Crop management options to reduce nitrogen pollution in Liangzihu lake basin, Central China

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ABSTRACT

In Central China, high mineral nitrogen (N) application rates lead to low N recovery and high N losses. Large amounts of the nitrate-N are leached from agricultural soil and end up in aquatic ecosystems, negatively affecting both ecosystem and human health. Such effects are particularly pronounced in the Liangzihu Lake basin, Central China, where the application of mineral N to the predominating maize-wheat rotation systems on coarse-textured soils can exceed 300 kg ha^{-1}. We hypothesize that improved crop management can reduce the current nitrate-N pollution while enhancing system performance. The present study initially identified the main drivers of excessive N use by household surveys. Subsequent field experiments between 2012 and 2013 evaluated the effects of modified fertilizer N management and the use of N-catching cover crops on soil-N dynamics, N-use efficiency, yield of maize and wheat, and nitrate-N leaching. Finally, the field trial data were used to parameterize the EPIC model to estimate N leaching losses under current and alternative crop and N management.

Current N application rates average 229 kg N ha^{-1} $season^{-1}$, which is higher than the cereal crop requirements of 150-180 kg N ha^{-1}. The main reasons for the excessive use of mineral N are related to low farmland productivity ($r = -0.184$, $p = 0.003$), small farm size ($r = -0.168$, $p = 0.006$), a high share of off-farm income (coefficient = 25.94, $p = 0.003$), and a low education level of the household head (coefficient = -11.20, $p = 0.034$).

The field experiment could show that cultivating a cover crop combined with a reduced application rate (290 kg N ha^{-1} in 3 splits) and multiple splitting of mineral N fertilizer can achieve similar yields (6.4-6.9 Mg ha^{-1}) to those obtained with current management (470 kg N ha^{-1} in 2 splits). In addition, this alternative crop and fertilizer management increased the agronomic N-use efficiency by 7 kg grain kg^{-1} N applied to both wheat and maize, and enhanced the N fertilizer recovery by 15% in wheat and 20% in maize. In addition, nitrate-N leaching was reduced by 15 kg N ha^{-1} in both the first-year maize and wheat crops.

Once calibrated with the data from the field experiment, the EPIC model was able to predict crop biomass and the soil water content under moderate (long-term mean) climate conditions with a determination coefficient higher than 0.5 and a model bias of less than 3%. However, the model underestimated the soil water content in dry years with a bias of >36%. Moreover, it tended to slightly overestimate nitrate-N leaching with 13-181 kg N ha^{-1} for the entire experimental period and in both 1 m and 1.8 m soil depths.

It is concluded that (1) the current N application rate in the study area are excessive because of insufficient awareness and the easy and low-cost availability of mineral-N fertilizers, (2) the currently high N losses from crop fields can be substantially reduced by reducing application rates and by replacing bare fallow periods with legume cover crops without negative trade-offs on crop yields, and (3) the calibrated EPIC model can be used to predict the aboveground crop biomass and the soil water content, but it tends to overestimate nitrate-N leaching. Consequently, there is a need to inform farmers about the negative effects of excessive N use, popularize alternative agronomic management options, and adapt the existing EPIC model to improve the prediction of nitrate pollution in Central China.

KURZFASSUNG

In Zentralchina führen die großen Mengen an ausgebrachtem mineralischem Stickstoff (N) zu niedriger N-Rückgewinnung und hohem N-Verlust. Ein Großteil des aus den landwirtschaftlichen Flächen ausgewaschenen Nitrat-Stickstoffes endet in aquatischen Systemen und wirkt sich sowohl auf Ökosysteme als auch auf die menschliche Gesundheit negativ aus. Solche Effekte können besonders im Liangzihu Becken in Zentralchina beobachtet werden, wo die Verwendung von mineralischem Dünger im dort vorherrschenden Mais-Weizen-Rotationssystem auf grobkörnigen Böden über 300 kg ha^{-1} betragen kann. Wir haben die Hypothese, dass ein verbessertes Getreidemanagement die derzeitige Nitrat-Stickstoffbelastung verringern und gleichzeitig die Systemleistung verbessern kann. Diese Studie hat zunächst die hauptsächlichen Faktoren der exzessiven N-Verwendung durch Haushaltsbefragungen identifiziert. In nachfolgenden Feldexperimenten zwischen 2012 und 2013 wurden die Effekte der veränderten N-Düngeranwendung und die Verwendung von stickstoffbindenden Bodendeckern auf die Boden-N-Dynamik, auf die N-Nutzungsseffizienz, auf den Ertrag von Mais und Weizen und auf die Nitat-N-Auswaschung untersucht. Abschließend wurden diese Feldexperimentdaten genutzt, um das EPIC-Modell zu parametrisieren und damit den N-Verlust durch Auswaschung unter den derzeitigen sowie alternativen Anbau- und N-Management abschätzen zu können.

Gegenwärtige N-Ausbringungsmengen haben einen Durchschnittswert von 229 kg N ha^{-1} $Saison^{-1}$, das über dem Bedarf von 150-180 kg N ha für Getreide liegt. Der Hauptgrund für die exzessive Nutzung von mineralischem Dünger hängt mit der niedrigen Produktivität des Ackerlandes ($r = -0.184$, $p = 0.003$), den kleinen landwirtschaftlichen Betrieben ($r = -0.168$, $p = 0.006$), dem hohen Anteil an außerbetrieblichen Einkommen (Koeffizient = 25.94, $p = 0.003$) und einem niedrigen Bildungsstand des Haushaltsvorstandes (Koeffizient = -11.20, $p = 0.034$) zusammen.

Das Feldexperiment konnte aufzeigen, dass der Anbau von Bodenbedeckungsfrucht kombiniert mit verringerter N-Verwendung (290 kg N ha^{-1} in 3 Anwendungen) und mehrfache Aufteilung von mineralischem N-Dünger ähnliche Erträge erzielen kann (6.4-6.9 Mg ha^{-1}) wie im derzeitigen Management (470 kg N ha^{-1} in 2 Anwendungen). Zusätzlich erhöhte dieses alternative Feld- und Düngemittelmanagement die agrarökonomische N-Nutzungseffizienz von 7 kg Getreide pro kg verwendetem N bei Weizen sowie Mais, und verbesserte die N-Düngerrückgewinnung um 15% bei Weizen und 20% bei Mais. Zudem wurde die Nitrat-N-Auswaschung um 15 kg N ha^{-1} bei beiden, Erstjahresmais und Weizen, verringert.

Sobald das EPIC-Modell mit den Daten der Feldexperimente kalibriert war, konnte man die Feldbiomasse und den Bodenwassergehalt unter moderaten (langfristiges Mittel) Klimabedingungen mit einem Bestimmtheitsgrad größer als 0.5 und einem Modellfehler von weniger als 3% vorhersagen. Jedoch unterschätzte das Modell den Bodenwassergehalt in der Trockenzeit mit einem Fehler > 36%. Außerdem tendierte es zur leichten Überschätzung der Nitrat-N- Auswaschung über den gesamten Experimentzeitraum in beiden Bodentiefen, 1m und 1.8 m, mit 13-181 kg N $ha^{-1.}$

Schlussfolgerungen sind, dass (1) die derzeitige N-Anwendungsrate in der Studienregion aufgrund eines unzureichenden Bewusstseins und der kostengünstigen und einfachen Verfügbarkeit von mineralischem Dünger so exzessiv ist, (2) die gegenwärtigen hohen N-Verluste auf Ackerflächen wesentlich durch verringerte Ausbringungsmengen sowie die Bepflanzung von unbedeckten Brachflächen mit Hülsenfrüchten als Bodenbedeckung ohne negative Kompromisse von Erträgen reduziert werden können, und (3) das kalibrierte EPIC-Modell genutzt werden kann, um die oberflächliche Biomasse und den Bodenwassergehalt vorauszusagen, auch wenn das Modell zur Überschätzung der Nitrat-N-Auswaschung tendiert. Daraus resultiert die Notwendigkeit, Bauern über die negativen Auswirkungen von exzessiver N-Verwendung zu informieren, alternative agroökonomische Managementoptionen bekannt zu machen und das existierende EPIC-Modell anzupassen, um die Voraussagen über die N-Belastung in Zentralchina zu verbessern.

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1. GENERAL INTRODUCTION

1.1 Background

Agriculture has existed for thousands of years and provides food to meet the increasing human demand. To increase yields, synthetic fertilizers have been widely applied as an external nutrient source for the past 60 years (Goulding, 2004). While these fertilizers have largely contributed to the 1.5-fold increase in global grain yield between 1970 and 2010 (Addiscott et al., 1992), they have also negatively impacted the natural nutrient cycle and caused severe problems worldwide (Galloway et al., 2008). The off-site consequences such as surface water eutrophication (Hall et al., 2001), groundwater pollution (Delgado and Shaffer, 2002), and greenhouse gas emissions (Behera and Panda, 2009), have raised concerns about the environmental impacts caused by the current fertilizer application practices. Pollution and depletion of water resources through agriculture-related activities are severely jeopardizing economic development and threatening human health (Schilling and Wolter, 2001). To address the conflicts between yield increase and nitrogen (N) pollution, sustainable agricultural intensification, which increases yields while reducing nutrient losses, is urgently needed (Garnett and Godfary, 2012; Garnett et al., 2013).

1.1.1 Nitrogen fertilizers and their use

Plant roots take up N in the form of NO_3^- or NH_4^+ ions. Nitrogen bound in organic forms in the soil can only be used by plants after it is mineralized into the NH_4^+ form by hydrolytic ammonification, and its subsequent chemo-lithotrophic oxidation to NO_3^- (nitrification). In the soil, NH_4^+ is less mobile than NO_3^- because the negatively charged clay mineral surfaces can electrostatically absorb the NH_4^+ irons. The negatively charged NO_3^- ion, on the other hand, is not absorbed and can be easily moved by water in the soil profile and thus leached. In some developing countries, only 30%-35% of the fertilizer N is taken up by plants, and about 20%-50% of the fertilizer N is lost by runoff and leaching, depending on soil and climatic conditions (Mapiki et al., 1993; Mundus et al., 2008). Most of the N from farmland is lost in the form of NO_3^- (Di and Cameron, 2002). These losses have caused considerable environmental problems that pose serious threats to regional development (Barton and Colmer, 2006).

1.1.2 Problems caused by excessive N fertilizer use in agriculture

Nitrogen losses and surface water eutrophication

The excessive N use in agriculture has caused a massive increase in surface water eutrophication globally. This has led to health problems; habitat degradation; changing food-web structure (Howarth et al., 2000), loss of biodiversity, and increased frequency, spatial extent and duration of harmful algal blooms (Boesch, 2002). In Denmark, 94% of the N load comes from agricultural activities (Vighi and Chiaudani, 1987). In 1994, 60% of the N in water bodies in the Netherlands originates from N fertilizer application (Lena, 1994), In the USA, non-point source pollution, of which agricultural activities account for 75%, contributes to 66% of the N load. Recently, the Water Wheel (Water Research Commission, South Africa; issue September/October 2008) reported that 54% of the lakes/reservoirs in Asia are affected by eutrophication, in Europe 53%, in North America 48%, in South America 41%, and in Africa 28%; most of the nutrients originate from agricultural activities (Nyenje et al., 2010). In China, It has been estimated that 9.75×10^5 tons of dissolved N enter the Yangtze River, Yellow River and Pear River every year; the dissolved N stems largely from agricultural activities (Duan et al., 2000).

Drinking water pollution and related health problems

Groundwater quality can deteriorate over time because of the cumulative effects of agricultural practices (Addiscott et al., 1992). Since 1994, the Chinese Academy of Agricultural Science has monitored the water quality of 600 wells used for drinking water across China. Results showed that 20% of the surveyed groundwater has nitrate concentrations exceeding the threshold defined in China drinking water regulations (10 $mg{\cdot}L^{-1}$) (Zhang and Tian, 1995). Although Hubei Province is rich in water resources, 71% of the residents there are drinking nitrate-polluted water (Li and Fan, 2009).

The consumption of nitrate-contaminated water poses health risks. The World Health Organization (WHO) set the threshold of drinking water NO_3^- concentration at 10.0-11.3 $mg{\cdot}L^{-1}$ (World Health Organization, 1984). Consuming water contaminated with NO_3^- polluted can affect blood oxygen-transport in young children and cause the “blue baby” syndrome (Golden and Leifert, 1999). A strong relationship between high NO_3^- concentration in drinking water and stomach cancer in adults has also been established (Mckinney et al., 1999).

Energy waste

Improving N fertilizer use efficiency in major cropping systems is a central component of efforts to not only produce more food, but also to reduce resource consumption (Lobell et al., 2004). Although 78% of earth's atmosphere consists of nitrogen, the inert N_2 gas must first be converted to ammonium by biological (microbial) or industrial (Haber-Bosch) fixation processes before becoming available to plants. Industrial N fertilizer production requires energy, which is mainly generated from fossil fuels. In intensive agricultural systems, N fertilizer application accounts for approximately 40% of the total energy input (Küsters and Lammel, 1999). Therefore, N fertilizers need to be used more efficiently for both economic and environmental reasons.

Because of the problems caused by N losses from agro-ecosystems, strategies minimizing such losses need to be developed. Nitrogen losses are difficult to control because N movements are often intermittent and associated with numerous factors such as land management, rainfall and its temporal distribution, irrigation practices, and the amount and timing of fertilizer application (Carpenter et al., 1998). Integrated approaches to manage NO_3^- concentration in soil solution, and water dynamics in soil profiles are necessary for reducing the NO_3^- related environmental impacts (Tamini and Mermoud, 2002).

1.1.3 Reasons for excessive N fertilizer use and related water pollution in China

Extensive use of N fertilizers is one of the main factors contributing to increasing global yields. Global N fertilizer application rates increased 7-fold from 1965 to 2002; 25% were applied in China, on an area amounting to only 7% of the global farmland (Wang et al., 2012b). China became the world's largest chemical fertilizer consumer in the late 1990's (Williams, 2005). Three main determinants have been identified: growing food demand, reduction of organic fertilizer use, and subsidies for mineral N fertilizer industries.

Increasing demand for food

China's population grew from 975 million in 1979 to 1,354 million in 2012 (Chinese National Bureau of Statistic, 2013) and is expected to reach 1,500 million in 2030 (Liu and Diamond, 2005). In addition, by 2003, more than 860,000 ha of arable land were occupied by land uses other than agriculture (Larson, 2003). Furthermore, the living standard in China improved considerably after the introduction of economic reforms in 1978. Providing sufficient food to feed the rapidly growing population is an enormous challenge. Increased fertilizer use has played a key role in keeping food production in pace with the population growth in China during the past decades. However, because of a decrease in nitrogen use efficiency (NUE[1]) with increasing N application rates, the incremental yields diminished. They may even show a negative trend when N inputs massively exceed crop demand (Figure 1.1).

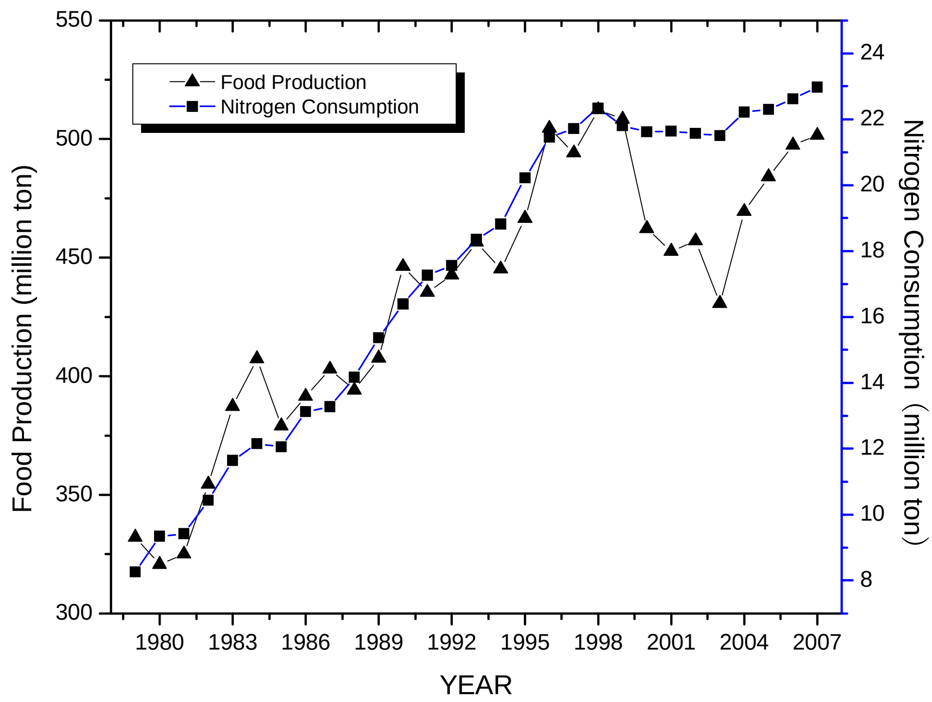

Figure 1.1 Nitrogen consumption and food production in China from 1979 to 2007. Data source: Chinese national agriculture yearbook 1980-2008.

Reduction in organic fertilizer use

The amount of organic fertilizer used in China has dropped sharply in the last decades. In 1949, 100% of the nutrients applied to Chinese farmland were from organic sources; in 1975, 60% of the N input still originated from organic fertilizers and green manures, mainly from the floating fern *Azolla* and the leguminous cover crop *Astragalussinicus*.

[1]Nitrogen Use Efficiency (NUE) in this research is defined as the N fertilizer that contributes to the yield compared to the control group (N_0).

However, it dropped to 20% by 2000 (Zhu et al., 2006). There are several reasons behind this reduction.

Firstly, compared to organic fertilizer, farmers can achieve higher profits with synthetic fertilizers. It was observed that Chinese farmers used about 30% of their farmland to cultivate green manure in the 1940s, while they used the same amount of farmland to cultivate cash crops in the 2000s; the money earned from the cash crops was used to buy synthetic fertilizers (Giampietro and Pastore, 2001). Although the same fraction of land is involved, the farmers who use synthetic fertilizers have more free time to do off-farm work and thus can earn more money than organic farmers.

Secondly, because of accelerated urbanization and development of large-scale livestock production systems, attributed to China's policies, livestock systems have been separated from crop production systems. Thus, most of the human and animal wastes are no longer used as organic fertilizer in farming. Accordingly, modern agricultural systems rely more on synthetic fertilizer rather than on organic fertilizers as their nutrient input.

Thirdly, with emerging labor shortages or increasing agricultural wages, the high labor demand for producing legume seeds, maintaining azolla ponds, applying and incorporating organic fertilizer sources and for transport increasingly restricts the use of organic amendments (Becker et al., 1996).

Subsidies in the fertilizer industries

From 1949 to 1993, the Chinese government invested a total of US$ 7.28 billion in the chemical fertilizer industries (Li et al., 2013). In contrast, recent data showed that more than US$ 18 billion were supplied to the Chinese fertilizer market through a massive subsidy program in 2010 alone (Li et al., 2013). These subsidies were used to fund infrastructure construction, reduction of transportation cost, provision of cheap energy, tax reductions, etc. They supported thus small and medium-sized fertilizer factories, allowing them to provide cheap fertilizers to Chinese farmers. The artificially low-priced fertilizers contributed to the nationwide trend of excessive fertilizer application (Qiao et al., 2003;Yang and Sun, 2008).

Water pollution through excessive N application

While N loads into water originate from different sources, synthetic fertilizer losses associated with agriculture activities have been the main source of water pollution in China since the 1980s (Ju et al., 2004). In the last decades, these N loads have caused aquatic ecosystem degradation and eutrophication (Zhu and Chen, 2002). For instance, about 50% of the N loads in the Yangtze and Yellow rivers are from synthetic N fertilizer losses (Duan et al., 2000). In the latest "Environmental quality standards for surface water" (GB3838-2002) published by the Chinese Environmental Protection Administration, surface water are classified into five quality levels: the highest quality level is Class I, while Class III is regarded as the threshold criterion for drinking water. According to data collected from field monitoring of “seven water systems and three main lakes[2]” in 1998, 63.1% of the surface water area was classified as lower than Class IV (State Environment Protection Agency, 1998). In 2003, the water quality had hardly improved, i.e., 61.9% of the surface water was still lower than Class IV (State Environment Protection Agency, 2003). Consequently, nitrate-N, from agricultural activities, is one of the main pollutants that contributes to water pollutions.

1.1.4 Strategies to improve N use efficiency

To increase NUE and reduce adverse impacts on the natural ecosystems, numerous studies have been conducted on issues pertaining to N fertilizer since the mid-19th

2Seven water systems and three main lakes in China include: Hai River, Liao River, Yellow River, Huai River, Songhua River, Yangtze River, Pear River, Taihu Lake, Dianchi Lake and Chaohu Lake.

century. The researches varied in size, ranging from plot to global scale (Ju et al., 2009; Mueller et al., 2012).

Plot-scale research

Plot-scale research, a direct way to quantify the N cycle at small scale, has been employed in many studies. The earliest plot-scale research on different forms of N was conducted in the world's oldest research station at the Rothamsted Classical Experiment Station, UK, in 1842 and 1843 (Leigh and Johnston, 1994). Later, the functions of winter cover crops with respect to soil protection were tested at the Alabama Agricultural Experiment Station, USA, in 1896 (Mitchell et al., 2008). In the 1930s and 1940s, the effects of crop management on soil were assessed from the N perspective at the Sanborn Field Experiment Station, Missouri, USA (Brown, 1993). Since then, researchers worldwide have contributed an enormous amount of data from countless field experiments dealing with the N cycle at plot level.

After isotope methods were introduced, it became possible to demonstrate the N distribution in field experiments and its effects on natural agro-ecosystems under different field management strategies. Most studies have shown that improved soil and crop management combined with appropriate genotypes and slow-release fertilizers can reduce N losses, and maintain, or even increase yields (Becker et al., 2007). The quantity of N losses from agriculture is highly dependent on the scale of research, because crops grown at lower toposequence position can use N lost from upslope areas. Accordingly, a combination of plot and watershed-scale research is necessary to reveal the real impact of agriculture on the water system at a regional level (Chen et al., 2013).

Research on nitrogen transport simulation using modeling

The estimation of N loads and identification of the N source are essential to improve NUE and reduce N losses (Chen et al., 2013). With the aim of reducing pollutant load released from agricultural activities at the watershed scale, numerous studies have focused on N-load estimation (Tian et al., 2012). Since the 1970s, computer-based models have been developed to quantify the N emissions from agricultural activities under different conditions. Because N dynamics are driven by water flow, most of the models were developed by hydrological and chemical associations, e.g., EPIC (Erosion Productivity Impact Calculator), SWAT (Soil and water assessment tools), ANSWERS (Areal nonpoint source watershed environment response simulation), AGNPS (Agricultural nonpoint source pollution model) (D.K.Borah and M.Bera, 2003), NLEAP (Nitrate Leaching and Economic Analysis Package) (Delgado et al., 1998) etc. These models have been widely used and provide good results for nutrient management at watershed scale in many countries. However, these models need large amount of field data, and require calibration and evaluation prior to application. Although some export coefficient models that require less data have been widely applied to estimate nutrient loads to water systems, they cannot provide information on the transport mechanisms. This information is, however, essential for deriving strategies to improve field management (Lu et al., 2013). Accordingly, sufficient field data and model performance evaluation are necessary for predicting N loads and simulating N-transport mechanisms at the watershed scale.

Research at larger scales in a socio-political context

Policies that consider the socioeconomic context are regarded as the most effective way to increase NUE at regional level if they are implemented correctly (Yunju et al., 2012). However, although many innovative cropping systems and policies have been proven to be more sustainable and environmentally friendly by researchers and politicians, farmers have been reluctant to adopt them because of financial reasons (Caporali and Campiglia, 2000) and risk avoidance (Paudel et al., 2000). Therefore, sound policies should be based not on only the considerations of researchers or politicians, but also on those of farmers. Only then are farmers likely to respect such policy recommendations. For instance, effective agro-technical extension services (Jia et al., 2013), and improved access to input and output markets (Waithaka et al., 2007) have been proven to be useful strategies for reducing N fertilizer application by small-scale farmers. Hence, information from household surveys is necessary to facilitate effective and practical polices planning in order to reduce N pollution (Li et al., 2006).

1.1.5 Hypothesis and objectives

Nitrogen pollution is a complex problem requiring interdisciplinary strategies that cut across different scales of observation. This research hypothesizes that improved crop management can reduce the current nitrate-N pollution while enhancing systems performance. The general objectives were to estimate the quantity of N losses from farmland at field scale, to evaluate the performance of the EPIC model, and to assess possible mitigation strategies for reducing the adverse impacts resulting from agricultural activities. The specific objectives were as follows:

(1) Study farmers' attitudes with respect to N fertilizer application and determine the key factors associated with N overuse at drainage basin scale.

(2) Evaluate the impacts of transition season and modified mineral fertilizer-N management on N use efficiency and yield

(3) Determine the effect of transition season and modified mineral fertilizer-N management on NO_3^- and NH_4^+ losses through leaching.

(4) Calibrate the EPIC model, and evaluate its performance on N losses and crop yields estimation.

1.2 Materials and methods

1.2.1 Household survey

For the personal interview survey, 300 households were selected in the Liangzihu Lake drainage basin. Stratified randomized sampling methods were used to select the target households. The questionnaire covered four aspects: characteristics of the farmers (e.g., age, education level of household head), economic situation of surveyed households, knowledge background of interviewees, and infrastructure factors influencing fertilizer purchase and transportation.

Before commencing the survey, investigator training and pilot survey were conducted to ensure the result accuracy of the result. Details of sample selection and result analysis are described in Chapter 2.

1.2.2 Study site

The research was conducted in the Liangzihu Lake basin, Hubei province, Central China. To achieve the abovementioned objectives, research was conducted by interdisciplinary methods:

(1) Field experiment: The 24 experimental plots were established at Tuanjie village (28 m asl, 30°14´ latitude and 114°23´ longitude), each 40 m^2 (5 m × 8 m) and located in the field with randomized block design.

(2) Model simulations: Based on the measured data, the performance of EPIC model on N losses simulation was evaluated.

(3) Household survey: The household survey was conducted in the Liangzihu Lake basin, which covers an area of 2085 km^2 and includes four different counties, to identify the factors associated with the farmers' excessive N fertilizer use.

1.2.3 Data collection

Sampling

Soil solution samples were sampled using a ceramic suction cup at 1.0 m and 1.8 m depths. Soil samples were collected from the root zone (0-100 cm) at 20-cm intervals. Aboveground plant tissues of maize and wheat were sampled at harvesting. The soil and water samples were transported to the laboratory in containers at a constant temperature of 2 °C for chemical analysis.

Metrological data measurement

The metrological data include maximum, average and minimum air temperature; relative humidity; precipitation; solar radiation; dew point; and wind direction and speed. The data were measured at 30-min intervals by a weather station (Watchdog 2700 ET, USA) that is located 0.5 km away from the field.

Soil water content measurements

The soil volumetric content was measured at bi-weekly interval using soil moisture sensors (Spectrum, SM-100, USA), that were installed at 1.0 m and 1.8 m depths.

Chemical analyses

The soil solution samples and the soil samples were taken at 15-day intervals. The soil sampling interval was shortened to 7 -days during the critical time (after N fertilizer application). Soil sample collection began on 10 August 2012 and continued until the end of the field experiment (25 August 2013). Soil solution and water sampling began at the same time as the field experiment. The NO_3^- and NH_4^+ contents in the soil, soil solution and water samples were analyzed in the laboratory. The plant tissues were separated into grain and straw, and oven dried at 70 °C until their weight remained constant for the purpose of biomass calculation and N-content analysis.

The chemical analysis methods for the plant tissues and soil samples are described in Chapter 3, and for the soil solution samples in Chapter 4

1.2.4 Data analysis

The Duncan Multiple Range test at $P \leq 5\%$ level was used the software, Stata 12.2 to determine the significance levels. The location was mapped using ArcGIS 10.0. The data from the questionnaire were analyzed through Pearson correlation analysis and linear regression analysis using Stata 12.2.

1.3 Outline of thesis

Based on the research objectives, this thesis is organized into six chapters. Following the general introduction (chapter 1), each of the four chapters (chapter 2-5) specifically addresses one of above-mentioned objectives:

Chapter 2 defines the factors associated with the overuse of N fertilizer in the drainage basin based on the household surveys.

Chapter 3 describes N fertilizer contribution to agronomic use efficiency under different field management treatments.

Chapter 4 describes the dynamics of soil water and N leaching losses with different field management.

Chapter 5 evaluates the performance of EPIC model on yield and N losses simulation.

Chapter 6 contains the general discussion, conclusions and mitigation strategies for N pollution and discusses their implications on policies.

2. FACTORS INFLUENCING FARMERS' DECISIONS ON N FERTILIZER USE

2.1 Introduction

To satisfy the rapidly growing demand for food and other agricultural commodities during the past 40 years, China's farmers tend to apply on average 30%-60% more than the recommended rate of mineral nitrogen fertilizer (Ju et al., 2009). This is causing severe environmental problems at both local and global scales. Typically associated with excessive N use at local scale are the eutrophication of the aquatic environment (Pedersen et al., 2009) and nitrate pollution of groundwater (Almasri and Kaluarachchi, 2007). On a large scale, disturbance of the global N cycle (Galloway et al., 2008) and the enhanced emission of climate relevant trace gases (Mosier et al., 1998) are associated with N overuse. Policy makers in the country are becoming increasingly aware of the problems associated with N overuse, and new policies are being developed to sustain on the one hand the increasing demand for food, while on the other hand minimizing negative environmental impacts of excessive N fertilizer consumption. Thus, an "N-testing" project, basing application rates on soil-N values and target yield levels was approved in China in 2005 as a strategy proven to be beneficial in other countries (Bosch et al., 1995). However, its implementation largely failed due to a lack of extension capacity and of other incentives to support an up-scaling to the national level. To date, it remains unclear why Chinese farmers consistently exceed recommended N application rates despite widely recognized environmental problems and a generally low use efficiency of the inputs. A commonly mentioned culprit is the relatively low cost of about € 200 per ton of subsidized mineral fertilizer N which is below the world market price of about € 300 per ton of N (Huang et al., 2011).

Past research on possible factors influencing N fertilizer use in China is contradictory and appears to be location specific. For example, a negative relationship between farm size and N use was reported for the Chaobai watershed in northern China (Zhou et al., 2010), while no such link was observed in the Songhuaba watershed in Yunnan province (Yunju et al., 2012). Other authors found that, depending on the study area, seasonal labour migration tends to affect N fertilizer use both positively (Ebenstein, 2011) and negatively (Zhou et al., 2010). This evidence of a high location specificity of the factors governing N overuse suggests a more differentiated approach that should consider site-specific differences in ecological, economical, and cultural factors (Huang et al., 2011).

The Liangzihu Lake drainage basin in Hubei Province of Central China is particularly affected by N pollution, and the quality of the aquifers has been declining particularly as a result of high nitrate concentrations in the water (Qiu et al., 2001). The water pollution, especially the N pollution problem, is likely to affect regional development in the long-run (Kuangfei et al., 1999).

To reduce agricultural N pollution, it is necessary to determine the factors driving farmers' excessive use of N fertilizer. Accordingly, the objectives of this study were to: (1) determine the factors that influence farmers' behaviour with respect to use of N fertilizers in Central China, and (2) provide suggestions to reduce excessive N application in the study region. The results of this research are seen to provide information required for facilitating policies for better N fertilizer management in Central China.

2.2 Materials and methods

2.2.1 Site description

A household survey was conducted in the Liangzihu Lake drainage basin, Hubei Province, from April to June 2013. The drainage basin is located in the southeast of the Jianghan plain in Hubei province and covers an area of 2085 km^2, belonging to the counties of Jiangxia, Liangzihu, Daye and Xian'an. The main characteristics of these four counties are listed in Table 2.1. Liangzihu Lake has a surface area of 271 km^2 and an average water depth of 2.54 m; the lake is connected with the Yangtze River in the east (Li and Sun, 2009). The drainage basin is very rich in water resources. For instance, there are many lakes spread throughout the region, all being inter-connected by rivers or creeks. The research area has a subtropical monsoon climate with an annual average precipitation of 1,100 mm, and an annual average temperature of 16 ºC. The dominant crops are rice, maize, wheat and cotton, with cotton and wheat growing in the cold season, and rice and maize in the hot season. Oilseed rape and groundnuts are also occasionally cultivated in the region. Most farmers in the study area are small-scale farmers (average size of farmland = 0.29 ha/household) who practice a very intensive crop production with high yields and 1-2 crops per year.

Table 2.1Characteristics of the surveyed counties within the study region

Characteristics	Liangzihu	Jiangxia	Xian'an	Daye
Sample size	95	95	47	46
Area (km^2)	500	2010	1502	1566
Arable farmland (km^2)	127	355	355	362
Population	164,846	351,200	393300	662,500
Households	44,319	97,000	97,900	169,800
Income per capita (Yuan)	7,010	9,898	6,588	8,079

2.2.2 Sampling methods

To ensure the confidence level at 95% level, a sample of 300 households was selected among the clusters of settlement located in the Liangzihu Lake drainage basin (Levy and Lemeshow, 1999). Each settlement cluster consists of several villages. Stratified randomized sampling methods considered the following approach: (1) one settlement cluster from each group was randomly selected, and the villages in the cluster were stratified into two groups according to per capital income (high income > 6000 Yuan[3] per year and 6000 Yuan per year ≥ low income), (2) several villages from each group were selected for the household survey, (3) households were randomly selected from the sample frame provided by the village head, and (4) face-to-face interviews using structured questionnaires were conducted with the household head or the person who was the major decision maker and manager of the farming activities. As farmers tend to apply large amounts of different types of organic manure to fruits and vegetables, and as their N contribution is difficult to quantify (Ju et al., 2004), such production systems were excluded from the analysis. Thus, from the initially selected 300 households, 17 were excluded because these farmers grew only fruit trees and vegetables. Accordingly, the results are based on the information of 283 sample households. The number of samples and descriptions of the surveyed households are listed in Table 2.1 and Table 2.2, respectively. Investigator training and pilot survey were used to ensure the quality of the questionnaire procedure. Investigators received three days training to ensure that questions were asked in a standardized way; a pilot survey was conducted to make the questionnaires more clearly and easily understood by farmers.

[3]Average currency exchange rate in 2012: 1 US $ = 6.3125 Yuan

Table 2.2 Variables selected in the questionnaire and household description

Category	Variable	Unit	Observations	Mean	Std.Dev	Min	Max
Characteristic	N fertilizer application rates	kg·N·ha^{-1}	283	229.22	106.21	40.91	637.5
	Age of household head	Years	283	55	11.27	15	83
	household size	Number of persons	283	5.19	2.25	1	13
	Labor availability	Number of person/HH	283	2.62	1.39	1	9
	Education level of household head	+)	283	1.27	1.1	0	5
	Farmland area	Ha	283	0.58	0.71	0.33	6.67
	Disaster	1 = with, 0 = without	283	0.69	0.46	0	1
Economic	Total income	10.000 Yuan	283	2.74	2.49	0.15	23
	Off-farm income (10.000Yuan)	Continuous variables	283	1.37	2.13	0	22
Knowledge	Fertilizer quality evaluation	0=don't know; 1= know	283	0.15	0.36	0	1
	Farmland fertility evaluation	++)	283	2.9	0.57	1	4
	Technical training	1=yes; 0= no	283	0.17	0.37	0	1
	Ways to access knowledge	+++) the statistics are missing →				1 (69%)	
Infrastructure	Distance to farmland	km	283	1.19	3.65	0.1	60
	Distance to fertilizer market	km	283	2.71	4.22	0	60
	Distance with water resources	km	283	0.44	0.74	0	6
	Road conditions	++++)	283	1.75	0.74	1	3
	Fertilizer transportation method	+++++) the statistics are missing →				1 (12%)	

+) 0=without; 1=less than 6 years; 2=between 6 to 9 years; 4= between 9 and 12 years; 5= more than 12 years

++) 1=very fertile; 2=fertile; 3=normal; 4=poor

+++) 1=experience; 2= discuss with other farmers; 3= books; 4=TV/Internet; 5=other ways; 6= more than one way

++++) 1=village level; 2=county level; 3=provincial level; 4=national level

+++++) 1=truck; 2=labor; 3= motorbike; 4= home delivery service

2.2.3 Variable selection

The selected variables were classified into four sections based on previous research (Kormawa et al., 2003).

- Section 1: Farm and household characteristics (age of household's head, household size, yields, occurrence of disasters in the past five years)
- Section 2: Production factors (farmland area, labor availability, off-farm income);
- Section 3: Knowledge factors (education level, ways to access knowledge, ability to evaluate the quality of fertilizer and the fertility of farmland, access to and use of training measures);
- Section 4: Infrastructure factors (distance to the market, distance to water bodies, road conditions, and transport facilities).

In 20 % of the households, two crops per year were cultivated, and the multiple cropping index (MCI) was used as follows:

$$\text{MCI} = \frac{\text{Sowing area}}{\text{Farmland area}} \times 100\% \qquad (2.1)$$

The percentage share of off-farm income was transformed into an index to estimate its impact on the amount of fertilizer N applied. To allow comparisons of yield between commodities, the farmland productivity was calculated as:

$$\text{Agricultural output value (yuan)} = \sum_{i=1}^{i=n} c_i \times p_i \qquad (2.2)$$

$$\text{Farmland productivity (yuan}\cdot\text{ha}^{-1}) = \frac{\text{Agricultural output value}}{\text{Farmland area}} \qquad (2.3)$$

$$\text{Off-farm income percentage (\%)} = \frac{\text{Off-farm income}}{\text{Total income}} \times 100 \qquad (2.4)$$

$$\text{N fertilizer application density (kg}\cdot\text{N}\cdot\text{ha}^{-1}) = \frac{\text{N fertilizer applied} \times \text{fertilizer-N content}}{\text{Farmland area}} \qquad (2.5)$$

$$\text{N fertilizer application rates (kg}\cdot\text{N}\cdot\text{ha}^{-1}) = \frac{\text{N -fertilizer application density}}{\text{MCI}} \qquad (2.6)$$

where, c_i is the yield of crop *i*, p_i is the suggested price of crop *i* given by the provincial government.

2.2.4 Statistical analysis

Pearson analysis established the correlations between the surveyed variables. A multiple linear regression model was used to identify and estimate the drivers of mineral fertilizer use. To reduce co-linearity, farmland area and farmland productivity were excluded from the model (Belle, 2008).

Bootstrapping (replication = 500) was introduced to test the stability of the results. Calculations were performed using Stata 12.1.

2.3 Results and discussion

2.3.1 General determinants of nitrogen application

Various factors appear to determine the mineral N fertilizers application rate. The correlation analysis shows a positive relation between the N application rate and the percentage share of off-farm income ($r = 0.1776$, $p = 0.004$; Table 2.3). Such relationships have been reported before by Zhou et al. (2010). However, farmland productivity shows a highly significant negative correlation with N application rate ($r = -0.184$, $p = 0.003$), which is again supported by findings of other researchers in China (Jia et al., 2013). Different explanations were given for these findings. Firstly, farmers tend to apply more N fertilizer to the fields with unfavorable growing conditions, to compensate for reduced productivity that is perceived to be associated with such conditions (Ju et al., 2009). Another explanation is that excessive N fertilizer may cause mutual shading, high competition and pest damage which can reduce yield (Peng et al., 2006). Therefore, the results can be interpreted in two ways: More N fertilizer leads to lower yields or when yields are lower farmers to apply more N fertilizer. The grain yield response to applied mineral N generally follows a quadratic response function

(Meyer-Aurich et al., 2010). Thus, yield increments get smaller with increased N application rates and may even decline at very high doses (Zhu and Zhang, 2010). Most of the surveyed households (82%) apply N fertilizer rates above 150 $kg \cdot N \cdot ha^{-1}$(Figure 2.1) which is the rate required to reach the maximum profit for grain crops (Goulding, 2004). Therefore, we assume that the negative correlation in our result between farmland productivity and the amount of mineral N applied was caused by excessive use of N fertilizer.

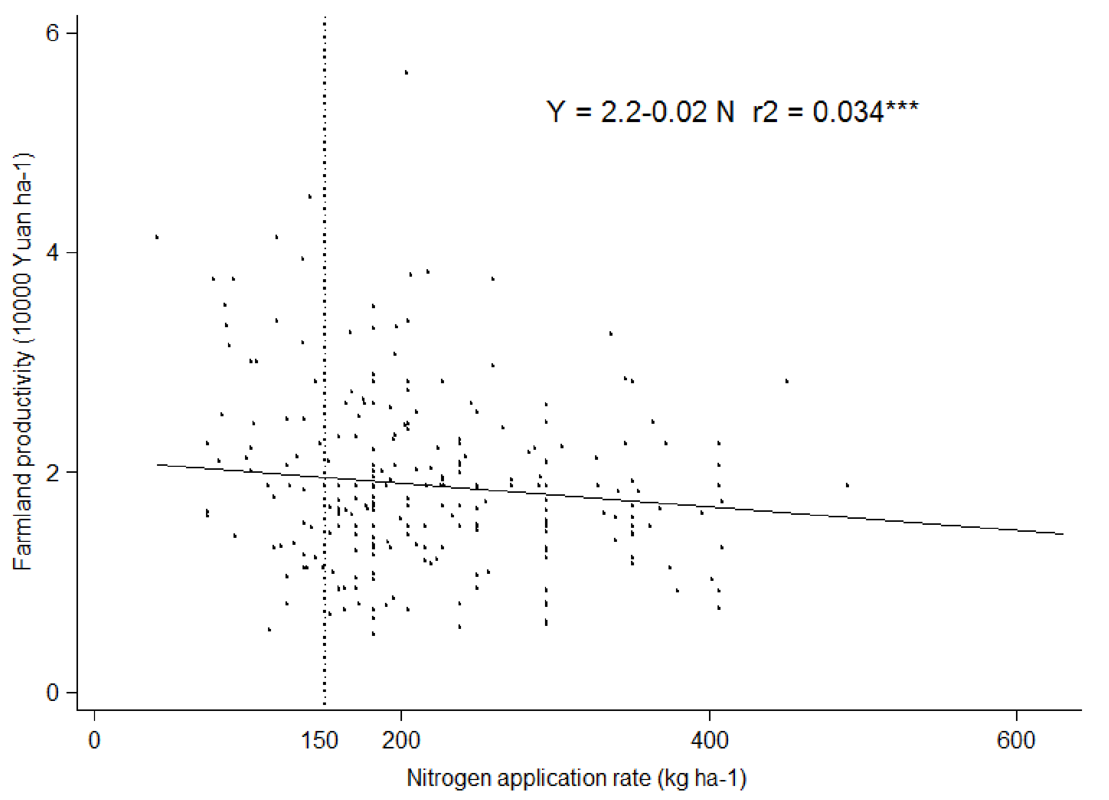

Figure 2.1 Correlation with N fertilizer application rates and farmland production.

The distance between farmland and water resources shows positive correlations with N application rate (r = 0.1031, p = 0.092). Thus, the further away the farmland was from water resources the more N was applied. The mean distance between farmland and water was less than 500 m and nearly all farmlands were located at a distance of less than 2 km from the next open water body (Table 2.2), which indicates that the study region is rich in water resources. Two reasons could explain this positive correlation. Firstly, the farmlands that are located further from water resources have lower productivity, which is indicated by the negative correlation between these two variables ($r = -0.019$, $p = 0.092$); therefore, farmers are likely to apply more fertilizer to these fields as a compensation. Secondly, as farmers share irrigation equipment in the study region, they tend to irrigate with large quantities of water and exceed the crop requirements when they have the right to use the equipment. The excessive irrigation could cause N fertilizer losses through leaching; therefore, over-irrigation could motivate farmers to apply even more N fertilizer (Cameron et al., 2013).

The mineral-N application rate was negatively correlated with farm size ($r = -0.1682$, $p = 0.0058$), as households with more farmland area tend to rely more on agricultural income and less on off-farm revenues. This is similar to the negative correlation between off-farm income and farmland area ($r = -0.3058$, $p = 0.000$). Therefore, farmers with more farmland tend to spend more time on farm work, and are more likely to adopt improved N-management techniques, which lead to lower N application rates. In research from northern China, a similar correlation between farmland size and N fertilizer use was observed. The trend may be explained by an increase in N fertilizer efficiency as farms become larger (Zhou et al., 2010).

Table 2.3 Correlation between surveyed variables

	Age	HHS	La	Edu	DFl	DFe	DW	RC	%OF	FProd	Napp	FArea
Age	1.0000											
Household size (HHS)	0.1950***	1.0000										
Labor availability (La)	-0.0586	0.4244***	1.0000									
Education level (Edu)	-0.3978***	-0.1465**	0.0943	1.0000								
Distance to farmland (DFl)	-0.0419	0.0879	0.1309	0.0134	1.0000							
Distance to fertilizer (DFe)	0.0041	-0.0131	0.0677	0.0715	0.0094	1.0000						
Distance to water resources (DW)	-0.0726	-0.0190	-0.0507	-0.0232	0.0303	0.0243	1.0000					
Road conditions (RC)	0.0017	0.0922	0.0548	-0.0548	-0.0535	-0.0041	0.1246	1.0000				
Off-farm income percentage (% OF)	-0.3235***	0.1073*	0.2540***	0.2297***	-0.0697	-0.0905	0.0044	0.0891	1.0000			
Farmland productivity (FProd)	0.0721	-0.0147	0.0456	-0.0095	0.0675	-0.0059	-0.0190	-0.0135	-0.2143***	1.0000		
N fertilizer application rates (Napp)	-0.0404	0.0199	-0.0254	-0.1002	-0.0260	-0.0890	0.1031*	-0.0078	0.1776***	-0.1842***	1.0000	
Farmland area (FArea)	-0.0171	0.0902	0.0667	-0.0012	0.0250	0.0617	0.0171	0.0989	-0.3058***	0.0176	-0.1682***	1.0000

* Significant at 10% level, ** Significant at 5% level, ***Significant at 1% level

2.3.2 Farmer-specific determinants of nitrogen use

Multivariate linear regression gives a depth analysis of the extent of selected factors influencing the rates of mineral N fertilizer application (

Table 2.4). The raw bivaritate correlation associations (section 2.3.1) were adjusted for the influence of other involved variables. Two variables, i.e., off-farm income percentage and education level, were found to be significantly associated with the amount of mineral N used with co-efficient of 26 (p = 0.003) and -11 (p = 0.034), respectively.

Table 2.4 Factors influencing farmers' N fertilizer application

Category	Factor	Coefficient	Std.Err	p Value		P Value bootstrap
Characteristic	Education level of household head	-11.20	5.23	0.034	**	0.028
	Age of household head	-0.77	0.53	0.883		0.878
	Disaster	5.01	11.18	0.654		0.690
	Household size	0.842	2.70	0.761		0.807
	Labor availability	-2.01	4.42	0.650		0.671
Economic	Off-farm income (%)	25.94	16.98	0.003	***	0.002
Knowledge	Farmland fertility evaluation	1.69	9.21	0.862		0.697
	Technical training	-16.28	15.41	0.293		0.223
	Fertilizer quality evaluation	8.12	14.87	0.599		0.639
	Ways access to knowledge			0.522		
Infrastructure	Distance to fields	0.28	14.87	0.981		0.971
	Distance to fertilizer market	-1.40	1.23	0.299		0.411
	Distance to water resources	12.74	6.98	0.163		0.151
	Transportation method			0.671		
	Road conditions	-1.19	7.22	0.705		0.713

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

With the off-farm labour wages increasing in China since the early 2000s, farmers pay more attention to their off-farm work rather than to farm work, which has caused an increase in fertilizer use (Brauw and Giles, 2008; Wang et al., 2011a). Increasing labour wages are reportedly the reason for the Chinese farmers' preference for high N-input management rather than the traditional N management, which demands higher labour input (Jia et al., 2013). Accordingly, as skills for improving fertilizer management require additional labour input, it is a challenge to persuade farmers engaged in off-farm employment to adopt them. Figure 2.2 shows the number of farmers employed as off-farm workers and fertilizer consumption in Hubei province from 1990-2010. Data indicate that fertilizer consumption increased with the number of farmers engaged in off-farm employment in Hubei province. Similarly, the regression results in the current study indicate that the share of off-farm income was positively associated with the rate of N applied ($r = 0.1776$, $p = 0.004$). This can be for two reasons. First, farmers engaged in off-farm work have more cash to buy more fertilizer (Waithaka, et al. 2007). Second, the households that rely more on off-farm income are more busy with their off-farm work, and more N fertilizer is applied to their farmland as a compensation for less farm work (Waithaka et al., 2007; Han and Zhao, 2009). The comparison of Chinese farmers' behaviour with respect to N fertilizer application from the 1940s to 2000s by Giampietro and Pastore (2001) provides a clear explanation of this issue from an economical perspective. They found that in the 1940s, Chinese farmers used about 30% of their farmland to cultivate green manure to produce organic fertilizer; however, farmers used the same amount of farm land to cultivate cash crops and bought synthetic fertilizer with the income from these crops in the 2000s. The farmers then had more free time to do other work and had higher profits. Accordingly, the increase in off-farm employment could cause farmers to spend less time on farm work and to be reluctant to accept proper N fertilizer management skills. This could be the main reason for the increase in N fertilizer application rates.

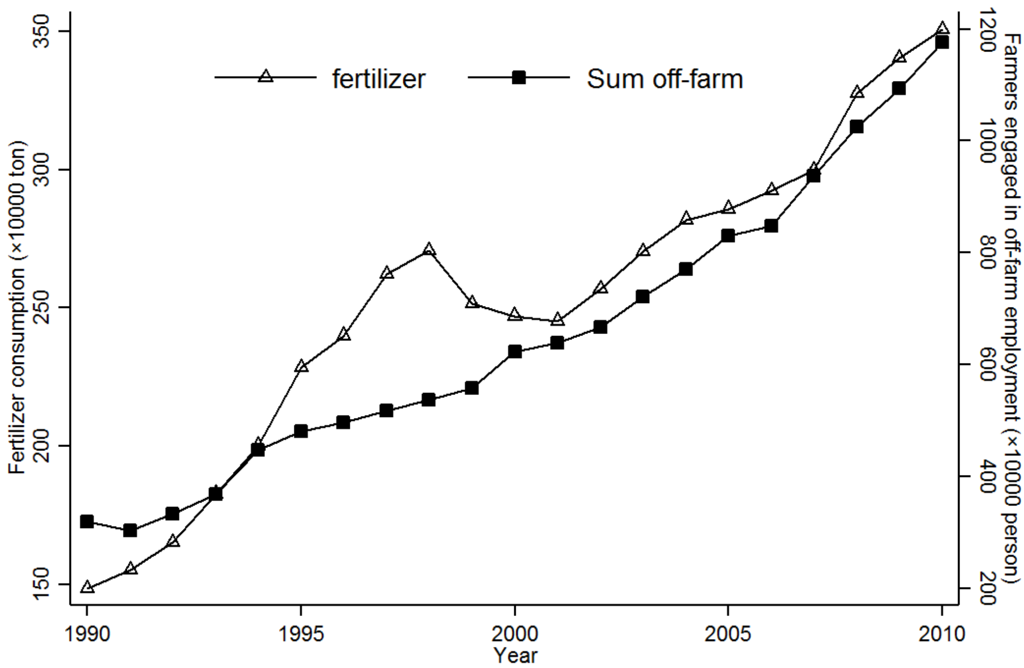

Figure 2.2 Fertilizer consumption and off-farm employment in Hubei province 1990-2010. Source: Hubei agricultural yearbook (1991-2011)

Lack of knowledge and information on required amounts of fertilizers and on crop response to applied N are the main reasons for the Chinese farmers' overuse of fertilizer (Huang et al., 2008). Although no statistically significant correlation was found between knowledge and the amount of N applied, results indicate that the surveyed households have a lack of knowledge on N fertilizer. In our study, only 16% of the interviewees knew how to judge the quality of fertilizer, while, 72% estimated their farmland as having normal fertility, but were not able to give any reasons for this assessment. Regarding the impact of technical training on the amount of N fertilizer used, other studies show different results. Thus, Huang et al. (2009) observed that technical training can improve N-management strategies and reduce amount of N fertilizer applied by 20%-30%, while other researchers argue that technical training has only a limited impact, because most of the techniques presented by the training were only reluctantly adopted by the farmers (Wang et al., 2011a). The impact of technical training on N fertilizer use was not significant in the current study. However, the trained and un-trained farmers behaved differently with respect to N fertilizer use (Table 2.5). Trained farmers tended to apply less N fertilizer, had more ways to obtain knowledge and were more likely to know how to evaluate fertilizer quality. Technology adoption in agriculture is a complicated process, which depends on various factors and takes time (Jia et al., 2013). In the current study, only a small percentage (16%) of interviewees had received technical training in the previous 5 years; all of them received training only once, which is not enough to have a significant influence on amount of N fertilizer applied. Therefore, the lack of evidence in our analyses regarding the link between technical training and amount of N fertilizer used should not lead to the conclusion that training is in general of no impact.

Table 2.5 Farmers' N fertilizer behavior based on education level and technical training.

Items	Ways to access knowledge (%)						Knowledge on fertilizer quality (%)	N rates ($kg{\cdot}N{\cdot}ha^{-1}$)
	Experience	Discussion	Books	Internet /TV	Others	Multiple		
Education level								
Without	81.61	3.45	0.00	0.00	0.00	14.94	13.79	225.02
≤6 years	70.59	2.94	0.00	1.47	2.94	22.06	10.29	223.98
6-9 years	56.99	8.60	1.08	3.23	3.23	26.88	19.35	210.81
9-12 years	63.64	0.00	0.00	0.00	9.09	27.27	18.18	206.98
>12 years	87.50	12.50	0.00	0.00	0.00	0.00	25.00	189.61
Technical training								
Not trained	75.43	3.88	0.43	1.29	1.29	17.67	14.22	220.96
Trained	39.13	10.87	0.00	2.17	8.70	39.13	21.74	201.28

On the contrary, the regression shows that education level was negatively correlated with amount of N fertilizer applied with a co-efficiency of -11 ($p = 0.034$). This is in line with the findings that N fertilizer application rates decreased from 225 kg N ha^{-1} to 190 kg N ha^{-1} with increasing education level (Table 2.5). The farmers with both the lowest and highest education level clearly rely on their experience with respect to the rate of N fertilizer application. We assume this is because most of the illiterate farmers had done farm work for a long time and were reluctant to accept new information due to lack of basic knowledge. In contrast, the farmers with the highest education are very self-confident and therefore hesitate to learn N fertilizer management techniques in other ways other than in discussions about their experience with others. Regarding the negative association between education level and fertilizer application rates, two reasons could explain this. Firstly, although the decisions of both groups of farmers on N fertilizer use rely on experience, educated farmers can get useful information through reading the information about fertilizer application on the fertilizer package and through discussions with other farmers.

Furthermore, education can help farmers to know how to evaluate fertilizer quality, which can reduce N fertilizer application rates (Yang and Sun, 2008). Our study results reveal that farmers with more than 6 years education have better knowledge on how to evaluate fertilizer quality.

The variables referring to fertilizer transportation in our study did not show any statistically significant correlation to N fertilizer application rates, which differs from the results in other research. Previous results indicate that the distance from home to the fertilizer market and fields are factors that have a negative impact on N fertilizer application rates (Kormawa et al., 2003; Zhou et al., 2010). The insignificant correlation between fertilizer transportation and N fertilizer application rates in our study could be explained by the advanced development of transportation infrastructure in the study region. Firstly, the impact of fertilizer transportation could be weakened with improved road conditions. In the surveyed region, all fertilizer transportation roads are concrete roads, which are convenient for the vehicles. Secondly, the factors relating to fertilizer transportation did not play an important role in changing the amount of N fertilizer applied when cars, trucks or motor bikes were used to transport fertilizer. In our study, 88% of the surveyed households transported their fertilizer in vehicles. Thirdly, extensive development of fertilizer markets and services could compensate the transportation influence. For instance, 99% of the households lived less than 10 km from a fertilizer market, which can be easily reached in vehicles. Meanwhile, 40% of the surveyed household had a free home delivery service.

2.4 Conclusions and policy implications

An overuse of N fertilizer in the Liangzihu Lake drainage basin was observed, with average application rates ranging from 169 kg N ha^{-1} to 275 kg N ha^{-1}. Farmland productivity shows a negative relation with N fertilizer application rates (r = -0.1842, p = 0.003). Most of the surveyed farm households (80%) had N fertilizer application rates higher than 150 kg N ha^{-1}, which is the rate needed to reach a maximum profit for cereal crops. Furthermore, the correlation analysis results show that N fertilizer application rate is negatively correlated with farmland area (r = -0.168, p = 0.006), which means that large-scale farmers show lower application rates than small-scale farmers. Therefore, it is necessary to provide technical support to small scale farmers. Moreover, policies encouraging 'family farms' with more farmland and sustainable intensified agriculture should be facilitated.

The results of the regression analysis show that only the share of off-farm income and education level are significantly correlated with a reduced and more reasonable rate of applied mineral N. Off-farm income percentage is positively correlated with application rate, because off-farm employment could restrict farmers' working time. The farmers could thus spend less time on farm work and be reluctant to accept the improved N fertilizer management techniques as these are more time-consuming. Appropriate policies targeting macro-economic adjustment should be implemented to increase farmers' agricultural income percentage. This could encourage farmers to spend more time on farm work and raise their willingness to learn advanced N fertilizer management skills. Education level was negatively correlated to N fertilizer application rates as education changed ways to access knowledge, and the educated farmers were able to evaluate the quality of the N fertilizer. Accordingly, policy makers should offer more opportunities to the farmers to finish their basic education, which could help them to reduce N use. Furthermore, with the development of fertilizer markets and transportation infrastructure in the surveyed region, factors relating to fertilizer transportation did not show a significant correlation with N fertilizer application rates.

Nevertheless, farmers' N fertilizer practice is a complex system, which cannot be explained adequately by a single theory or several factors (Kung and Cai, 2000). Although factors significantly related to N fertilizer application rates at household level were determined in this study, analysis on other factors such as policy factors on the government level and cost-benefit factors at the market level is urgently needed to deepen the insight on the complete picture of factors that are associated with excessive N use. Moreover, time series data from household surveys would be helpful to prove and estimate factors which are driving N fertilizer overuse.

3. EFFECT OF CROP AND N FERTILIZER MANAGEMENT ON GRAIN YIELD, N USE EFFICIENCY, AND SOIL N DYNAMICS

3.1 Introduction

It is estimated that nitrogen (N) losses of around 92-105 million ton per year from agricultural activities occur globally through denitrification, leaching and erosion (Smil, 1999), contributing to 33% of the global reactive N losses (Boyer et al., 2004). The N losses from agriculture have caused severe damage to the environment (Galloway et al., 2008). China has to feed 22% of the world population with only 7% of the world's arable land (Wang et al., 2012b). To reach and maintain high yield levels, more than 30% of the global N fertilizers were applied in China during 2006-2007 (Heffer, 2009). However, due to overuse of N fertilizer, only 18-35% of the applied N was recovered by crops (Ju et al., 2009). This low N recovery has caused severe environmental degradation and pollution of water bodies with nitrate (Feng, 2007). Minimizing these N losses while maintaining or increasing yields are a prerequisite for the sustainable agricultural intensification in China.

Central China has a subtropical monsoon climate, with abundant rainfall and fertile soils. Agricultural land use is very intensive with mineral fertilizer inputs of 172-291 kg N ha^{-1} $season^{-1}$ (Wang et al., 2013a). A considerable share of this applied N fertilizer is not used by crops. It may remain temporarily in the soil after crop harvest, where it is prone to leaching to deeper soil layers and into the groundwater, particularly during the bare fallow transition periods between crops. Cover crop plantation during transition period instead of bared fallow is one of the mostly popular field managements that reduce N leaching (Salmerón et al., 2011); while, non-legume cover crops were proved to have risk to reduce following crop yield (Salmeron et al., 2010), thus, leguminous cover crops are primarily chosen as cover crop species. So far, replacing bare fallow with a leguminous cover crop during the transition season is currently not practiced in Hubei Province (Tonitto et al., 2006). Legume cover crop has been considered as a promising option to trap soil N in biomass, thus reducing N losses (Gabriel and Quemada, 2011). Furthermore, recycling the trapped N may additionally enhance yields and N use efficiency (NUE) (Becker et al., 2007).

To improve NUE, N fertilizer application must be synchronized with crop-N requirements (Pasuquin et al., 2012). Currently, the N fertilizer application rate generally exceeds crop demand in China (Mueller et al., 2012), and a recent study suggests that they can be cut by 30 -60% without reducing crop yields (Ju et al., 2009). In addition, multiple split applications are required to match N supply with the crop demand at different growth stages (Sitthaphanit et al., 2010). The difficulties of consistent supply-demand synchronization has been highlighted by Dinnes et al. (2002a). However, split application of mineral-N fertilizer alone may not be sufficient to enhance NUE or to curb N losses, as results tend to be inconsistent (Pasuquin et al., 2012). Such inconsistencies are likely to be related to neglecting differential dynamics of the soil-N supply, particularly during periods when fields lie fallow. Thus, replacing the bare fallow with an N-catching legume cover crop during the transition season combined with mineral-N management practices that take into account native soil -N supply is hypothesized to reduce input rates while improving NUE and yield. The objectives of this chapter comprise evaluation transition season and modified mineral fertilizer -N management regarding: (1) soil-N dynamics in the root zone (0-100 cm), (2) grain yield, and (3) agronomic and physiological N fertilizer use efficiency as well as crop N-recovery.

3.2 Materials and methods

3.2.1 Experimental site

A field experiment was carried out in 2012-2013 at a farmer's field in Tuanjie village, located in Hubei Province, Central China (28 m asl, 30°14´ latitude and 114°23´ longitude). The subtropical monsoon climate in this region is characterized by an annual average precipitation of 1,100 mm and temperatures of 15.7 ºC -16.4 ºC, with a mean frost-free period of 230-300 days. The soils are ferric Acrisols (FAO classification system- WRB; FAO 2003). With an average farm size of only 0.23 ha per household (Hubei Provincial Bureau of Statistics, 2008), farmers commonly cultivate two crops per year. The main crops are rice and maize during the summer season, and wheat and rapeseed during the winter season. Mineral N fertilizers are applied at rates of 170-290 kg N ha^{-1} per season, usually as urea or ammonium bicarbonate (Wang et al., 2012a). The mean yields are 7.5 Mg ha^{-1} for paddy rice, 6.0 Mg ha^{-1} for wheat, 2.3 Mg ha^{-1} for rapeseed and 6.5 Mg ha^{-1} for maize (National Bureau of Statistics of China, 2010). Between the summer and winter season crops there is a fallow period of 8-12 weeks during which precipitation is high (Figure 3.1). This potentially contributes to large soil N losses by nitrate leaching (Kramberger et al., 2009).

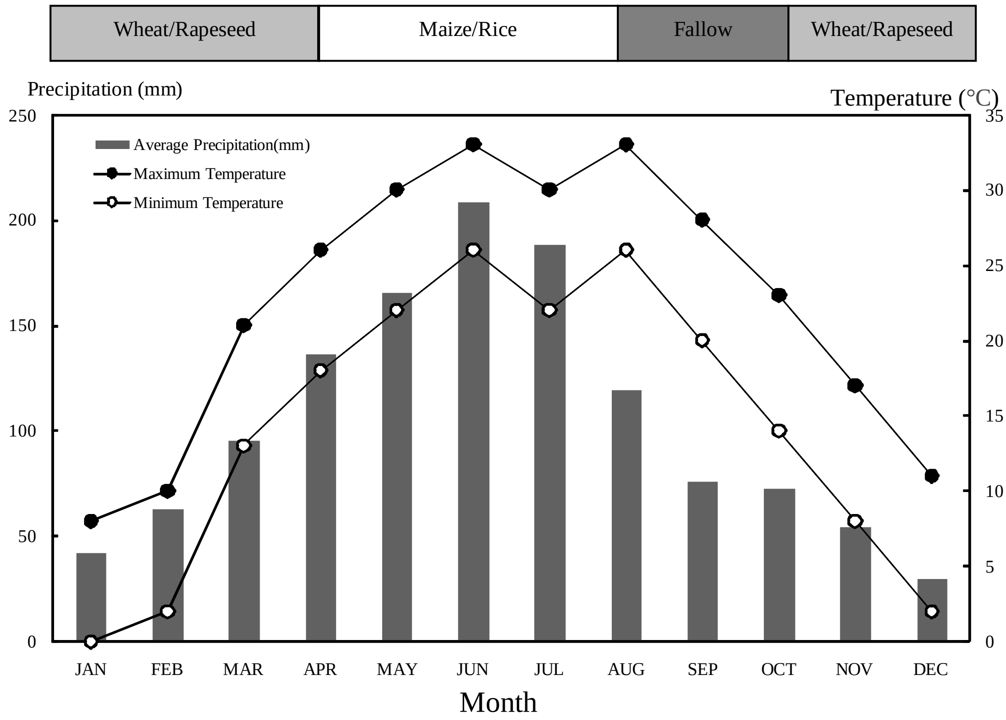

Figure 3.1 Average monthly precipitation, maximum and minimum monthly temperature in Hubei Province, Central China (1951-2008).

3.2.2 Field preparation and experimental design

Prior to this study, the experimental field area had been homogenized for 5 years by growing a single crop of summer maize followed by an 8-month fallow period. Land was prepared manually using a hoe. Selected initial soil properties are listed in the Table 3.1

Table 3.1 Selected initial soil properties of the experimental field area in Hubei Province

Depth (cm)	0-20	20-60	60-100	100-140	140-180
Soil texture	Silt loam	Silt loam	Silt loam	Silt loam	Silt loam
Clay (%)	16	16	16	14	14
Silt (%)	74	70	68	68	67
Sand (%)	10	14	16	18	19
Bulk density (g mL^{-1})	1.39	1.46	1.54	1.62	1.64
Organic matter (g kg^{-1})	6	4	4	3	3
pH (1:2.5)	5.2	5	5	5	5.1
Available K (mg kg^{-1})	48	45	48	55	58
Available P (mg kg^{-1})	16	15	16	16	16
Available N (mg kg^{-1})	43	32	24	24	26
CEC (c·mol kg^{-1})	9	8	8	9	11
NO_3^--N (mg kg^{-1})	0.8	1.1	1.1	1.1	1.1
NH_4^+-N (mg kg^{-1})	4.5	3.7	4.6	4.9	4.3

Available P and K: modified Olsen extraction; CEC: cation exchange capacity.

The experiment was carried out based on a completely randomized block with two factors (field management with and without cover crop and four N fertilizer application rates) and three replications (24 plots of 40 m^2 each) in an orthogonal design. The N fertilizer application rates comprised a control without N fertilizer (N_0), a reduced N fertilizer rate of 280 kg N ha^{-1} $year^{-1}$ (N_1), a locally recommended N fertilizer rate with 380 kg N ha^{-1} $year^{-1}$ (N_2) and farmers' conventional N fertilizer rate of 470 kg N ha^{-1} $year^{-1}$ (N_3). The amounts of N fertilizer applied and the timing of the applications are listed in Table 3.2. Individual plots were ridged with plastic sheet to 40 cm below ground to prevent water movement between plots. Test crops included maize (*Zea Mays. L,* Denghai No. 9) and winter wheat (*Triticumaestivum,* E'mai No. 27) grown in rotation. Cowpea (*VignaunguiculataL.Walp,* Zhijiang'aiman No. 1) was cultivated as a cover crop during the transition period between the harvests of maize to the seeding of wheat.

Table 3.2 Mineral N fertilizer application rates on summer and winter crops in the field experiment in Hubei province (2012-2013) (kg N ha^{-1})

Treatment	Total	Crop					
		Maize			Wheat		
		Sowing	Tillering	Jointing	Sowing	Anthesis	Shooting
CN_0/BN_0	0	0	0	0	0	0	0
CN_1/BN_1	290	48	64	48	39	52	39
CN_2/BN_2	380	80	120	0	72	108	0
CN_3/BN_3	470	100	150	0	88	132	0

CN_0, CN_1, CN_2 and CN_3 refer to legume cover crop treatment receiving no N fertilizer, reduced, recommended and farmers' N fertilizer rates, respectively; BN_0, BN_1, BN_2 and BN_3 refer to bare fallow treatment receiving N fertilizer treatments as mentioned above.

Basal fertilizers were applied at 180 kg P ha^{-1} as calcium superphosphate (95 kg in the maize season and the rest in the wheat season) and 140 kg K ha^{-1} as potassium chloride (75 kg in the maize season and the rest in the wheat season) incorporated prior to sowing at a depth of 5-8 cm. Pre-emergence herbicides and hand hoeing were used for weed control during the copping period when necessary. All plots were managed by farmers and controlled by the researcher. First-year maize (2012) was sown on 17 April 2012 at 50 cm × 50 cm spacing and harvested on 10 August 2012. The transition period started from 11 August 2012 and ended on 20 October 2012. In regard to cover crop treatments, cowpea was sown at 40 cm × 50 cm spacing while others were left as the weedy fallow treatments. No fertilizer was applied in the transition period. Winter wheat was cultivated from 21 October 2012 to 19 May 2013 at a density of 2.4 million seeds ha^{-1} with row spacing of 20 cm. Second-year maize (2013) was sown in a seed bed, transplanted to the experimental field on 20 May 2013, and harvested on 25 August 2013. The adopted practices during the second year maize (2013) were same as in the first year (2012).

3.2.3 Sampling and chemical analysis

Aboveground biomass, grain yield and crop-N uptake were based on three randomly selected areas of 1 m^2 each, inside each plot. Plant samples were oven dried at 70 °C until reaching constant weight after an initial heating at 105 °C for 30 minutes. The dry matter of the aboveground biomass was separated into grain and straw, and ground to pass a 0.25-mm sieve for further N analysis. Samples were digested with H_2SO_4–H_2O_2 and determined in line with the Kjeldahl method (Bremner, 1960).The amount of N fixed by the legume cover crops was not determined and was assumed to be 40 kg N ha^{-1} (Jemo et al., 2006). The N fixed by the legume cover crops was regarded as additional N input only in the wheat season.

Prior to the field experiment, soil samples were collected from 180 cm depth (0-20 cm, 20-60 cm, 60-100 cm, 100-140 cm and 140-180 cm) for initial soil analyses (Table 3.1). The soil texture was analyzed by laser particle analyzer (Mastersizer 2000, UK); soil organic matter was oxidized to CO_2 by $K_2Cr_2O_7$ – H_2SO_4 and using oil-bath heating at 180°C to determine organic matter content; soil pH was determined in a water and soil solution of 2.5:1; available N was determined by dissolving soil samples in 1.0 M NaOH and analyzed with the titrimetric method (Zhang and Gong, 2012); available P was analyzed with the Olsen-P method based on extraction of air-dry soil with 0.5 M $NaHCO_3$ (pH 8.5) (Olsen et al., 1954); available K was analyzed by extracting samples with 1.0 M NH_4OAc and determined by a flame photometer (Van Reeuwijk, 2002); cation exchange capacity (CEC) was determined in 0.025 M $(NH_4)_2C_2O_4$ -0.025 M NH_4Cl, and 2 drops phenolphthalein indicator added to determine the 0.05 M NaOH consumption.

The soil NO_3^--N and NH_4^+-N contents in the root zone (0-100 cm) at 20 cm depth intervals were sampled at bi-weekly intervals starting from the sowing of the cover crop. After N fertilizer application, samples were collected every week for a period of one month. Four soil cores were taken from each plot and mixed by depth to provide composite soil samples representing different depths of each plot. All samples were placed in a closed plastic bag, immediately frozen and transported to the laboratory. Fresh soil samples weighing 10 g were extracted with 100 ml 1 M KCl after shaking for 2 hours at 100 r.p.m. The NO_3^--N and NH_4^+-N concentration in the soil extracts were determined colorimetrically. Finally, the concentration values (mg N kg^{-1} soil) were translated into amounts (kg N ha^{-1}) considering the soil bulk density.

All samples were divided for triplicate analysis before digestion. To ensure the analytical quality, standard solutions with gradient content were examined at the same time with samples for standard curves, where the R^2 of standard curves should be higher than 0.999.

3.2.4 Data analysis

Statistical analyses and graphic presentations were made with STATA 12.2 and Microsoft Excel. Mixed modeling for nest analysis of variance (ANOVA) was performed to statistically determine the differences in soil NO_3^--N and NH_4^+-N content under different treatments at fixed layers and time. The Duncan Multiple Range test at $P \leq 5\%$ level was used to determine the significance levels.

Three different indexes were used to explore the efficiency of N fertilizer use, namely: agronomic N fertilizer use efficiency (aNUE, kg additional grain kg^{-1} N applied), physiological nitrogen efficiency (pNUE, kg N uptake kg^{-1} N applied), and apparent N fertilizer crop recovery (RE, in percentage), and calculated as follows:

$$aNUE = \frac{Y_N - Y_{CK}}{F_N + F_B} \tag{3.1}$$

$$pNUE = \frac{Y_N - Y_{CK}}{U_N - U_{CK}} \tag{3.2}$$

$$RE=\frac{U_N - U_{CK}}{F_N + F_B}\times 100 \quad (3.3)$$

where Y_N is the grain yield with N fertilizer application (kg ha^{-1}); Y_{CK} is the grain yield of the control group without N fertilizer application (kg ha^{-1}); F_N is the amount of N fertilizer applied (kg N ha^{-1}); F_B is the amount of N fixed by the legume cover crop (kg N ha^{-1}); U_N is the crop-N uptake in aboveground biomass at maturity with N fertilizer application (kg N ha^{-1}); U_{CK} is the crop-N uptake of the control treatment without N fertilizer (kg N ha^{-1}).

3.3 Results

3.3.1 Grain yield and aboveground biomass

Aboveground biomass and grain yield differed between treatments (Table 3.3). In the absence of mineral N fertilizer application, first-year maize (2012) yield was about 0.8-1.3 Mg ha^{-1} and thus 27%-57% lower than with mineral N amendments. The legume cover crop increased the yield of the subsequent wheat crop by 17% and that of the second-year maize by 13% in comparison to the no-N-input control, while no significant effects were observed when the recommended or farmers' N fertilizer rates were applied. The reduced and the recommended N fertilizer rates resulted in similar yields, while those receiving farmers' N management showed highest grain yield in the first season (2012) maize crop.

Table 3.3 Yield and aboveground biomass ($Mgha^{-1}$) of main season crops with different N application rate and transition season strategies in Hubei Province (2012-2013)

Treatment	Maize(2012)		Wheat (2012)		Maize(2013)	
	Grain	Biomass	Grain	Biomass	Grain	Biomass
CN_0	5.98^{c}	14.37^{c}	4.10^{d}	6.62^{c}	3.95^{e}	11.58^{d}
BN_0	5.90^{c}	14.36^{c}	3.48^{e}	6.66^{c}	3.51^{f}	11.39^{d}
CN_1	6.88^{b}	18.32^{b}	6.60^{a}	11.33^{a}	6.96^{ac}	17.21^{bc}
BN_1	6.88^{b}	18.39^{b}	6.41^{b}	11.84^{a}	6.84^{b}	17.54^{bc}
CN_2	6.95^{b}	18.82^{a}	6.38^{b}	11.62^{a}	6.93^{b}	17.67^{ab}
BN_2	6.85^{b}	18.87^{a}	6.42^{b}	11.43^{a}	6.92^{ab}	17.94^{a}
CN_3	7.28^{a}	18.65^{a}	5.80^{c}	9.71^{b}	6.75^{cd}	17.44^{bc}
BN_3	7.26^{a}	18.86^{a}	5.83^{c}	9.98^{b}	6.71^{d}	17.28^{c}

Within the column, values followed by different letter are significantly different at $p < 0.05$ with Duncan test. CN_0, CN_1, CN_2 and CN_3refer to legume cover crop treatment receiving no N fertilizer, reduced, recommended and farmers' N fertilizer rates, respectively; BN_0, BN_1, BN_2 and BN_3refer to bare fallow treatment receiving N fertilizer treatments as mentioned above.

3.3.2 Agronomic indices of fertilizer use efficiency

The legume cover crop decreased the physiological N use efficiency (pNUE) at all studied N fertilizer rates in wheat and in the second-year maize (Table 3.4). In wheat, a higher N fertilizer rate increased pNUE, an effect that was not observed in maize, irrespective of the season. The agronomic efficiency (aNUE) of wheat and the second-year maize decreased with increasing N application rates, while aNUE was similar in the first-year maize crop (2012) among all treatments. The legume cover crop reduced aNUE compared to the bare fallow treatments. No differences between bare fallow and cover crop treatments were observed in the second-year maize season (2013) with the farmers' N fertilizer application rate.

The legume cover crop did not significantly influence the apparent N fertilizer crop recovery (RE) in any of the three crop seasons (Table 3.4). However, RE decreased with N-application rates in both the cover crop and the bare fallow treatments. Thus, in contrast to the reduced N application rate, the cover crop did not affect the use efficiency of applied N.

Table 3.4 Agronomic indicators of N fertilizer use efficiency with different N application rate and transition season strategies in Hubei Province (2012-2013)

Treatment	pNUE (kg kg^{-1})			aNUE (kg kg^{-1})			RE (%)		
	Maize (2012)	Wheat (2012)	Maize (2013)	Maize (2012)	Wheat (2012)	Maize (2013)	Maize (2012)	Wheat (2012)	Maize (2013)
CN_1	10.8^{a}	45.1^{e}	32.3^{b}	5.6^{ab}	13.2^{b}	18.3^{b}	52^{ab}	28^{a}	58^{a}
BN_1	11.3^{a}	58.6^{b}	34.5^{a}	6.1^{a}	15.4^{a}	20.7^{a}	54^{a}	27^{a}	60^{a}
CN_2	10.8^{a}	50.6^{c}	30.6^{b}	4.8^{b}	10.4^{d}	14.9^{c}	45^{de}	19^{b}	49^{b}
BN_2	11.3^{a}	64.8^{a}	35.4^{a}	4.8^{b}	13.4^{b}	17.0^{b}	42^{e}	19^{b}	48^{b}
CN_3	11.2^{a}	45.5^{d}	29.1^{b}	5.2^{b}	6.5^{c}	11.2^{d}	47^{cd}	13^{c}	39^{c}
BN_3	11.0^{a}	67.6^{a}	36.5^{a}	5.4^{ab}	9.4^{d}	12.8^{d}	47^{bc}	12^{c}	35^{c}

Within the column, values followed by different letter are significantly different at $p < 0.05$ with Duncan test. CN_0, CN_1, CN_2 and CN_3 refer to legume cover crop treatment receiving no N fertilizer, reduced, recommended and farmers' N fertilizer rates, respectively; BN_0, BN_1, BN_2 and BN_3 refer to bare fallow treatment receiving N fertilizer treatments as mentioned above. pNUE is physiological nitrogen use efficiency; aNUE is agronomical nitrogen use efficiency; RE is apparent recovery nitrogen efficiency percentage.

3.3.3 Mineral soil N dynamics

The NO_3^- and NH_4^+ are the main inorganic forms of N in the soil. In this study, the dynamics of NO_3^--N and NH_4^+-N were determined in different soil layers at 15 -day intervals after the harvest of the first-year maize (2012). In general, the average content of both NO_3^--N and NH_4^+-N in the soil profiles tended to increase with N application rates (Table 3.5), whereby the content in NO_3^--N largely exceeded that of NH_4^+-N (Figure 3.2). Legume cover crop and reduced N application treatments did not have a significant effect on residual soil NH_4^+-N in the root zone (0-100 cm). Furthermore, cover crops did not significant influence the soil mineral N content in the root zone (0-100 cm) during the transition season, irrespective of the mineral N rate applied to the preceding cereal crop (Table 3.5). In contrast, cover cropping reduced soil NO_3^- content significantly, except in the control plots without N fertilizer during the wheat and the second-year maize seasons.

Table 3.5 Average soil NO_3^--N and NH_4^+-N content (kg ha^{-1}) during transition, wheat and maize seasons as affected by N application and transition season management in Hubei Province (2012-2013)

Treatments	Transition season		Wheat season		Maize season	
	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+
CN_0	12.9^e	4.5^d	6.1^f	9.6^{cd}	13.2^f	9.4^{ab}
BN_0	14.1^e	3.9^d	8.1^{ef}	9.1^d	14.3^f	8.1^{bc}
CN^1	17.7^{de}	9.9^{bc}	9.2^e	11.0^{bc}	24.2^e	9.7^{ab}
BN_1	22.1^{cd}	7.1^{cd}	14.6^d	10.7^{cd}	28.1^{de}	9.9^{ab}
CN_2	25.9^{bc}	10.2^{bc}	20.2^c	10.6^{cd}	32.9^{cd}	10.8^a
BN_2	29.8^{ab}	8.7^{bc}	26.2^b	12.8^b	37.0^c	8.0^{bc}
CN_3	29.7^{ab}	11.5^b	19.4^c	14.9^a	46.9^b	7.2^c
BN_3	33.1^a	16.48^a	31.5^a	14.9^a	54.6^a	10.0^{ab}

Values in a column followed by the same letter do not differ significantly according to the performed mixed modeling ANNOVA test p=0.05. CN_0, CN_1, CN_2 and CN_3 refer to legume cover crop treatment receiving no N fertilizer, reduced, recommended and farmers' N fertilizer rates, respectively; BN_0, BN_1, BN_2 and BN_3 refer to bare fallow treatment receiving N fertilizer treatments as mentioned above.

The dynamics of NO_3^--N in the root zone during the transition seasons revealed a risk of N leaching. At farmers' N fertilizer application rates, we observed the highest soil nitrate content in the root zone while much lower soil N was observed in the untreated control plots. The combination of a reduced N fertilizer rate with a cover crop during the transition season resulted in relatively low soil nitrate contents during the transition season after harvesting the maize crop (Figure 3.2). Compared to the high farmers' N fertilizer rate, the cover crop combined with reduced N fertilizer rate was able to reduce the peak nitrate content by 25-88% in the transition season, 62-69% in the wheat cropping season and 39-45% in the maize cropping season.

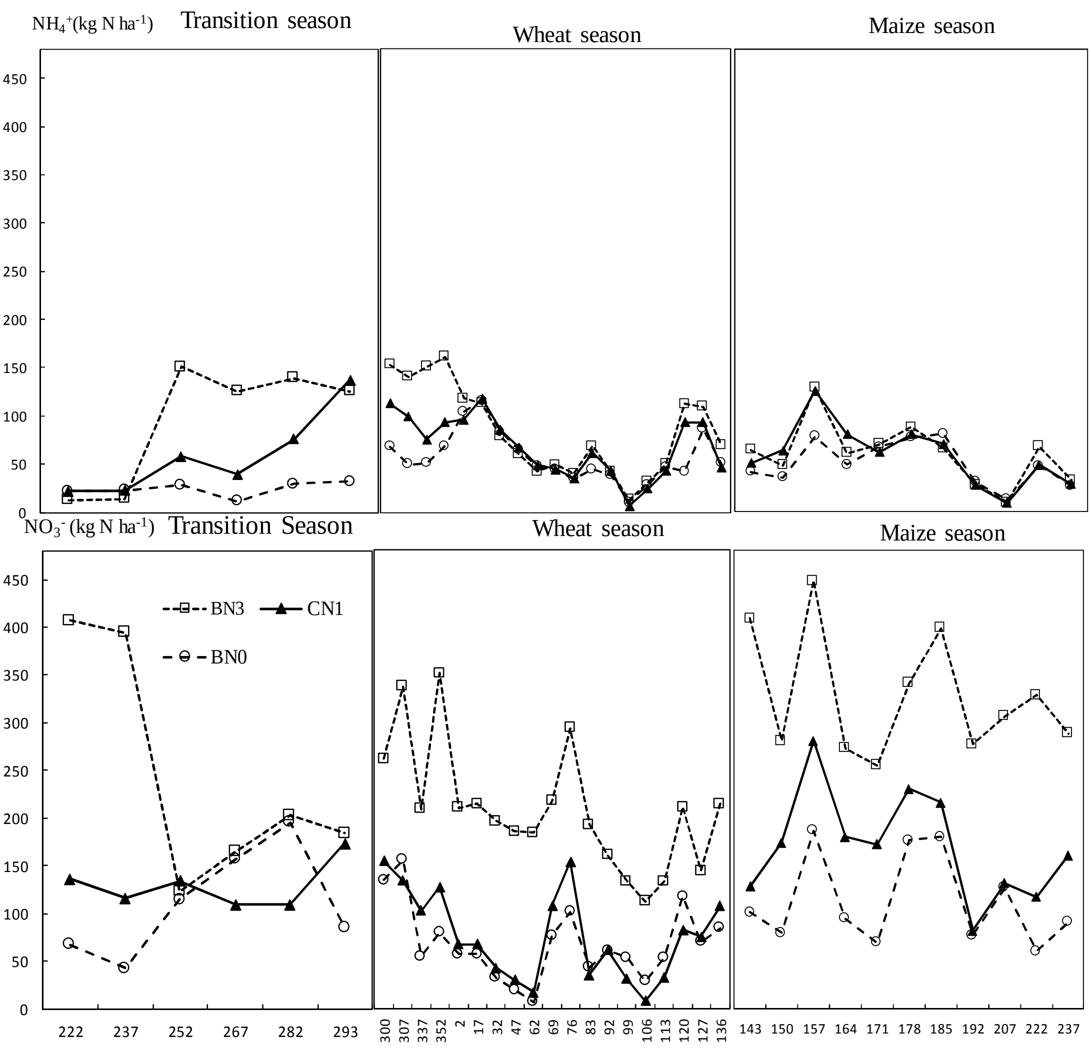

Figure 3.2 Effect of reduced N fertilizer rate and legume cover crop on mineral soil N (ammonium and nitrate) in root zone (0-100 cm) in Hubei Province (2012-2013). CN_1 means legume cover crop receiving reduced N fertilizer rates. BN_0 and BN_3 mean bare fallow receiving no N fertilizer and farmers' N fertilizer rates, respectively

In contrast, the treatments had less influence on soil NH_4^+-N, irrespective of the cropping season (Figure 3.2). All treatments showed similar patterns with peak soil NH_4^+-N values at the beginning of the wheat season and lowest values in the maize season and no significant differences between treatments.

3.4 Discussion

3.4.1 Effects of management options on yield and N-use efficiency.

The results showed that cover cropping increased grain yields when treated with no-N or reduced-N fertilizers. However, increased grain yield was not observed in plots treated with the locally recommended or the even higher farmers' N fertilizer rate.

Reported effects of cover cropping on grain yield in literature have been inconsistent. Odhiambo (2011) observed increased corn yields after legume cover crops in smallholder farms. Whereas, Kramberger et al. (2009) reported decreased yields in some cases. Meanwhile, Gabriel and Quemada (2011) reported that corn yield did not respond to legume cover cropping. The main cause for the different observations is that legume cover crops will only be able to improve grain yield if the amount of N fertilizer cannot satisfy the crop requirements. This is not the case in the present study, whereby N fertilizer application rate exceeded the crop requirements and grain yield did not respond to legume cover treatments. Miguez and Bollero (2005) concluded, based on the comparison of the results of 34 studies using a meta-analytic approach, that the yield, which increased due to legume cover cropping, could still be decreased through higher N application rates (Miguez and Bollero, 2005). Accordingly, a legume cover crop instead of bare fallowing could increase the grain yield if the

N-application rate does not exceed the crop demand. Otherwise, it might not influence the subsequent crop yield.

The control treatment without N fertilizer had significantly lower grain yield and aboveground biomass compared to the other N fertilizer rates. This indicates that additional N input is necessary to maintain sustainable yields (Larson and Frisvold, 1996). The grain yield of maize from the first-year (2012) to second-year (2013) declined considerably because of N deficiency in the soil resulting from continuous no -N fertilizer treatment (Nyombi et al., 2010). The reduced-N and recommended N fertilizer treatments had statistically similar grain yields and aboveground biomass throughout the three crop seasons.

This study also showed that the farmers' management of N fertilizer usage could significantly increase the crop yield at the beginning of the season. However, it can reduce the yield of the following season if crops are continuously treated with a high amount of N fertilizer. The sharp change in yield is due to the inability of existing N content in the soil to satisfy crop demand; the crops treated with high-N fertilizer absorbed more N, resulting thus in higher grain yields. However, after one maize season, the soil was rich in N as a result of residual N. Continuous and high N fertilizer application could result in excessive N relative to crop demand. This could lead to mutual shading and higher crop competition, which leads to lower yield (Qiao et al., 2013).

Similarly, Meyer-Aurich et al. (2010) showed that a quadratic response function fits the relationship between crop yield response and N fertilizer application rate. The results of our study from three cropping seasons did not reveal an optimal N rate that maximizes grain yields. Other factors, especially soil N content, may play a more important role (Islam and Garcia, 2012). The similar grain yield and aboveground biomass observed under different N treatments in this study could be explained by lower N-use efficiency at increasing N-application rates.

Importantly, the legume cover crop exhibited significantly decreased the physiological nitrogen use efficiency (pNUE) at all tested N fertilizer rates, which is in line with previous research (Cassman et al., 2002). Compared to bare fallow fields, the legume cover crop without N fertilizer application improved the yield of wheat and maize by 15% and 11% respectively. This showed that legume cover crop systems rely less on additional mineral N fertilizer input than bare fallow systems, which lowers pNUE (Cassman et al., 1996).

The agronomic N fertilizer use efficiency (aNUE) decreased significantly with increased mineral N fertilizer rate in the wheat and second-year maize (2013) crops, but not in the first-year maize (2012) season. After 8 months of fallow, the experimental field was deficient in N at the beginning of the experiment. Yields increased with higher N fertilizer rates, and therefore no significant N fertilizer effects on aNUE were observed in the first maize (2012) season. In the wheat and second-year maize crops, the N losses increased with higher N input. Therefore, when N supply exceeds crop demand, additional N input leads to lower aNUE (Di and Cameron, 2002). The legume cover crop decreased the aNUE at all tested fertilizer rates. This may be due to excessive N supply relative to crop demand.

The legume cover crop did not influence the apparent N fertilizer crop recovery (RE) in any of N fertilizer treatments. Cover crops can capture N in the soil, but the decomposition of cover crop residues can also increase N immobilization. Furthermore, if the amount of N released through the decomposition of the cover crops exceeds the demand by the following crop, the biomass-N captured by cover crops can be leached into the subsoil and ground water (Arlauskiene and Maiksteniene, 2012). To improve RE, decomposition of cover crop residue and N demand of main crop should therefore be considered when implementing a legume cover crop management system (Justes et al., 2009). Nitrogen losses may explain the decline of RE at increasing N fertilizer rates observed in this study (Zhang et al., 2012).

3.4.2 Effects of management options on soil N dynamics

High mineral N content in soil presents the risk of N loss through runoff and leaching (Tian et al., 2007). Two-split mineral N fertilizer treatments had higher soil NO_3^- residue than three-split treatments after the harvest of the first-year maize (2012), most was lost within 30 days. Therefore, the period of time shortly after maize harvest is critical for protecting soil NO_3^--N from leaching. However, since the legume cover crops were not well established in the short term, this treatment could not reduce the soil mineral N content in this critical period (Figure 3.2). Sowing cover crops before harvesting the main crops should therefore be tested in the future (Arlauskiene and Maiksteniene, 2012). Compared to farmers' N fertilizer rates with bare fallow treatment, reduced three-split mineral N fertilizer and legume cover crop management options can significantly decrease the soil NO_3^--N residue after the main crop harvest (Figure 3.2) because of several factors. Firstly, the cover crop traps the soil mineral N in the biomass, which reduces soil NO_3^--N content. Secondly, bare fallow plots have higher nitrification activity than cover crop, which transforms more soil organic-N to NO_3^--N (Janušauskaitė et al., 2013). Thirdly, three-split N fertilizer application could well meet the crop requirements, thus less NO_3^--N remains as residue in the soil layers after crop harvesting. However, because of high nitrification rate in arid land cropping systems and ready transformation of NH_4^+-N into NO_3^--N through nitrification, neither cover crop treatments nor different N application rates changed the NH_4^+ content significantly.

Positive correlations between residual N after the harvest of the main crops and N application rates were observed independently of the legume cover crop (Figure 3.3). Soil NO_3^- content increased significantly with an increase in the N application rate, which is in line with other research (Zheng.Y.M et al., 2007). Therefore, three-split application and reduced-N fertilizer management combined with legume cover cropping is an effective way to reduce residual soil N after harvesting the main crops, which in turn reduces the risk of N losses (Pasuquin et al., 2012).

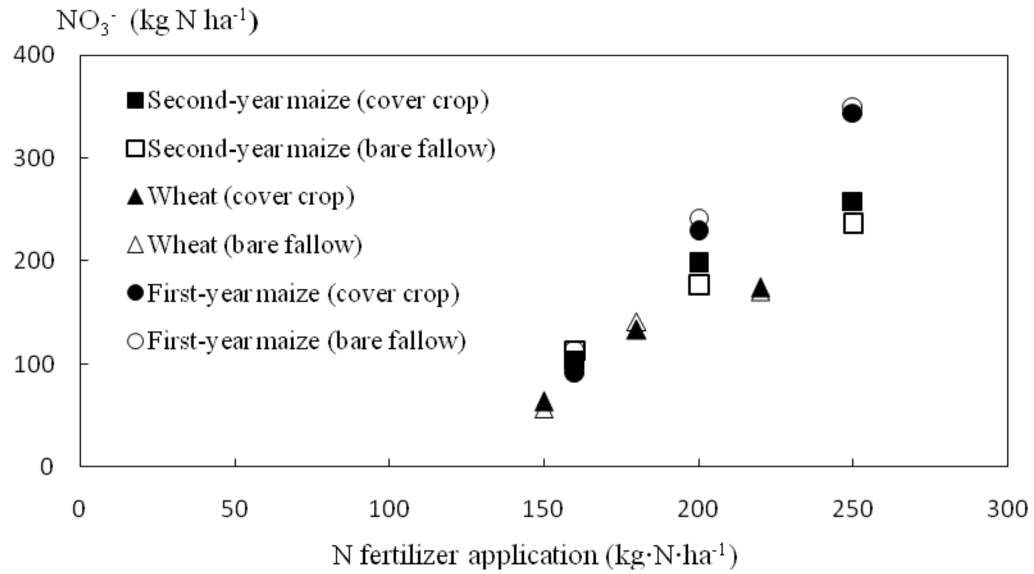

Figure 3.3 Effect of N fertilizer application rate on soil nitrate residual in the root zone (0-100 cm) after harvest of main crops in Hubei Province, Central China (2012-2013).

3.5 Conclusions

Managing crops using three-split dosage and reduced-N fertilizers in combination with legume cover cropping preserved yield and aboveground biomass, which implies higher aNUE and RE than current conventional practice. Legume cover crop treatment, reduced-N fertilizer and split application rates decreased soil NO_3^--N content in the root zone (0-100 cm) during the cropping period. Large amount of soil NO_3^--N were lost within 30 days after the maize harvest, as the legume cover crop does not prevent such loss if it is sown after the harvest of the main crop. In all three cropping seasons, NO_3^--N residue in soil after the harvest of the main crop had positive correlation with N application rates.

4. EFFECTS OF CROP AND N FERTILIZER MANAGEMENT ON NITRATE LEACHING

4.1 Introduction

Overuse of N fertilizer considerably enhances N leaching, which in turn causes severe groundwater pollution, impacting the water quality and endangering human health. Most of the leached NO_3^--N originates from mineralized soil organic matter beyond the growing season, due to soil moisture increase in autumn and winter (Di and Cameron, 2002; Kramberger et al., 2009). Leaving agricultural land fallow during the transition season between two crops increases the risk of NO_3^--N leaching (Di and Cameron, 2002). Therefore, replacing the bare fallow land surface with a cover crop during the transition season is an option to reduce NO_3^--N leaching (Vos and van der Putten, 2004). Becker et al. (2007) reported that growing a short-cycle cover crop (< 90 days) instead of leaving the land bare and reusing the crop residues may reduce N losses due to leaching and denitrification. Moreover, growing N-fixation crops during the fallow period could absorb additional N from the atmosphere into the cropping system and reduce the chemical N fertilizer demand (Pande and Becker, 2003). Further benefits of replacing bare fallow by cover crops such as improved N-use efficiency (Dinnes et al., 2002b), reduced NO_3^--N leaching (Vos and van der Putten, 2004), enhanced soil aggregate stability and water retention capacity (Quemada and Cabrera, 2002; Gabriel and Quemada, 2011), and weed suppression (Abawi and Widmer, 2000) were also reported. However, the benefits of a legume crop will be weakened with increasing N fertilizer application rates (Gabriel and Quemada, 2011). The benefit of reducing N loss becomes uncertain at high mineral N fertilizer application rates (Cassman et al., 2002), especially when cover crop residuals are used as green manure for the following crops (Tonitto et al., 2006). Therefore, to maximize the benefit of legume cover crops, research should focus on how to integrate cover crop management into strategies of mineral N fertilizer management in terms of application time and amount (Miguez and

Bollero, 2005). Nevertheless, only little information is available on the quantitative analysis of N leaching influenced by cover crops in combination with N fertilizer managements.

The hypothesis of this study is that reduced three-split N fertilizer strategy and avoiding bare fallow have the potential to reduce N loss through leaching. The specific objectives were to determine the effect of the above-mentioned managements on: (1) water balance, (2) NO_3^--N and NH_4^+-N concentration in the soil solution, and (3) amount of NO_3^--N and NH_4^+-N lost through leaching.

4.2 Materials and methods

4.2.1 Experimental design and field management

The conditions at the experimental site and the basic design of the experimental field managements are presented in Chapter 3. Two porous ceramic suction cups and soil water content sensors (Spectrum, SM-100, USA) were installed in each plot at 1.0 m and 1.8 m depth, respectively. Bentonite was used to avoid preferential flow after suction cup initialization. This was carried out following the method published by Lord and Shepherd (1993).

4.2.2 Sampling and field measurement

Meteorological data

Meteorological data were collected at 0.5 km distance from the field by a weather station which was provided by Spectrum Company (Watchdog 2700 ET, USA). The following data were collected in 30-min intervals: maximum, average and minimum air temperature, relative humidity, precipitation, solar radiation, dew point, wind direction and wind speed. The reference evapotranspiration (ETo) required for AquaCrop (version 4.0) model input was estimated using the software of ETo calculator (version 3.1) developed by the Food and Agriculture Organization (FAO) and based on the Penman-Monteith approach (Gabriel et al., 2012).

Surface runoff and soil solution sampling

After each rainfall event, the volume of water accumulated in the runoff collection tanks was determined using a volume-depth relationship. Then, 300 ml of the water was sampled in a pre-cleaned bottle, stored in a fridge below 4°C, and transported to the laboratory for NO_3^--N and NH_4^+-N concentration analysis. However, runoff N was negligible during the study period (<1% of the applied N) and is not discussed further.

Soil solution samples were taken in porous ceramic suction cups in 1.0 and 1.8 m depth. Samples were obtained by applying a suction of 70 kPa using a portable vacuum pump. To determine the mineral N concentration in the soil solution, three samples taken from the cup at a sampling day and mixed. The samples were filled in pre-cleaned bottles in 15-day intervals and stored in the fridge at a temperature below 4°C, and transported to the laboratory for NO_3^--N and NH_4^+-N concentration analysis within 24 hours.

The samples were passed through an anion-exchange resin for NO_3^--N separation and concentration, and then measured at 220 nm and 275 nm using a UV spectrophotometer (UV2100, Ruili, Beijing). The samples for NH_4^+-N concentration analysis were pre-treated by adding $ZnSO_4 \cdot 7H_2O$ (100 g L^{-1}) and NaOH (1 mol L^{-1}) and filtered, and finally determined by the Nessler reagent spectrophotometry method using a spectrophotometer with 410 nm (Krug et al., 1979).

Soil water content measurement

Soil water content (in volume %) at 1 and 1.8 m depth were measured by soil water content sensors, which were calibrated before use. Calibration curves with the relation between soil volumetric water content and mV output from the probes were established in the laboratory following the method provided by the Spectrum Company using the soil from the experiment field. To ensure the accuracy of the soil water content sensor, gravimetric soil water content at 1 m depth was measured when the soil solution samples were taken.

4.2.3 Model calibration and evaluation

The amount of water percolated in 1.0 m and 1.8 m depth was simulated by the AquaCrop model. Aboveground biomass at different crop stages was used for model calibration. However, only one-season data were available with respect to transition and wheat period; the calibrated model was evaluated using the soil water content data of the same period (Ramanarayanan et al., 1998). The parameters used for the AquaCrop model input are listed in Table 4.1. These parameters were taken from four sources: measurements in the field (M), referring results from similar research (R), calibrated in this study (C), and default values from the model (D). The agreement between the measured and simulated soil water content values was used for model performance evaluation. In particular, the following criteria were applied:

$$\text{RMSE (root mean square error)} = \sqrt{\frac{1}{n}\sum(S_i - M_i)^2} \quad (4.1)$$

$$\text{RRMSE (relative root mean square error)} = \sqrt{\frac{1}{n}\sum(S_i - M_i)^2} \times \frac{100}{\overline{M}} \quad (4.2)$$

$$\text{d (index of agreement)} = 1-\left[\frac{\sum(S_i - M_i)^2}{\sum(|S_i - \overline{M}| + |M_i - \overline{M}|)^2}\right] \quad (4.3)$$

where S_i and M_i indicate the simulated and measured values, respectively; n indicates the number of observations; $\overline{M}$ indicates the average values of measured data.

According to the results reported by Jamieson et al. (1991), the model performance can be considered excellent in case of a RRMSE < 10%, good if 10% ≤ RRMSE < 20%, acceptable if 20% ≤ RRMSE < 30%, and poor if RRMSE > 30%. d varies between 0 and 1, with 1 indicating a perfect fit of simulated and measured values, while 0 means no agreement between simulated and measured values (Wang et al., 2013b).

Table 4.1 Values assigned to specific model parameters to simulate the yield responses of different crops in Hubei Province (2012-2013)

Parameters	Crops			Source
	Maize (2012)	Wheat	Maize (2013)	
Base temperature	8	5	10	R
Cut-off temperature	30	35	30	R
Crop coefficient for transpiration at CC=100%	1.06	0.18	0.429	D
Water productivity	33	17	33	D
Leaf growth threshold p-upper	0.14	0.25	0.14	D
Leaf growth threshold p-lower	0.72	0.65	0.72	D
Stomata conductance threshold p-upper	0.69	0.5	0.69	D
Stomata stress coefficient curve shape	3	3	3	D
Senescence stress coefficient p-upper	0.69	0.85	0.69	D
Senescence stress coefficient curve shape	3	3	3	D
Reference harvest index	47%	50%	47%	D

GDD from sowing/transplanting to 90% emergence	1741	88	86	M
GDD from sowing to senescence	1741	819	1355	M
GDD for sowing to maturity	2009	1481	1682	M
Minimum rooting depth (m)	2	2	2	R
Fertility stress	CN0 (Relative biomass = 76%) BN0 (Relative biomass = 76%) Fertilized plots without fertility stress	CN0 (Relative biomass = 57%) BN0 (Relative biomass = 57%) Fertilized plots without fertility stress	CN0 (Relative biomass = 65%) BN0 (Relative biomass = 63%) Fertilized plots without fertility stress	M
Canopy cover per seedling at 90% emergence/transplanting (CC_0)	0.3	1.62-1.96	3.4	C
Canopy growth coefficient (CGC)	13.2%	15.1%-17.3%	5.5%	C
Maximum canopy cover (CCx)	50%	17%-28%	45%-57%	C
Mulches (Percent of soil surface covered)	0	Cover crop= 50%; Bared fallow = 0%	0	M

CN_0, CN_1, CN_2 and CN_3 mean legume cover crop treatment receiving none, reduced, recommended and farmers' N fertilizer rates, respectively. BN_0, BN_1, BN_2 and BN_3 means bare fallow treatment receiving none, reduced, recommended and farmers' N fertilizer rates, respectively. R means values taken from similar researches. M means values were measured in the field. C means values were calibrated parameter in current study. D means values are default values from the model.

4.2.4 Statistical analysis

The amount of mineral N leaching through the soil profile was calculated by multiplying the N concentration in the soil solution with the volume of percolated water. To represent the actual N leaching, the trapezoidal rule was used as suggested by Lord and Shepherd (1993). Accordingly, the total N leached during two sampling intervals (kg ha^{-1}) was calculated as:

$$\text{N leached} = \frac{0.5(c_1 + c_2)v}{100} \quad (4.4)$$

where c_1 and c_2 are the N content in successive pairs of sampling occasions (mg NO_3^--N L^{-1}), v is the amount of percolation between two sampling occasions (mm).

4.3 Results

4.3.1 Model calibration and evaluation

Calibration

The AquaCrop model calibration was based on the assumption that fertilizer stress did not occur at the N-fertilized plots, whereas fertilizer stress was taken into account at the control plots (without N fertilizer). With respect to consideration of the share of the surface covered in the model, the following differences between bare fallow and cover treatments in the wheat season where made: (i) when the residues of the cover crop were chopped and left in the field for winter wheat, the parameter for the soil surface covered was set at 50% mulch cover; (ii) the parameter in the bare fallow treatments was set 0%. The calibration procedure adjusted the canopy cover until the percentage error between observed and simulated aboveground biomass at different stages was less than 5%. The parameters set after calibration are presented in Table 4.1. The calibrated model produced simulated values of the aboveground biomass which were in good agreement with the measured values at different stages (Figure 4.1).

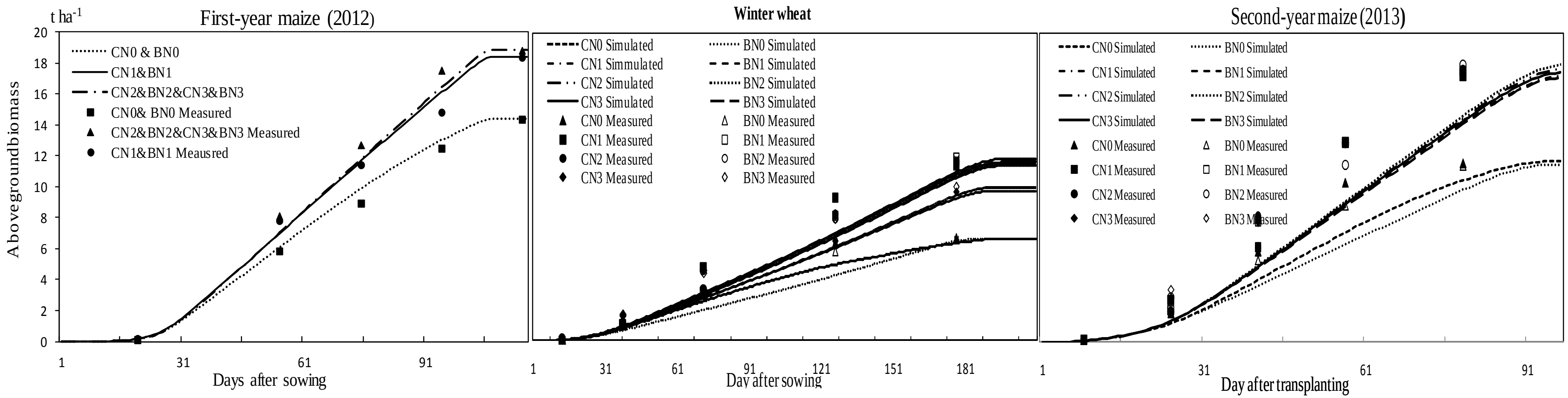

Figure 4.1 Simulated and measured aboveground biomass (Mg ha^{-1}) in three cropping seasons (2012-2013). CN_0, CN_1, CN_2 and CN_3 means legume cover crop treatment receiving none, reduced, recommended and farmers' N fertilizer rates, respectively. BN_0, BN_1, BN_2 and BN_3 denotes bare fallow treatment receiving none, reduced, recommended and farmers' N fertilizer rates, respectively

Evaluation

Model evaluation is necessary to determine the accuracy of simulated values compared to measured values. The good agreement between measured and simulated soil water content is reflected by relative root mean square error (RRMSE) and d-indexes (Table 4.2). Although AquaCrop does not have a function for simulating the living mulch, the volumetric soil water content simulated by the model during cowpea cultivation is acceptable (RMSE = 0.82-1.52%， RRMSE = 1.13-2.94 % and d = 0.32-0.73 in 1 m depth; RMSE = 0.28-0.70%， RRMSE = 0.96-2.41 % and d = 0.28-0.49 in 1.8 m depth). The results achieved by assessment of the statistical model performance prove that the calibrated Aquacrop model can be used to simulate the water balance under the conditions of the study site.

Table 4.2 Results of statistical model evaluation based on soil volumetric data simulated by Aquacrop and measured in the field in Hubei Province (2012-2013)

Depth (m)	Treatment	First-year maize (2012)			Transition season			Wheat			Second-year maize (2013)		
		RMSE	RRMSE (%)	d	RMSE	RRMSE (%)	d	RMSE	RRMSE (%)	d	RMSE	RRMSE (%)	d
1	CN0	0.83	2.79	0.72	0.87	2.94	0.52	1.52	5.08	0.47	0.54	1.87	0.31
	BN0	1.34	4.52	0.73	0.45	1.54	0.73	1.32	4.43	0.51	0.64	2.23	0.34
	CN1	0.62	2.10	0.79	0.52	1.77	0.34	1.00	3.41	0.46	0.98	3.75	0.99
	BN1	0.70	2.38	0.82	0.58	2.01	0.40	0.83	2.83	0.55	0.87	3.38	0.99
	CN2	1.48	5.04	0.70	0.33	1.13	0.43	0.77	2.65	0.47	1.15	4.49	0.99
	BN2	0.53	1.77	0.86	0.52	1.76	0.32	1.04	3.52	0.54	1.06	4.20	0.99
	CN3	0.90	3.02	0.71	0.44	1.52	0.43	0.82	2.79	0.57	0.82	3.29	0.99
	BN3	1.22	3.97	0.75	0.59	2.06	0.47	0.70	2.39	0.58	1.08	4.24	0.99
1.8	CN0	0.82	2.74	0.70	0.44	1.49	0.45	1.02	3.41	0.51	0.59	2.02	0.33
	BN0	0.82	2.73	0.67	0.58	1.99	0.28	0.96	3.20	0.55	0.44	1.52	0.34
	CN1	1.02	3.38	0.72	0.53	1.82	0.46	1.14	3.81	0.48	2.33	8.26	0.40
	BN1	0.94	3.14	0.68	0.40	1.37	0.17	1.85	6.15	0.43	0.64	2.22	0.46
	CN2	0.94	3.16	0.66	0.28	0.96	0.41	1.38	4.60	0.45	0.34	1.16	0.45
	BN2	0.84	2.77	0.70	0.49	1.68	0.44	0.77	2.61	0.47	0.30	1.03	0.32
	CN3	0.80	2.70	0.64	0.70	2.41	0.38	1.27	4.25	0.49	0.68	2.30	0.46
	BN3	1.31	4.53	0.63	0.48	1.66	0.49	1.17	3.93	0.50	0.68	2.30	0.41

CN_0, CN_1, CN_2 and CN_3 means legume cover crop treatment receiving none, reduced, recommended and farmers' N fertilizer rates, respectively. BN_0, BN_1, BN_2 and BN_3denotes bare fallow treatment receiving none, reduced, recommended and farmers' N fertilizer rates, respectively. RMSE is root mean square error; RRMSE is coefficient of variation of the RMSE; d is index of agreement.

4.3.2 Estimated water balance in different seasons

The magnitude of the soil water balance components is similar between different field treatments (Table 4.3). The amount of precipitation varied greatly between the seasons in the two years: 709 mm rainfall occurred in the first-year maize (2012) season, whereas only 101 mm were measured in the second year-maize (2013) season, which is very low compared to the 50-year average precipitation (701 mm). The precipitation during the transition season (August to October) was 57 mm and clearly lower than the 50-year value (269 mm). The precipitation in the wheat season exceeded the 50-year average (286 mm) by 32 mm.

Table 4.3 Estimated water balance components (mm) in 1 m soil profiles with different treatments during different seasons in Hubei Province in 2012-2013

Treatments	First year maize (2012)					Transition season					Wheat					Second-year maize (2013)				
	Rain	ET	Tr	Δs	Drain	Rain	ET	Tr	Δs	Drain	Rain	ET	Tr	Δs	Drain	Rain	ET	Tr	Δs	Drain
CN0	709	384	180	-172	497	212	127	66	47	38	318	193	74	-75	201	101	283	179	-202	20
BN0	709	384	180	-172	497	212	153	0	38	21	318	212	48	-72	178	101	265	154	-183	19
CN1	709	416	231	-188	482	212	127	98	64	22	318	201	90	-81	199	101	328	233	-236	9
BN1	709	416	231	-188	482	212	154	0	54	4	318	230	93	-87	175	101	331	237	-239	9
CN2	709	418	234	-189	480	212	127	98	65	20	318	201	91	-81	198	101	330	240	-231	2
BN2	709	418	234	-189	480	212	154	0	55	3	318	227	90	-86	176	101	332	243	-234	2
CN3	709	418	234	-189	480	212	127	98	65	20	318	192	74	-74	201	101	327	236	-228	2
BN3	709	418	234	-189	480	212	154	0	55	3	318	222	76	-80	176	101	324	232	-226	2

CN_0, CN_1, CN_2 and CN_3 means legume cover crop treatment receiving none, reduced, recommended and farmers' N fertilizer rates, respectively. BN_0, BN_1, BN_2 and BN_3 denotes bare fallow treatment receiving none, reduced, recommended and farmers' N fertilizer rates, respectively. ET indicates soil evaporation and crop transpiration; Δs is the soil water storage changes during the whole period. Rain means precipitation, ET evapotranspiration, Tr crop transpiration. Drain stands for water drained out of the soil profile.

According to the simulated results, the plots with a cover crop had around 7 mm and 14 mm more drainage than bare fallow plots in the transition and wheat season, respectively. Due to the fact that the cover crop decreased the evaporation in the transition season, lower evapotranspiration (ET) and higher soil water content values than in the bare fallow treatments were observed. Although cover crops reduced ET by 10-26 mm in comparison to bare fallow in the wheat season, soil water content was similar due to higher drainage (around 20-30 mm). Thus, a legume cover crop as living mulch during the transition season can reduce evaporation while increasing drainage and soil water content. Utilizing the cover crop residuals as green manure in the next crop season tends to decrease the ET and in turn increase soil water content and drainage.

4.3.3 NO_3^--N andNH_4^+-N concentration in the soil solution

The analysis of NO_3^--N and NH_4^+-N concentration in the soil solutions indicates the potential pollution risk to groundwater. Compared to the NO_3^--N concentration, the NH_4^+-N concentration can be neglected (less than 5% of NO_3^--N concentration), therefore NH_4^+-N concentration values are not provided in the present study. The average and maximum concentrations of NO_3^--N were influenced by both cover crop and different N fertilizer treatments (Table 4.4). As soil solution samples cannot be pumped out from suction cups during very dry conditions, samples representing these conditions are absent in the average NO_3^--N concentration calculation. In general, soil solutions from 1 m depth had higher NO_3^--N concentrations than samples taken at 1.8 m during all three main crop seasons; however, this difference could not be observed in the transition season (Table 4.4).

Table 4.4 Average and maximum NO_3^--N concentration of leachate (mg N L^{-1}) from 1 m and 1.8 m during different season in Hubei Province in 2012-2013

Depth (m)	Treatment	NO_3^--N concentration							
		First-year maize (2012)		Transition Season		Wheat		Second-year maize(2013)	
		Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum
1	CN0	2.21	3.86	2.39	2.85	4.04	8.62	3.13	4.28
	BN0	2.33	3.51	3.61	3.94	4.63	8.28	3.26	4.21
	CN1	8.73	10.25	4.81	6.15	8.25	10.53	6.74	8.04
	BN1	8.92	11.03	8.62	11.67	11.63	17.81	7.82	10.29
	CN2	10.85	20.58	6.64	8.26	9.69	13.99	13.45	14.24
	BN2	10.91	21.59	11.02	14.19	13.78	21.20	17.15	18.16
	CN3	13.07	20.70	8.72	12.91	14.71	20.55	20.32	25.24
	BN3	13.65	21.72	11.12	13.73	18.78	23.17	26.97	33.09
1.8	CN0	2.63	3.63	1.64	1.98	4.09	8.21	4.49	6.98
	BN0	2.57	3.58	1.70	2.28	4.09	8.80	4.64	6.65
	CN1	4.42	5.81	7.79	11.02	7.61	9.02	6.66	8.27
	BN1	4.56	6.33	10.01	12.57	8.95	11.64	9.01	12.04
	CN2	5.66	8.50	10.17	13.10	8.40	9.67	8.65	10.08
	BN2	6.24	8.55	12.49	15.79	10.85	13.83	12.09	15.03
	CN3	8.48	11.47	12.08	17.75	8.90	10.90	12.61	18.10
	BN3	8.49	11.09	15.56	20.24	14.50	21.84	18.53	25.86

CN_0, CN_1, CN_2 and CN_3 means legume cover crop treatment receiving none, reduced, recommended and farmers' N fertilizer rates, respectively. BN_0, BN_1, BN_2 and BN_3 denotes bare fallow treatment receiving none, reduced, recommended and farmers' N fertilizer rates, respectively

Both average and maximum of NO_3^--N concentrations in the soil solutions increased with higher mineral N fertilizer rates. The maximum NO_3^--N concentration in 1 m depth reached up to 30 mg L^{-1}, and occurred in the maize season at the plots with the farmers' N fertilizer rate in combination with bare fallow. Reduced N fertilizer rates combined with legume cover crop management can reduce this peak to less than 10 mg L^{-1} (Figure 4.2). Legume cover crop treatment reduced both average and maximum NO_3^--N concentration values. Apart from the plots without N fertilizer application, reduced three-split N fertilizer combined with cover crop is the only treatment that kept the average and maximum NO_3^--N concentration in the leachate under 11.3 mg L^{-1} (limit of NO_3^--N content in the drinking water provided by World Health Organization) during the entire cropping period.

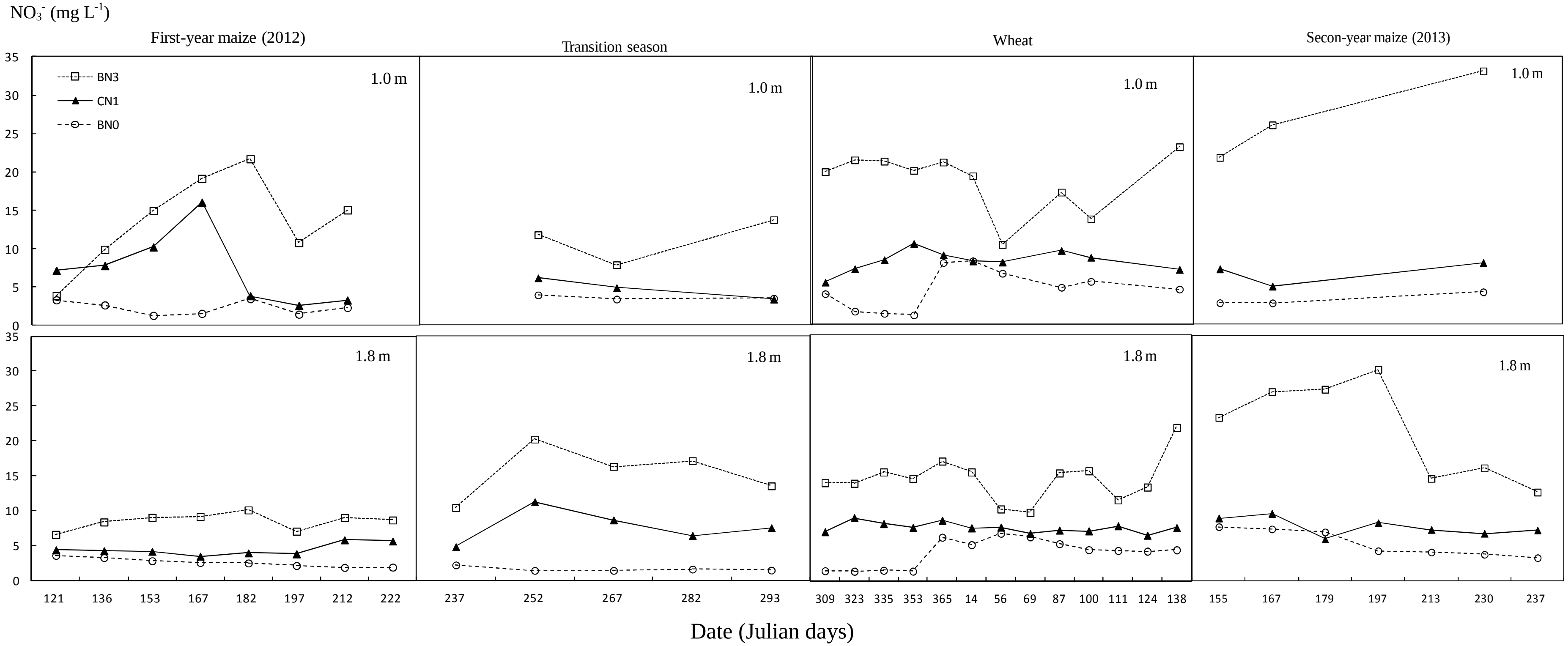

Figure 4.2 NO_3^--N concentration of the leachate from 1.0 and 1.8 m depth with different treatments during maize, transition and wheat seasons in 2012-2013 (mg L^{-1}). CN_1 means legume cover crop receiving reduced N fertilizer rates. BN_0 and BN_3 means bare fallow receiving none and farmers N fertilizer rates, respectively.

4.3.4 NO_3^--N and NH_4^+-N leaching losses

NO_3^--N was the dominating fraction of mineral-N lost in the soil solution with all treatments and during the entire experimental period (Table 4.5). About 33-50 kg N ha^{-1} and 18-40 kg N ha^{-1} were lost in the first-year maize (2012) season with different N fertilizer rates in 1 m and 1.8 m depth, respectively, which accounts for 18% -24% of the applied mineral N fertilizer. Only 15-29 kg N ha^{-1} and 15-26 kg N ha^{-1} respectively were lost in the wheat season, which accounts for 9-13% of the applied mineral N fertilizer. In contrast, only 0.5-0.9 kg N ha^{-1} and 0-1.2 kg N ha^{-1} were lost by leaching in the second year maize (2013) season due to low rainfall (101 mm).

Table 4.5 Mineral nitrogen loading the leachate (kg N ha^{-1}) in 1 m and 1.8 m depth in Hubei Province in 2012-2013.

Depth (m)	Treatments	Mineral N loses							
		Maize 2012		Transition season		Wheat		Maize 2013	
		NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+
1	CN0	13.35	2.07	0.09	0.01	7.01	0.54	0.52	0.06
	BN0	13.08	2.09	0.12	0.02	7.84	0.51	0.57	0.04
	CN1	33.82	2.34	0.17	0.02	14.64	1.01	0.74	0.01
	BN1	31.80	2.18	0.29	0.04	17.51	1.18	0.82	0.02
	CN2	48.75	2.28	0.13	0.02	17.09	0.97	0.51	0.01
	BN2	47.70	2.39	0.20	0.03	22.31	0.95	0.59	0.01
	CN3	47.27	2.65	0.12	0.03	24.29	1.52	0.77	0.01
	BN3	48.14	2.81	0.17	0.04	28.26	1.34	0.81	0.01
1.8	CN0	12.48	1.18	0.34	0.07	7.22	0.49	1.18	0.04
	BN0	12.96	1.09	0.05	0.01	7.27	0.44	1.12	0.08
	CN1	17.44	1.28	1.84	0.14	14.65	0.66	0.51	0.01
	BN1	17.29	1.28	0.43	0.04	15.41	0.61	1.68	0.04
	CN2	25.32	1.40	2.04	0.19	16.60	0.74	0.00	0.00
	BN2	26.03	1.09	0.31	0.03	18.73	0.76	0.00	0.00
	CN3	38.37	1.28	2.43	0.17	17.24	1.21	0.00	0.00
	BN3	38.54	1.68	0.38	0.04	25.09	1.72	0.00	0.00

CN_0, CN_1, CN_2 and CN_3 means legume cover crop treatment receiving none, reduced, recommended and farmers' N fertilizer rates, respectively. BN_0, BN_1, BN_2 and BN_3 stands for bare fallow treatment receiving none, reduced, recommended and farmers' N fertilizer rates, respectively

Compared to the two-split N fertilizer management, three-split and reduced N fertilizer treatment lowered NO_3^--N leaching during the first-year maize (2012) season by 14-17 kg N ha^{-1} and 8-21 kg N ha^{-1} in 1 m and 1.8 m depth, respectively. This difference was 3-11 kg N ha^{-1} and 2-10 kg N ha^{-1} during the wheat season. However, the amount of NO_3^--N leaching did not vary (0-1.2 kg N ha^{-1}) with different mineral N fertilizer rates during the transition and second-year maize (2013) season.

Due to very low drainage (3-38 mm in the transition season and 2-20 mm in second-year maize season), low NO_3^--N leaching losses were observed in the transition and second-year maize (2013) season. Therefore, although the second-year maize (2013) season had the highest NO_3^--N concentration at the depths 1 m (33.4 mg L^{-1}) and 1.8 m (26mg L^{-1}), only a small amount of NO_3^--N was lost through leaching in this season due to low drainage as a consequence of low rainfall.

4.4 Discussion

4.4.1 Water balance

Although the amount of rainfall was drastically different between the two maize seasons, the transpiration (Tr) values were similar, which means that Tr/ET increases in the drought season (Table 4.3). Other research also shows that Tr/ET values vary between 36% and 66% in semi-arid ecosystems, and increase with less rainfall (Schlesinger and Jasechko, 2014). In this study, the less rainfall only reduced the evaporation, crop transpiration was similar between the two maize seasons. This indicates that, although rainfall in the second year (2013) was much lower than the 50-year average precipitation (701 mm), the crops did not suffer from water stress due to the good soil-water retention capacity of the silt loamy soil in the field.

In comparison to the bare fallow, cover crop, on the one hand reduced the evaporation, on the other hand increased the transpiration. Thus, its effect on soil water content and drainage volume is uncertainty. Both increasing (Muñoz-Carpena et al., 2008) and no effects (Zhang et al., 2009) on soil water content were reported. In this study, although the plots with a cover crop showed higher Tr, the ET was still lower than on the bare fallow plots in the transition season, which means that a cover crop can reduce evaporation which can compensate the increased Tr (Tonitto et al., 2006). Nevertheless, the drainage increased by cover crop in this study, which is contrasts with previous findings (Muñoz-Carpena et al., 2008; Ngome et al., 2011). The amount of drainage was influenced by many factors, such as evaporation rate, amount and intensity of rainfall. The rainfall evaporated fast in bare fallowed plots, thus bare fallow plots showed much higher evaporation (17-27 mm) and lower drainage values than the covered plots.

4.4.2 NO_3^--N concentration in soil solutions

The peak of NO_3^--N concentration occurred at different time in the tested two maize seasons. In monsoon climate, the peak NO_3^--N concentration in the soil solution usually happens at the beginning of monsoon rain and shortly after the fertilizer application, when rapid mineralization rates and large amount of drainage occurred at the same time (Pilbeam et al., 2004). However, the peak concentration will prone when the monsoon rain did not come as usual. Because the soils are drying when low rainfall occurring in monsoon season; soil mineralization rates are increasing when sufficient rainfall is wetting the dry soil (Birch, 1958).

NO_3^--N concentrations in 1 m are higher than in 1.8 m soil layer during the main crop season; however, high concentration moved to 1.8 m layer at the transition season (Figure 4.2). Similar research using Br^- as an indicator to check N peak movement in soil profiles in Beijing, China showed suggested that N peak can move to deeper soil layer after the monsoon rain season (Zhao, 2007). Therefore, in this study, it could be because NO_3^--N formed rapidly and accumulated in the upper soil layers due to the good vegetation coverage during the main crop seasons (Zhu et al., 2000); while, accumulated NO_3^--N in the upper soil layers are prone to leaching to deeper soil layers when the cover crop is not yet established and the soil surface is still bare.

Reduced N fertilizer application rates decreased the NO_3^--N concentration of soil solution in both legume cover crop and bare fallow treatments, which is line with findings from other research (Pilbeam et al., 2004). Furthermore, a strict linear correlation (R^2 = 0.99) between NO_3^--N concentration in drainage and N-application rates was reported by Dauden et al. (2004). Similarly, such relation was proved in the present study with good correlation (R^2 = 0.76). Accordingly, decreasing N fertilizer application rates can be regarded as an effective strategy to reduce the NO_3^--N concentration, however, if not handled properly may cause remarked yield reduction (Zhu et al., 2000).

Legume cover crop significantly decreased the NO_3^--N concentrations at both 1 m and 1.8 m depth. Similarly, Meisinger et al. (1991) reported that a legume cover crop can reduce the NO_3^--N concentration by 20 to 80% in comparison to bare fallow. Cover crops, in particular legume cover crops, have the potential to accumulate the soil-inorganic N and trap it in biomass as an organic form, which can reduce NO_3^--N leaching (Dinnes et al., 2002b). Tonitto et al. (2006) analyzed effects of cover crop on yield and N leaching from 31 corn based systems using meta-analysis method. Results suggested that replacing bare fallow with cover crop can reduce N concentration in soil solutions by 40%-70%. Moreover, this biomass that was used as green manure during the growing periods of the consequent crops also decreased the NO_3^--N concentration in the soil. The main reason for this is the fact that using cover crops as green manure can significantly improve soil fertility, increase the biological activity of the soil, and also, the available phosphorus content. As a consequence, N-use efficiency is increased and nitrate losses reduced (Piotrowska and Wilczewski, 2012).

In comparison to the farmers' conventional N fertilizer management and bare fallow treatment, reduced mineral N fertilizer combined with a legume cover crop lowered the NO_3^--N concentration in both 1 m and 1.8 m depth (Table 4.4). It can thus be concluded that both reduced mineral N fertilizer rates and legume cover crops can reduce the NO_3^--N concentration in the soil solution.

4.4.3 Extent of NO_3^--N leaching

Nitrogen leaching losses from agriculture systems originate from either native soil N mineralization or additional N input (Pilbeam et al., 2004). In the present study, non-fertilized plots showed lower NO_3^--N loss through leaching indicating that mineral N fertilizer is the main contributor to NO_3^--N losses in particular maize season. Because the temperature and rain increases at the same time in the monsoon climate region, thus, mineralization is very high which lead to high NO_3^--N leaching when excessive apply the N fertilizer before the rainy season (Ju et al., 2007). Therefore, to avoid NO_3^--N leaching, it is suggested to reduce the N fertilizer application rate in maize season in monsoon climate region (Zhu and Zhang, 2010).

N leaching varied between two years maize seasons under the same field managements, which is mainly caused by different precipitation (Chen et al., 1995). The correlation coefficient between N leaching and precipitation was reported 0.99 by Zhao (2006). Similarly, a comparison of the results in two maize seasons in this study obviously suggests that the extent of NO_3^--N leaching is highly dependent on the amount of precipitation.

In comparison to traditional N managements, reduced and three-split N fertilizer management can better synchrony with the main crop demand and reduce N losses. Therefore, research in Hunan Province, Central China report that split application of N fertilizer can significantly increase N uptake (Qin et al., 2013). Similarly, other research also has shown that reduced and three-split N fertilizer management can reduce nitrate leaching to groundwater and at the same time maintain maximum grain yield (Gehl et al., 2005). As a consequence, Power and Schepers (1989) stated that the most important way to reduce nitrogen losses driven by leaching is to apply correct amounts of N fertilizer at the proper time.

Replacing the bare fallow with legume cover crops has been proved as an effective strategy to reduce NO_3^--N leaching losses (Tonitto et al., 2006). The main advantage of the cover crops is its option to recycle N within the cropping agro-system which would otherwise be lost (Thorup-Kristensen et al., 2003). The contribution of legume cover crop during transition period in field rotation can exceed 100 kg N ha^{-1} (Mueller and Thorup-Kristensen, 2001), which can benefit the consequent crops in the rotation (Hanly and Gregg, 2004). However, the cover crop did not significantly reduce NO_3^--N leaching in the transition and second-year maize (2013) seasons in this research for two main reasons. Firstly, most of the soil residueNO_3^--N was lost shortly after harvest of the main crops when the post-sown cover crops had not yet established their root system (Arlauskiene and Maiksteniene, 2012). Secondly, very little rainfall occurred during the transition and second-year maize seasons, which led to a small amount of drainage. Moreover, effects of cover crop on N leaching and succeeding crops yield is not only depending on precipitation, but also depend on C/N ratio of cover crop residual (Restovich et al., 2012). Therefore, when replacing bare fallow with catching crops to reduce NO_3^--N leaching, the C/N ratio of catch crop residual should be considered. If the mineralized N from catch crop did not released in synchrony with consequent crop demand, it cannot reduce N leaching (Sainju et al., 2007).Thus, in this study, non-significant NO_3^--N leaching reduction by cover crops supposed due to late sowing, less precipitation or improper cover crop species selection.

It can be concluded that both reduced three-split N fertilizer application and replacing bare fallow with fast growing legume cover crops in the transition season can reduce the amount of NO_3^--N leaching. However, when precipitation is low or improper cover crop species selection such reduction is not observed (Gabriel and Quemada, 2011).

4.5 Summary and conclusions

We tested the effects of replacing bare fallow fields with legume cover crops in the transition season combined with N fertilizer management on water balance and N leaching. The modeled water balance shows that a cover crop increased soil water retention and decreased drainage during the transition period. Reduced N fertilizer application rates significantly decreased soil NO_3^--N concentration in both maize and wheat season. However, cover crops had no effect on NO_3^--N concentrations in soil solutions. Combining split –application of N fertilizer with a legume cover crop can significantly increase soil water retention and reduce N losses in a maize-wheat rotation system.

5. PERFORMANCE OF THE EPIC MODEL FOR SIMULATING WATER DYNAMICS AND NITRATE LEACHING

5.1 Introduction

Nitrogen (N) pollution of water resources from intensive agriculture and livestock production system is a growing concern in the Liangzihu Lake basin (30°05′～30°27′ N, 114°21′-114°50′ E) in Hubei Province, Central China (Li et al., 2009). Many results have confirmed that surface and groundwater pollution can be linked to excessive use of chemical fertilizers (Zhu et al., 2006; Liu et al., 2008). Nitrogen is one of the pollutants that has caused surface water eutrophication and groundwater pollution. The N-related pollution of drinking water and fish-farm water resources has posed serious health risks for the people in China, in particularly in areas with intensive agriculture and high population (Qiu et al., 2001). Findings indicate that more than 50% of the N loads in China originate from agricultural activities (Wu et al., 2013). Hubei Province has been identified as one of the high N-risk regions in China since 2000, because of intensive agriculture, high N input and high precipitation (Sun et al., 2008).

To improve the understanding of the inter-linkage between field management and water pollution, field studies have been conducted in China in the past decades (Ju et al., 2009). However, the realization of field studies has been limited, because they are time consuming and involve high costs (Rudra et al., 2011). Crop growth processes associated with hydrological modeling approaches have been proven to overcome these limitations. Thus, they have been applied as tools for estimating N pollution all over the world. Yet, model performance tests and validation under local climate and agricultural conditions is a prerequisite for site-specific nutrient transport simulation, which to date is not well documented in Central China.

There are a number of models that simulate the nutrient movement from agricultural land. Moreover, some researchers developed their own models for specific regions or purposes. However, most of these models were developed for specific study regions or based on the intention of particular application purposes and are therefore not applicable in every research context (Thomas et al., 1998). Thus, the selection of an appropriate model is crucial for any model simulation studies. In this study, the selected model needed to fulfill the following requirements: (i) suitability for field scale, (ii) proof of successful application in subtropical region with monsoon climate, and (iii) capability to simulate the influence of field management on N leaching. In addition, the important criteria suggested by McLaughlin (2001), in terms of data input requirement, calibration level requirement and output usefulness were also considered. Finally, the EPIC model was selected, because it (i) has been applied under many conditions including in China (Wang et al., 2011b), (ii) considers all relevant soil processes (Gaiser et al., 2010), and (iii) represents most of the relevant process for quantifying hydrological fluxes impacts on N movement and dynamics. Details on the comparison of the EPIC model with other nutrient simulation models are provided by McLaughlin (2001).

The EPIC model was originally developed for simulating soil productivity as effected by soil erosion (Williams et al., 1990). With its development and the additional provided components, the model has expanded the function to simulate nutrient transport and its related water quality problems (Williams et al., 1996). Sharpley et al. (1990) reported that the model can precisely predict the changes of N and phosphorus (P) content in the topsoil. Other studies also reported that, although N leaching is the most sensitive output function of the model (Roloff et al., 1998a), EPIC was proved to be able to estimate N losses with an acceptable level of accuracy by Roloff et al. (1998b). Both of the studies in Minnesota and Iowa indicated that changing trends in N leaching were acceptably simulated by the EPIC model (Chung et al., 2001; Chung et al., 2002). The model was introduced in China in 1990; however, due to numerous restrictions, its application in the country is still limited (Chun, 2007). Moreover, it was mainly used to simulate the yields (Chavas et al., 2009), crop water productivity (Liu et al., 2007), soil water dynamics (Wang and Li, 2010) and soil erosion (Zhang et al., 2008), but was rarely applied to N-losses simulation in China. Therefore, the actual performance of the EPIC model for N losses has not yet been adequately tested in China.

In the study presented in this chapter, we applied the EPIC model to simulate the N losses under different field management strategies in Liangzihu Lake basin. The main objective was to evaluate the simulation performance of the EPIC model for soil water content and N leaching in winter wheat-spring maize rotations in Central China.

5.2 Materials and methods

5.2.1 EPIC nutrient cycling component and required data input

EPIC is a process based model consisting of nine sub-models for weather, hydrology, erosion, soil temperature, tillage, crop growth, management, economics and nutrient cycling simulations. The nutrient cycling component is one of the major sub-models included in the EPIC model, which can simulate chemical fertilizer strategies, nutrient transformation in the field, crop uptake, and nutrient movement driven by water fluxes. The nutrient cycling component of the model includes the N mineralization and immobilization processes, which were developed based on the PAPRAN model published by Seligman and Van Keulen (1981). The N movement with water fluxes was simulated through three paths: surface runoff, percolation and lateral subsurface flow. In this study, the experimental field has a flat topography, thus the observed surface runoff is very low (less than 1% of each rainfall event), which could be neglected;

moreover, lateral subsurface flow was also not considered. Instead, the focus of this study was only on N leaching losses simulation.

The data input for the EPIC model can be divided into four categories: (1) field characteristics, (2) field management, (3) soil properties, and (4) weather data. With regard to the intended model output, users can choose different combinations of data input. More detailed information on model data input and model use is provided by Sharpley et al. (1990).

In this study, the EPIC model (version 0509) was evaluated using field data collected from the experimental field located in Liangzihu Lake basin, Hubei Province, Central China. Soil characteristics, field management, fertilizer practices and other field data that used for model calibration and evaluation are provided in Chapter 2 and 3.

5.2.2 Model parameterization

Parameterization of the model based on measured data and information derived from research under similar conditions. Field capacity and wilting point were estimated based on soil texture by the method provided by Saxton et al. (1986). Similarly, saturated hydraulic conductivity was estimated using the method given by Cook et al. (1985). There are five different methods to estimate the potential evapotranspiration in the EPIC model. In this study, due to the drought in 2013, the Baier-Robertson method was chosen, because it has been proven highly suitable under drought conditions (Roloff et al., 1998a). Due to the fact that weeds and pests were well controlled in all of the experimental plots, the influence of pests and weeds were not considered in the model simulation.

5.2.3 Model calibration

The measured aboveground biomass of maize and wheat in the period 2012-2013 were used in the calibration procedure. The calibration procedure included: (1)

sensitivity analysis of crop aboveground biomass to crop and soil parameters, and (2) the adjustment of the crop and soil parameters until the output of biomass values reached best fit in relation to the observed values. The organic matter was proven to be one of the most important factors that influenced the aboveground biomass and nitrate loads in the infiltrating water for all soil types (Rudra et al., 2011). Moreover, based on the suggestions from other researches and availability of data from field measurements (Gaiser et al., 2010), the biomass to energy ratio (WA) and carbon (C) fraction biomass pool (FBM) were confirmed as the most sensitive parameters influencing the aboveground biomass (Figure 5.1).

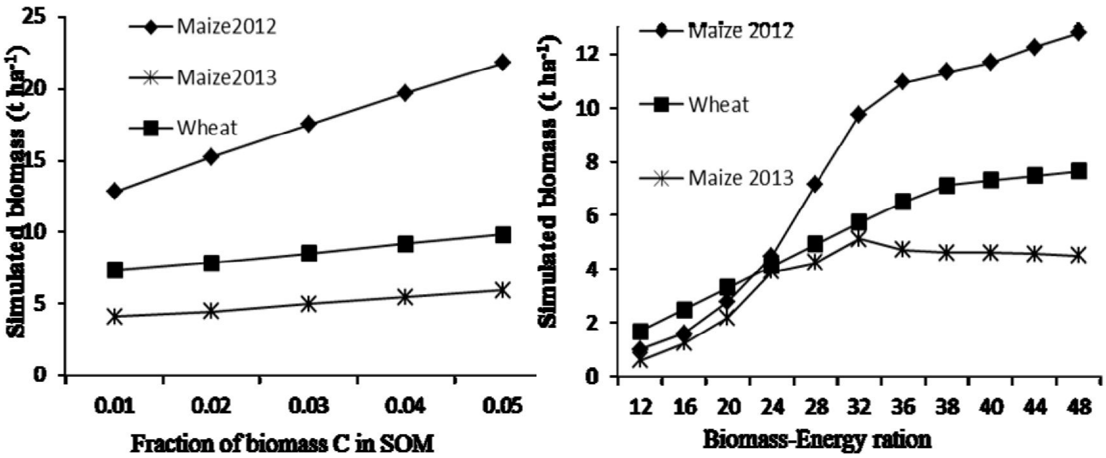

Figure 5.1 Sensitivity analysis of crop yield simulation with respect to FBM (fraction of biomass C in soil organic matter) and WA (biomass-energy ration) in Hubei Province, Central China.

5.2.4 Model validation

Due to the fact that EPIC nutrient simulation processes are related to the water fluxes, the N balance is parallel to the water balance in the field (Ramanarayanan et al., 1998). Thus, soil water content and amount of N leaching were used for model performance evaluation. According to the suggestions provided by Moriasi et al. (2007), the following indices were selected for model performance evaluation: (1) Nash-Sutcliffe efficiency (NSE), (2) percent bias (PBIAS), (3) ratio of the mean square error and the coefficient of determination (RSR), and (4) the coefficient of determination (R^2). The indices are calculated as follow:

$$NSE=1-\frac{\sum_{i=1}^{n}(Y_i^{obs}-Y_i^{sim})^2}{\sum_{i=1}^{n}(Y_i^{obs}-Y^{mean})^2} \quad (5.1)$$

$$PBIAS=\frac{\sum_{i=1}^{n}(Y_i^{obs}-Y_i^{sim})^2\times 100}{\sum_{i=1}^{n}(Y_i^{obs})} \quad (5.2)$$

$$RSR=\frac{\sqrt{\sum_{i=1}^{n}(Y_i^{obs}-Y_i^{sim})^2}}{\sum_{i=1}^{n}(Y_i^{obs}-Y^{mean})^2} \quad (5.3)$$

$$R^2=\left[\frac{\sum_{i=1}^{n}(Y_i^{obs}-Y^{mean})\times(Y_i^{sim}-X^{mean})}{\sqrt{\sum_{i=1}^{m}(Y_i^{obs}-Y^{mean})^2\times\sum_{i=1}^{n}(Y_i^{sim}-X^{mean})^2}}\right]^2 \quad (5.4)$$

where, Y_i^{obs} is the ith observed value, Y_i^{sim} is the ith simulated value, Y^{mean} is the mean observed value, X^{mean} is the mean simulated value, n is the total number of observations. The ranges of criteria used for evaluating model performance are listed in Table 5.1

Table 5.1 Range of selected indices for model performance evaluation. NSE is Nash-Sutcliffe efficiency, PBIAS is percent bias (%), RSR is ratio of the mean square error to the standard deviation, and R^2 is coefficient of determination.

Indices	Optimal	Very good	Satisfactory	Unacceptable
NSE	1	>0.65	>0	≤ 0
PBIAS	0	-20-20	-40- -20 & 20-40	<-40 &>40
RSR	0	≤ 0.5	0.5-1.0	≥1.0
R^2	1	>0.65	≥0.5	<0.5

5.3 Results and discussion

5.3.1 Model calibration

Sensitivity analysis

Sensitivity analysis is helpful to identify the parameters that largely influence the output values. Thus, more attention should be paid to them when calibrating the model (Thooko et al., 1994). In this study, FBM and WA were proven to strongly affect the aboveground biomass of both maize and winter wheat in all treatments, in particular in the first maize season (2012). Because the initial experiment conditions are homogenous, these two parameters are given the same value regardless of treatment. Thus, results of the sensitivity analyses are only shown with respect to the CN_0 (cover crop and without N fertilizer application) treatment (Figure 5.1). The simulated biomass is much higher than the measured values under the default value of FBM=0.04. Therefore, this was reduced to 0.01, as a result the simulated biomass nearly fit the observed values (Figure 5.1). The FBM influences the biomass probably by changing the mineralization of the soil N, which was important for crop growth at the beginning of the experiment (Gaiser et al., 2010). The WA was the last parameter to be adjusted for model calibration. To obtain the optimal fit to observed values, the WA for maize (default value was 40) and winter wheat (default value was 35) were adjusted to 50 and 30, respectively.

Simulation of aboveground biomass

The calibrated model accurately predicted the aboveground biomass in all treatments except in the non-fertilized second-year maize (2013) (Figure 5.2). In comparison with the other fertilized treatments, only the plots without N fertilizer application led to simulated biomass lower than the observed values. Particularly in the second-year maize season (2013), the biomass was underestimated in the non-fertilized plots by more than 25%. Similar results were found when the EPIC model was applied to simulate the sorghum in the subtopic region (Niu et al., 2009). The authors concluded that model reliability decreases with decreasing N fertilizer rates. The changes between the two maize seasons in the non-fertilized plots are mainly due to the fact that the model did not adequately estimate the yield variability between years caused by non-N fertilizer treatment (Williams et al., 1989). Due to the fact that non-N fertilizer treatment is not a realistic practice, this underestimation by the calibrated model can be considered as an acceptable level in this study.

5.3.2 Model validation

Soil water content

The calibrated model precisely predicted the soil water content in both 1 m and 1.8 m depths (Table 5.2). This result is in accordance to the research conducted by Wang and Li (2010), who reported that the EPIC model can well estimate the soil water content in winter wheat-spring maize rotation systems in the Chinese Loess Plateau. Nevertheless, the model underestimated the soil water content of all treatments in the second-year maize season (2013) in 1 m depth (NSE <0) (Table 5.2). This is mainly because there was a marked drought in that year; the underestimation of soil water contents in this season could be because the weak function for quantifying upward water movement of the EPIC model (Rabbel, 2013).

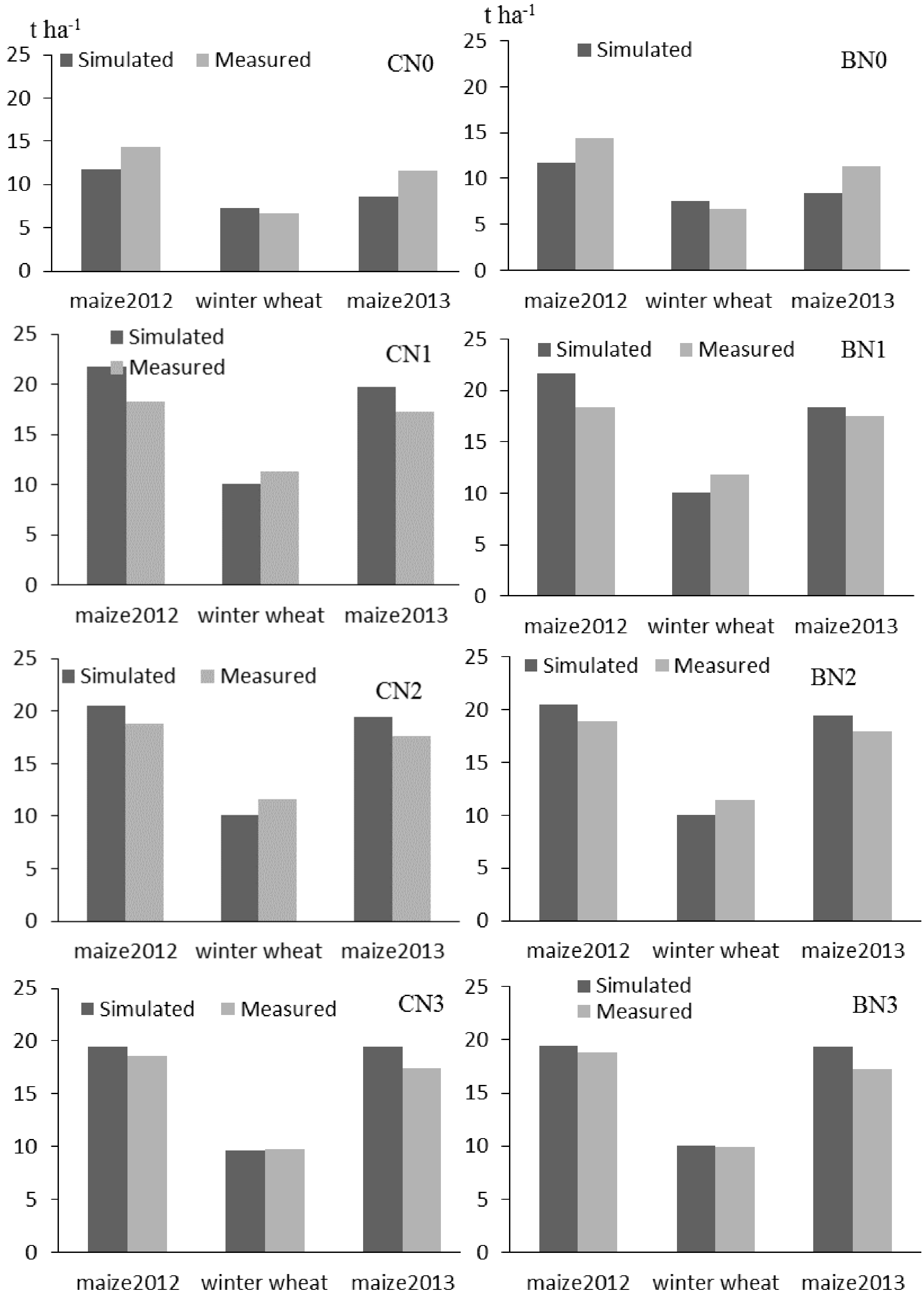

Figure 5.2 Calibrated EPIC model on aboveground biomass simulation in Hubei Province, Central China from 2012-2013.

In contrast, an underestimation did not occur in 1.8 m depth. When extreme climate conditions occur, the deeper layer will show a less distinct reaction. This can be concluded from the higher soil water content in 1.8 m depth compared to 1 m Therefore, the upward movement of water in 1.8 m depth was minimal and can be neglected, thus the water content in 1.8 m depth was well estimated. Overall, the validation results in the analyses show that the calibrated EPIC model can well estimate soil water content in both 1 m and 1.8 m depth under moderate climate conditions; while it underestimates soil water content in shallow (≤1m) soil layers under drought conditions.

Table 5.2 Evaluation of EPIC model performance applied to soil water content simulation in Hubei Province from 2012-2013. NSE is Nash-Sutcliffe efficiency, PBIAS is percent bias (%), RSR is ratio of the mean square error to the standard deviation, and R^2 is coefficient of determination. CN_0, CN_1, CN_2 and CN_3 refer to legume cover crop treatment receiving no N fertilizer, reduced, recommended and farmers' N fertilizer rates, respectively; BN_0, BN_1, BN_2 and BN_3 refer to bare fallow treatment receiving N fertilizer treatments as mentioned above.

Depth (m)	Treatments	Maize 2012				Transition				Wheat				Maize 2013			
		NSE	RSR	PBIAS	R^2	NSE	RSR	PBIAS	R^2	NSE	RSR	PBIAS	R^2	NSE	RSR	PBIAS	R^2
1	CN0	0.1	1.0	-2.8	0.5	0.3	0.8	-0.5	0.6	0.8	0.4	-3.2	0.5	-3.6	2.1	35.6	0.6
	BN0	0.1	1.0	-0.3	0.4	0.9	0.4	-1.0	1.0	0.8	0.5	-1.7	0.9	-1.7	1.7	31.8	0.8
	CN1	0.1	1.0	-2.8	0.6	0.5	0.7	-2.1	0.9	0.5	0.7	-1.8	0.9	-0.1	1.1	17.9	0.7
	BN1	0.5	0.7	-0.9	0.7	0.7	0.6	-2.4	0.9	0.6	0.7	-2.7	0.9	-0.6	1.3	25.0	0.9
	CN2	0.2	0.9	-3.2	0.6	0.4	0.8	-1.3	0.8	0.6	0.7	-3.3	0.9	-1.0	1.4	31.1	0.9
	BN2	0.4	0.8	-2.2	0.7	0.7	0.6	-0.9	0.8	0.7	0.6	-2.1	0.9	-1.9	1.7	34.5	0.5
	CN3	0.5	0.7	-1.4	0.6	0.5	0.7	-1.2	0.8	0.7	0.6	-2.8	1.0	-1.5	1.6	30.2	0.5
	BN3	0.6	0.7	-0.1	0.6	0.5	0.7	-2.9	1.0	0.6	0.7	-2.7	1.0	-2.3	1.8	33.6	0.6
1.8	CN0	0.8	0.4	1.1	1.0	0.1	1.0	0.3	0.5	0.3	0.7	0.3	0.6	0.2	0.9	15.2	0.9
	BN0	0.8	0.4	1.1	1.0	0.4	0.8	-0.3	0.5	0.0	0.8	-0.2	0.5	0.0	1.0	19.0	0.9
	CN1	0.6	0.6	1.1	0.7	0.2	0.9	-0.2	0.5	0.5	0.7	0.5	0.6	0.2	0.9	9.8	1.0
	BN1	0.8	0.5	1.6	0.9	0.8	0.5	-0.5	0.8	0.4	0.7	1.2	0.7	0.2	0.9	15.3	0.9
	CN2	0.2	0.9	0.5	0.5	0.2	0.9	0.5	0.5	0.1	0.7	0.5	0.5	0.5	0.7	12.9	0.9
	BN2	0.2	0.9	1.0	0.5	0.5	0.7	-0.1	0.5	0.3	0.7	-0.2	0.6	0.5	0.7	14.4	0.9
	CN3	0.2	0.9	-0.2	0.5	0.1	0.9	-0.8	0.9	0.4	0.6	0.7	0.7	0.6	0.6	7.7	0.8
	BN3	0.4	0.8	-1.5	0.5	0.7	0.6	-1.0	0.8	0.2	0.8	0.9	0.6	0.4	0.8	17.2	0.1

Simulation of N leaching

The amount of N leaching in the EPIC model simulations are not fit to the observed values in this study (table 5.3). The model was proved to have the highest variability in sensitivity when applied to N leaching (Roloff et al., 1998a). Therefore, the reported performances of EPIC model on N leaching simulation are varied. Rudra et al. (2011) found that the model could correctly simulate the long-term effects of tillage and residue mulching on N leaching. However, the performance of EPIC with respect to N leaching was found to be unsatisfactory in other studies (Forster et al., 2000), where both underestimation (Roloff et al., 1998b) and over-estimation (Chung et al., 2001) were reported. In this study, the EPIC model over-estimated the N leaching over the entire period except in the second-year maize season (2013), where there was very little rainfall (101 mm compared to the average 701 mm). In previous research, the imprecise estimation of N losses was explained by the inaccuracy in simulating the soil water content (Beckie et al., 1995). However, although soil water content is estimated at an acceptable level in the present study, N leaching still over-estimated. Thus, the inaccuracy in estimating the N transformation may be caused by other factors apart from soil water content. The level of over-estimation regarding N leaching for each rainfall event has a close relationship (R^2=0.65, $p<0.01$) with the leaching volume. Thus, it can be speculated that the over-estimation is due to over-estimation of the N concentration in the leachate. Consequently, the over-estimation could be explained by the over-estimation of leachate N concentration, which may be due to (i) most of the water leached through the small soil pores, where less N will dissolved in the water, while the EPIC model has poor representation of this condition (McLaughlin et al., 2006), (ii) the EPIC model has the tendency to over-estimate the mineralization, which consequently leads to over-estimation of the N concentration in soil solutions (Warner et al., 1997), and (iii) imprecise simulation of the temporal variability of N transformations in the field (Marchetti et al., 1997). Forster et al. (2000) reported that although EPIC did not precisely predict the absolute values, it successfully predicted the change direction and percent of change. Nevertheless, the change percentage is not well estimated in this study.

Table 5.3 Evaluation of EPIC model performance applied to N leaching simulation in Hubei Province from 2012-2013. NSE is Nash-Sutcliffe efficiency, PBIAS is percent bias (%), RSR is ratio of the mean square error to the standard deviation, and R^2 is coefficient of determination. CN_0, CN_1, CN_2 and CN_3 refer to legume cover crop treatment receiving no N fertilizer, reduced, recommended and farmers' N fertilizer rates, respectively; BN_0, BN_1, BN_2 and BN_3 refer to bare fallow treatment receiving N fertilizer treatments as mentioned above.

Depth (m)	Indices	CN0	BN0	CN1	BN1	CN2	BN2	CN3	BN3
1	NSE	-28.4	-31.3	-6.5	-12.7	-5.4	-6.9	-11.9	-12.2
	RSR	5.4	5.7	2.7	3.7	2.5	2.8	3.6	3.6
	PBIAS	-447.7	-377.0	-201.9	-310.6	-156.3	-174.7	-175.4	-221.5
	R^2	0.1	0.1	0.5	0.4	0.7	0.4	0.3	0.3
1.8	NSE	-29.2	-28.7	-18.1	-21.7	-12.6	-11.8	-5.2	-6.8
	RSR	5.5	5.5	4.4	4.8	3.7	3.6	2.5	2.8
	PBIAS	-263.2	-336.2	-160.7	-239.6	-139.9	-196.1	-97.6	-140.6
	R^2	0.2	0..3	0.4	0.4	0.5	0.5	0.6	0.5

The data in Table 5.4 show that the relative error of simulation in the transition season is much higher than in the other seasons, which indicates the insufficient performance of the EPIC model with respect to N leaching simulation in the transition season. In contrast, the model showed better performance in the maize 2012 season than in the other seasons (Figure 5.3). This is mainly because there were no differences between cover crop and bare fallow treatments in the maize 2012 season. However, the differences are extremely big during the transition period between these two treatments. Thus, the results of this research indicate that the EPIC model is not good at N leaching simulation in the transition season. Moreover, results show that the performance of the model will be poorer after transition season management. Overall, the performance of the model in this study with respect to N leaching simulation in the transition season and the resulting influences is not satisfactory.

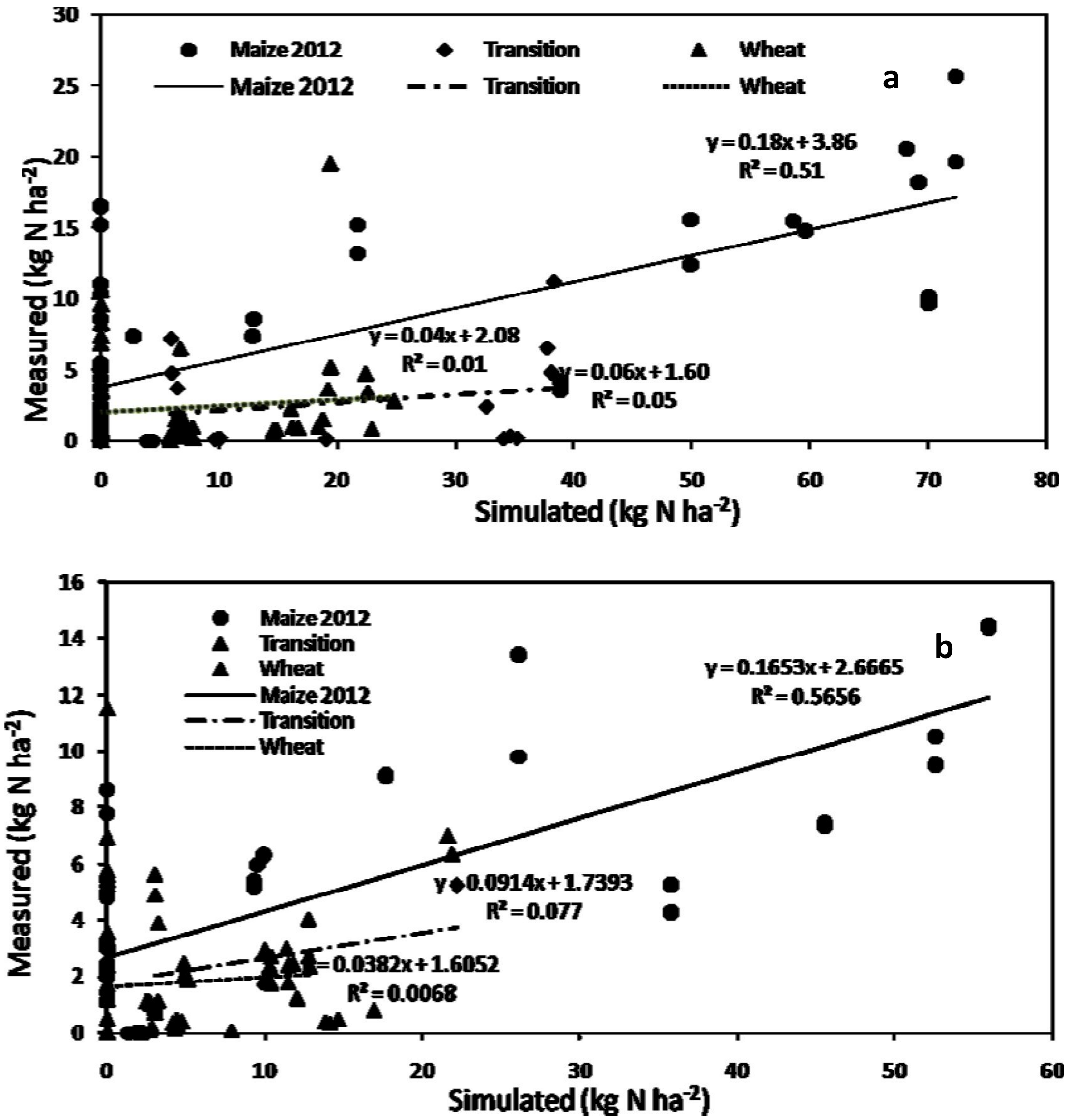

Figure 5.3 Partial regression of measured and simulated N leaching (kg N ha^{-2}) according to the different crop seasons in 1 m (a) and 1.8 m (b) soil depths.

Table 5.4 Overestimation of N leaching (kg N ha^{-1}) in simulation by EPIC model in Hubei Province from 2012-2013. The minus sign means underestimated. The numbers in parentheses are the relative error which calculated by referring to the measured values. CN_0, CN_1, CN_2 and CN_3 refer to legume cover crop treatment receiving no N fertilizer, reduced, recommended and farmers' N fertilizer rates, respectively; BN_0, BN_1, BN_2 and BN_3 refer to bare fallow treatment receiving N fertilizer treatments as mentioned above

Treatment	1 m					1.8 m				
	Amount	Maize 2012	Transition	Wheat	Maize 2013	Amount	Maize 2012	Transition	Wheat	Maize 2013
CN0	102.5 (4)	36.3 (2)	13.5 (135)	53.3 (7)	-0.6 (-1)	63.4 (3)	31.4 (2)	6.3 (15)	27.0 (3)	-1.2 (-1)
BN0	126.8 (5)	36.6 (2)	25.3 (181)	65.5 (8)	-0.6 (-1)	88.6 (4)	31.0 (2)	18.6 (265)	40.3 (5)	-1.2 (-1)
CN1	106.6 (2)	44.1 (1)	13.9 (73)	49.3 (3)	-0.8 (-1)	68.5 (2)	43.8 (2)	5.4 (3)	19.9 (1)	-0.5 (-1)
BN1	149.2 (3)	46.3 (1)	44.3 (134)	59.4 (3)	-0.8 (-1)	96.4 (3)	42.9 (3)	20.7 (44)	34.5 (2)	-1.7 (-1)
CN2	125.0 (2)	71.1 (1)	13.9 (87)	40.5 (2)	-0.5 (-1)	65.9 (1)	44.5 (2)	4.8 (2)	16.6 (1)	0 (0)
BN2	170.4 (2)	72.1 (1)	43.8 (182)	55.2 (2)	-0.6 (-1)	94.0 (2)	43.1 (2)	20.1 (59)	30.8 (2)	0 (0)
CN3	134.5 (2)	89.2 (2)	13.8 (86)	32.2 (1)	-0.8 (-1)	61.9 (1)	42.3 (1)	4.3 (2)	15.3 (1)	0 (0)
BN3	181.7 (2)	88.2 (2)	45.3 (216)	49.1 (2)	-0.8 (-1)	89.6 (1)	46.8 (1)	19.6 (52)	23.2 (1)	0 (0)

5.4 Conclusions

The EPIC model was calibrated for winter wheat-spring maize rotation systems. Based on the results, the conclusions are: (1) the calibrated model can precisely predict the soil water content in both 1 m and 1.8 m soil depth under moderate climate conditions; in contrast, it underestimates the soil water content under drought conditions; (2) the model largely overestimated N leaching, especially during the transition period in both soil depths; (3) the model can be used for simulating the aboveground biomass and soil water content for wheat-maize rotation systems in Hubei Province, Central China, but not for N leaching simulation.

6. GENERAL DISCCUSSION AND CONCLUSIONS

6.1 General discussion

Relative to the demand for grain crops, farmers in Liangzihu Lake basin are over applying mineral N fertilizer (Goulding, 2004). Key factors contributing to this excessive use are low farmland productivity, small farm size, high share of off-farm income, and low education level of the farmers. Similar results were reported from other studies in China (Zhou et al., 2010; Jia et al., 2013). Ju et al. (2009) argued that farmers tend to apply more mineral N fertilizer to low-productive farmlands to compensate for the unfavorable growing conditions. Another research also found small farm size and high share of off-farm income being closely associated with overuse of N fertilizer (Brauw and Giles, 2008). Farmers with small land holdings tend to rely more on off-farm income, causing them to spend less time on farm work. Consequently, N use efficiency decreases, and the mineral N application rate increases (Zhou et al., 2010). However, insufficient knowledge of proper fertilizer use is the main reason for excessive use of N fertilizer. Although extension services are essential to mitigate the overuse of mineral N fertilizer, farmers are reluctant to adopt techniques introduced by extension services after only one training session (Huang et al., 2008; Wang et al., 2011a). Equipping farmers with proper knowledge through improved basic education can result in the reduction of N application rates and improvement of N use efficiency.

Used in combination with cover crops, reduced N rates applied in multiple split doses reduce N leaching and can increase N fertilizer use efficiency. Similarly, Odhiambo (2011) reported that cover crops can recycle the N that may be lost through run-off and leaching. Additionally, reusing the residue of cover crops can increase the amount of soil organic matter and thus, as a result, yield improves. Moreover, in contrast to two-split application, three-split application was able to well meet the crop requirements, thereby increasing N use efficiency and decreasing N losses (Pasuquin et al., 2012). While cover crops tended to increase the drainage volume, the NO_3^--N concentration in the drainage water decreased as a result of plant uptake, making these cover crops so-called nitrate-catching crops (Tonitto et al., 2006).

In this study, the EPIC model accurately predicted the crop yield and water content in a normal year, but grossly underestimated the soil water content under drought condition. The model appears to be inadequate for predicting upward water movement, and underestimated the water content under drought conditions (Rabbel, 2013). On the other hand, the model largely overestimated N leaching, which is in accordance with other studies (Forster et al., 2000). This disparity is the result of an over estimation of NO_3^--N concentration in the leachate, which is caused by poor representation of water leaching through soil pore space (McLaughlin et al., 2006), temporal variability of N transformation (Marchetti et al., 1997), and an over-estimation of the native soil N mineralization (Warner et al., 1997).

6.2 Conclusions for nutrient management

Farmers in Central China use, on average, 229 kg N ha^{-1} every year in the form of mineral fertilizer, which is a very high rate compared to rest of the world. The excessive use of N fertilizer is mainly the consequence of insufficient awareness, a lack of knowledge of specific crop requirements, and the low cost and high availability of mineral-N fertilizers.

In maize-wheat rotation systems in Central China, the combination of legume cover crops with reduced mineral-N fertilizer application rates has been shown to (i) decrease NO_3^- concentrations in soil solution, (ii) limit NO_3^--N leaching losses, and (iii) reduce the soil residual N_{min} after harvest. However, this strategy improves neither agronomic N-use efficiency nor N-recovery rates.

While the calibrated EPIC model can successfully simulate aboveground biomass and soil water content under wheat-maize rotations, the model greatly over-estimates the amount of N leached from the soil.

6.3 Recommendations for reducing N losses

To date, environmental regulations on agricultural production systems are either unavailable or inappropriately implemented in China. Agriculture is solely regarded as a provider of food and fiber. Therefore, maximizing output is primary, and, ecological implications and side effects are considered secondary. Application strategies and future policies regulating the chemical fertilizer market must increasingly consider the environmental costs associated with excessive mineral -N application. Regulations need to be urgently introduced to align fertilizer use with crop demand.

In intensive agricultural systems with high mineral fertilizer input, farmers should avoid extended periods of bare fallow, particularly during the transition seasons between main-crops. Crop-specific, demand-based recommendations on application rates should be used in conjunction with cover crops. Resulting recommendations and guidelines about N fertilizer use must be site and season specific and need to take into account the resource base and farmers' endowment with production factors.

It is necessary to promote basic knowledge of proper fertilizer, as most farmers have insufficient knowledge of how to synchronize N fertilizer input with crop-N demand. Currently, they rely on their existing experience, i.e., "using more fertilizer leads to higher crop yield" (Jia et al., 2013), and consequently N-use efficiency is low.

6.4 Outlook on further research needs

6.4.1 Economic analysis

Economic strategies to reduce N fertilizer application rates

As agricultural pollution is obscure and mostly happens on a large scale, it is not easy to trace pollution back to its source. Consequently, society has to shoulder the costs of environmental pollution; neither farmers nor the fertilizer industry is interested in reducing N fertilizer application rates. Elsewhere, pricing policies have been shown to effectively curb application rates. For instance, mineral N rates in Indonesia decreased from 135 to 100 kg N ha^{-1} when fertilizer prices increased during the 1997 economic crisis (Abdulrachman et al., 2004). The ratio of fertilizer prices to prices of agricultural products is a key factor influencing N-application rates (Goulding, 2004). In China, the current agricultural pollution is mainly associated with fertilizer subsidies. A new agricultural cost-benefit balance that considers environmental costs may help reduce energy wastage and environmental pollution.

Economic analysis of alternative strategies

Cover crops and multi-split application of mineral N fertilizer have proven effective in reducing N losses to the environment. However, because using multi -split application and cover crops enhances the labor demand as compared to “traditional” field management systems, these may not be suitable for the current resource endowment of some production systems. On the other hand, legumes may provide an additional food or income source while saving N fertilizers. These strategies are thus likely to reduce the environmental costs, which to date, have seldom been considered and are difficult to evaluate.

6.4.2 Scaling up the models

Because of crop, soil and climate diversity, it is important to evaluate the nutrient losses within an environment with similar soil and climate conditions following a model-based extrapolation to watershed scale (Goulding, 2004). However, the present research has highlighted several shortcomings of scaling up such experiments to small watershed scale:

(1) Functions in the EPIC model are limited, and extrapolation of N losses to watershed scale showed a very poor fit.

(2) The study area is predominantly divided up into small land holdings occupied by small-scale farmers. Therefore, the watersheds consist of a large number of different plots, each with their own crops and management strategy, causing a diversity that hampered extrapolation efforts.

(3) Insufficient data exist for evaluating the model performance at watershed scale (Addiscott, 1998). Discharge hydrograph readings from small watersheds are intermittent, and data required for model calibration are often missing. Further research is needed to improve the nutrient loss estimates, and the progression from field to small watershed scale.

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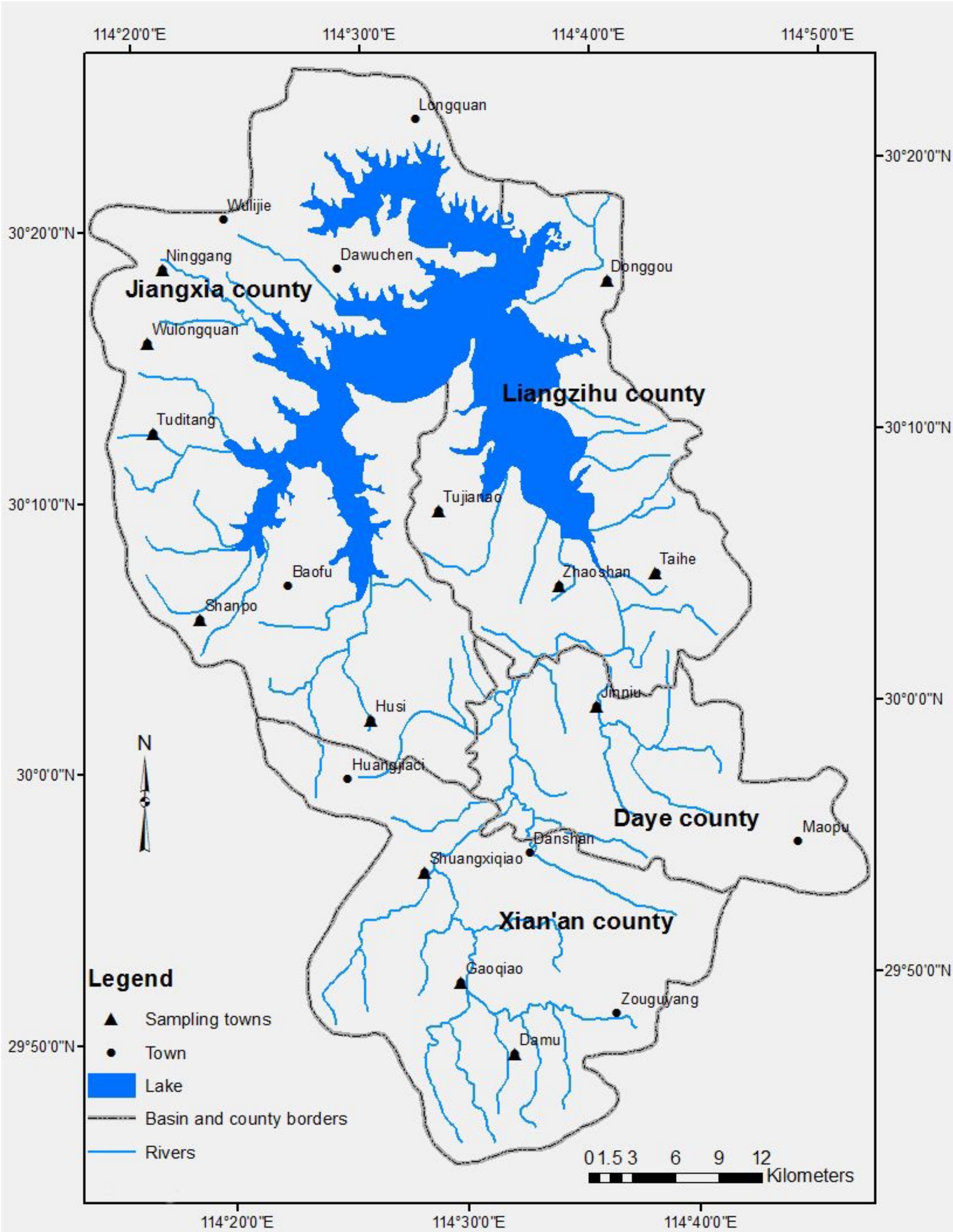
8. APPENDIX

Appendix 1 List of information about field management in Hubei Province, Central China (2012-2013)

Date	Field operation
2012	
15-April	Plough the experimental field to approximately 8-12 cm depth and level the field.
17-April	Apply basic N fertilizer and all of the P, K fertilizer prior to sowing. Sow maize at a hill spacing of 50 cm × 50 cm with 2 seeds per hill. Spray pre-emergence herbicides for weed control.
1-May	Apply topdressing N fertilizer. Remove smaller plant, if there 2 germinations on one hill.
31-May	Apply N fertilizer to plots with N_1 treatment. Clear weeds by hand hoeing.
10-August	Harvest maize, leave 5 cm stubble. Weigh fresh weight of plant tissues on site, and then transport plant tissues to the laboratory for chemical analysis in a closed plastic bag.
11-August	Remove maize residues from the plots; break the stubble and plough the field to approx. 8-12 cm depth. Sow cowpea in the cover crop treatment plots at a spacing of 40 cm × 50 cm. Weed control in plots with cover crop, leave weeds in bared fallow.
6-October	First cowpea pick. Pick cowpea fruit, and determine fresh weight of the production from each plot.
20-October	Second cowpea pick. Harvest straw and chop into 2-3 cm segments, leave straw on plots. Clean weeds in plots with bared fallow and chop into 2-3 cm segments. Plough all plots to approx. 8-12 cm depth, mixing plant segments with the soil.
21-October	Apply basic N fertilizer and P, K fertilizer for wheat season. Sow wheat by hand at the rate of 2.4 million seeds per ha with a row spacing of 20 cm. Spray pre-emergence herbicides for weed control. Control weeds by hand hoeing.
2013	
9-March	Apply topdressing N fertilizer.
6-April	Apply N fertilizer to plots with N_1 treatment.
17-April	Sow maize in a seedbed near experimental field.
19-May	Harvest wheat leaving 5-cm stubble, and weigh aboveground biomass. Transport plant tissues to laboratory in a closed plastic bag. Remove all straw from the plots. Destroy stubbles by hand hoeing and plow field to 8-12 cm depth before for transplanting the maize
20-May	Transplant maize into plots at a hill spacing of 50 cm × 50 cm. Field management is the same as in the previous maize season.
1-June	Apply top dressing N fertilizer.
24-June	Apply N fertilizer to plots with N_1 treatment.
25-August	Harvest maize and transport plant samples to laboratory.

Appendix 2 Map of household survey area in Liangzihu Lake basin, Hubei Province, Central China.



Appendix 3 Factors that Affect the Nitrogen Fertilizer Application[4]

INTRODUCTION: I am a student from center for development research, Bonn University. This questionnaire is used to analyze the factors that relate to nitrogen fertilizer application. As an expert in agricultural practice, your answer is very important for us. Your answer will be only used for research purpose. This questionnaire is treated with anonymity; please feel free to answer this questionnaire. Thanks for your cooperation!

Section 1 Background of farmers (Respondents are head of the householder)

Gender: _____ Age:__________ Irrigate/Rain fed Series NO:______

1. How many people in your family last year

A 1 B2 C 3 D 4 E 5 F______

1.1 Details about family members

Sex_________________________, Age_________________________,

Career______________________, Education_____________________

Salary______________________

2. How many labors[5] are available in your home last year?

A 1 B 2 C 3 D 4 E 5 F______

3. How much arable land do you have?

________ Mu, paddy field, arid land (15Mu=1ha)

4. Do you have any other job?

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[4]Most data from this questionnaire are from the year of 2013.

[5]Labor means more than 18 years old and do farm work when needed, who can have other part time job.

Yes, please answer next question   No

4.1 How much did you earned from other job last year?

____

5. What is your education level?

A Without B primary school C high school D specialized school E______

6. What kind of crop(s) do you plant last year?

A Wheat, ___mu B Maize, _____mu C Rapeseed , _____mu D Rice, _____mu E Peanut, _____mu F _________

7. How did you evaluate the fertility of your farmland?

A Very Fertile B Fertile C Not Fertile D Extremely Bad

7.1 How did you get this conclusion?

____

8. Does your farmland ever have a disaster[6] (drought/flood) within recent 5 years?

Yes, details_______________________   No

9. Did you exchange your farmland with other farmer regularly?

Yes, Change cycle is ___________Years   No

10 How many bags fertilizer did you applied in your farmland last year?

________bags, _____kg/bag. Type of fertilizer _________

[6]Disaster means any happening that causes great harm or damage; serious or sudden misfortune; calamity. Webster's Dictionary (Neufeldt & Guralnik, 1997)

_________ t organic fertilizer.   Type of organic fertilizer________

Section 2 Economic Factors

11. The total income[7] did your family earned last year (Chinese ¥)?

A. ≤20,000 B 20,000- ≤30,000 C30,000- ≤40,000 D 40,000- ≤50,000 E>50,000

12. Would you please estimate the yields that you had last year?

________kg (Wheat, Maize, Rice, Rapeseed, _____)

13. Had you received any subsides from government last year?

Yes, How much? _____________, For what? __________   No

14. How much did you expect to gain from 1000RMB of fertilizer application?

_______________________________.   I don't know

Section 3 Knowledge Factors

15. Have you ever received the fertilizer knowledge training?

Yes, Where ________, When_________   No

16. Where did you get the fertilizer knowledge?

A Experience   B Talk with other farmers C Book D Internet F______

17. How did you apply the fertilizer?

A Machine   B Manually C Other methods, ____________

18. Do you know how to identify the quality of fertilizer?

[7]Total income means annual household after-tax income includes salary, production sale and other income.

Yes, How?______________. Example: ____________Good, ___________Bad No, I don't know.

19. Compare to 5 years ago, did you change the quantity of nitrogen fertilizer application?

Yes, (increase/decrease) Why ________ No

20. Do you agree that "the more nitrogen fertilizer the better for crop"?

Yes, No, answer the next question

201.1. How much nitrogen fertilizer do you think is suitable for your crops?

____

21. Have you ever applied any other fertilizer except nitrogen, phosphorous and potassium?

Yes, Which ______________ No, never

Section 4 Other Factors

22. The distance between home and farmland?

_________Km. or _________minutes by _________.

23. The distance between home and nitrogen fertilizer sell point?

________Km or _________minutes by _________.

24. How did you transport the fertilizer?

A. Car. B. Labor. C. Motor bike D. ________

25. The road condition that used for nitrogen fertilizer transportation?

A. Village level B. County level. C. Municipal level. D National level.

26. Have you ever irrigated your farmland last year?

Yes, please answer the next question. No

26.1 How far from the water resource to your farmland?

_______________ Km.

27. Do you know any policies that affect your fertilization in recent 5 years?

For example: the "tax-free" policy.

____

28. Do you have special methods that may save the nitrogen fertilizer?

____