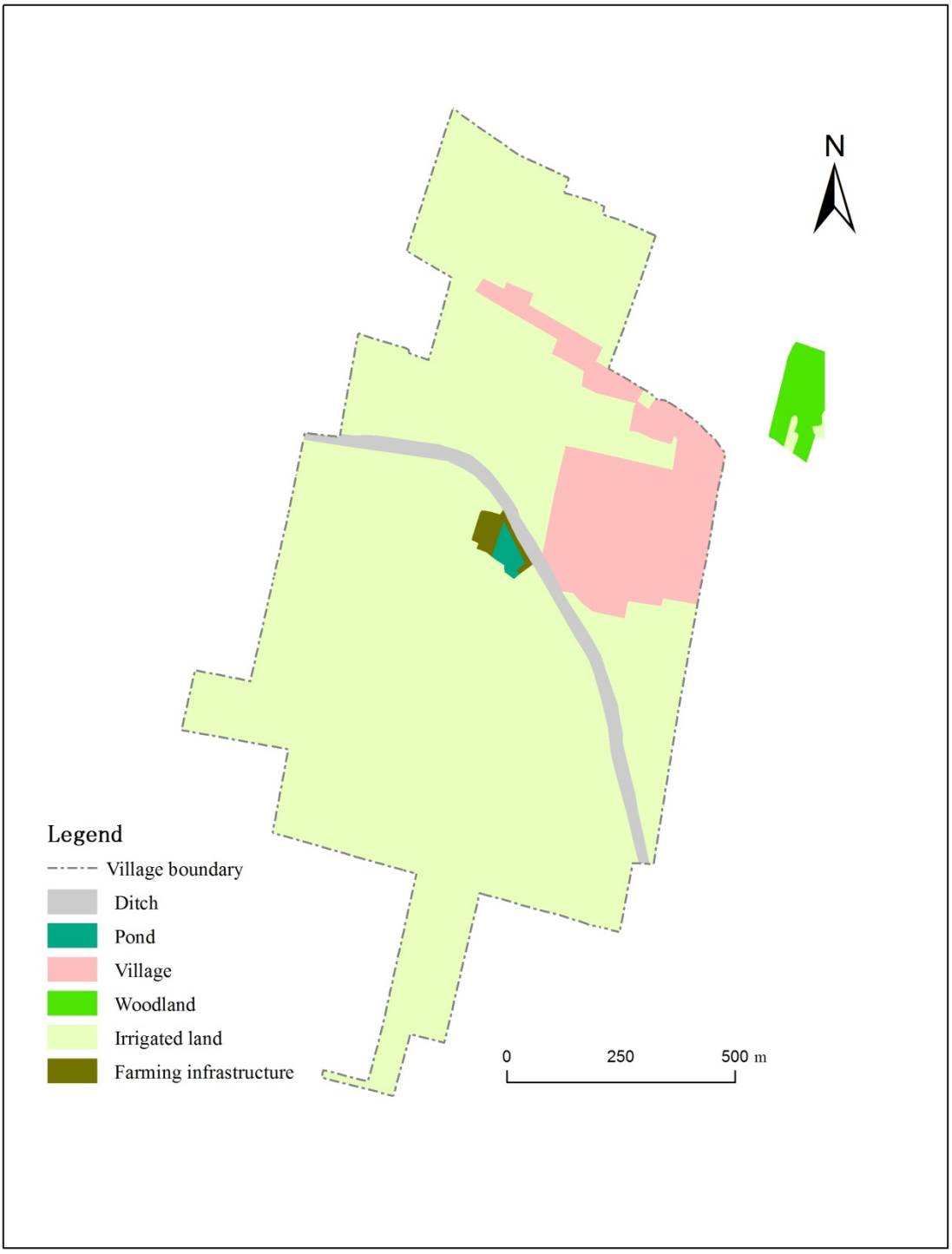
Map 1 Zhu-cun-pu village
Village refers to residential areas
Woodland was observed to be abandoned field
Irrigated land refers to general cultivated farmland



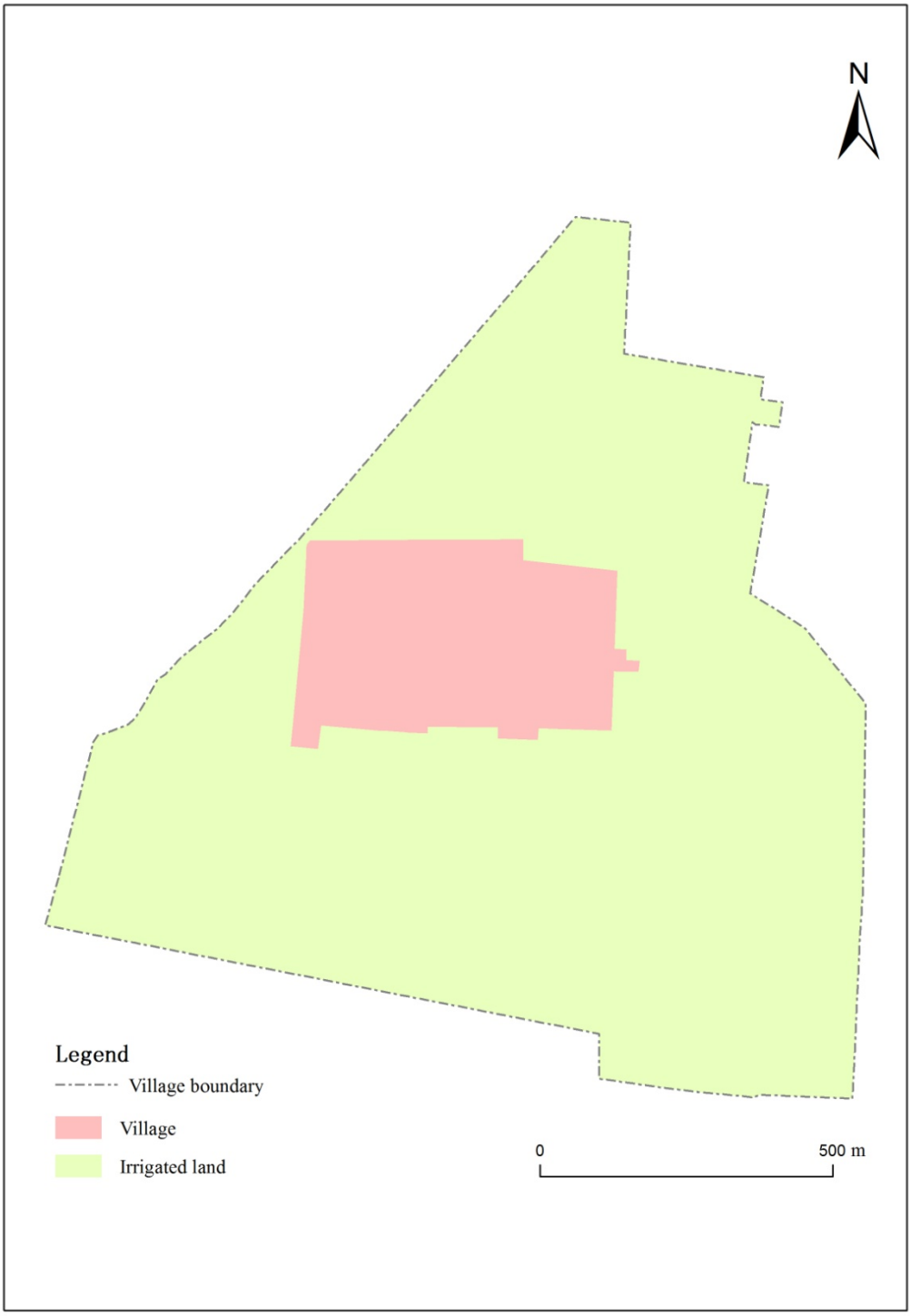
Map 2 Dong-yang-si village
Village refers to residential areas
Water fields were absent during visits
Irrigated land refers to general cultivated farmland
Farming infrastructure refers to wells, power relays, etc.



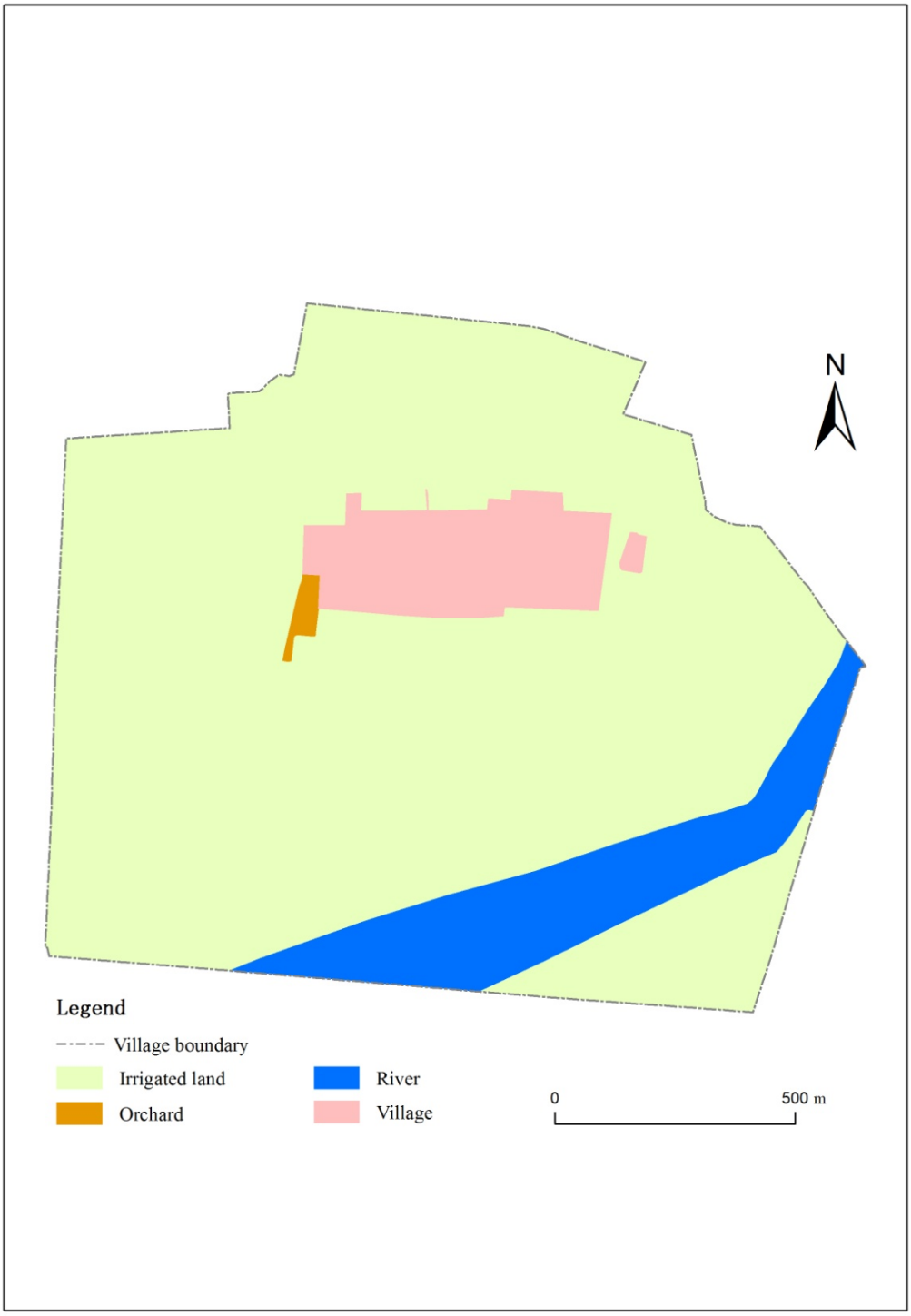
Map 3 Qian-gang village
Village refers to residential areas
Woodland was absent during visits
Irrigated land refers to general cultivated farmland
Farming infrastructure refers to wells, power relays, etc.
Transport infrastructure in this case is a county level road



Map 4 Dong-ying village
Village refers to residential areas
Irrigated land refers to general cultivated farmland
Farming infrastructure refers to wells, power relays, etc.



Map 5 Chang-zhai village
Village refers to residential areas
Irrigated land refers to general cultivated farmland



Map 6 Wan-zhai village
Village refers to residential areas
Irrigated land refers to general cultivated farmland
Orchard was absent during visits