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# Strategies for Managing Soil Nitrogen to Prevent Nitrate-N Leaching in Intensive Agriculture System

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## 1. Introduction

Nitrogen fertilizer has played a major role in the global food production over the past 60 years. And about 50 percent of total N comes from fertilizer supply. However, fertilizer N has a low efficiency of use in agriculture (10-50 percent for crops grown in the fields). One of the main causes of low efficiency is the large of N by leaching, runoff, ammonia volatilization or denitrification with resulting in pollution of groundwater and atmosphere. With the limitation on arable land area and the demand for more and more food production, the only way is to increase the efficiency of use of fertilizer N. Thus, it is important to know the forms and pathways of N loss and the factors controlling them so that procedures can be developed to minimize the loss and increase N use efficiency (NUE). A conceptual scheme indicates the nitrogen cycle in crop production systems. Annual N input was about 170 Tg, and about half of added N is removed from the field as harvested crop (85 Tg). The remainder of the N, defined as surplus N, either is lost to the environment or accumulates in the soil (Fig.1).

Food demand of the public is the major promotion for rapid development on intensive agriculture, which is becoming a dynamic industry in China. However, with an excess amount of nitrogen from animal manures and commercial fertilizers, many pollutant incidents have been found and reported on nitrate contamination in intensive agriculture especially in greenhouse vegetable production systems (Zhang, 1996; Ju, 2007; Li, 2002; Song, 2009). Environmental and economic concerns have prompted agriculture researchers and producers to seek for more and more efficient strategies for nutrient managements. The present public concerns on nitrate management are focusing on N, which exceeds crop demand and might migrate from agro-ecosystem to groundwater and surface water (Daniel, 1994). Economic considerations in nitrate managements mainly focus on efforts to improve N utilization and reduce costs of N inputs. Based on its necessity for mobility in the soil and risk to environment systems, popular N management thus aims to balance N inputs with

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crop requirements, and decrease the nitrogen loss to the groundwater when irrigation or rainfall occurs. This chapter provides an overview of the general role of nitrogen in agroecosystems and then discusses how various N management practices can contribute to preventing nitrate-N leaching in intensive agricultural systems.

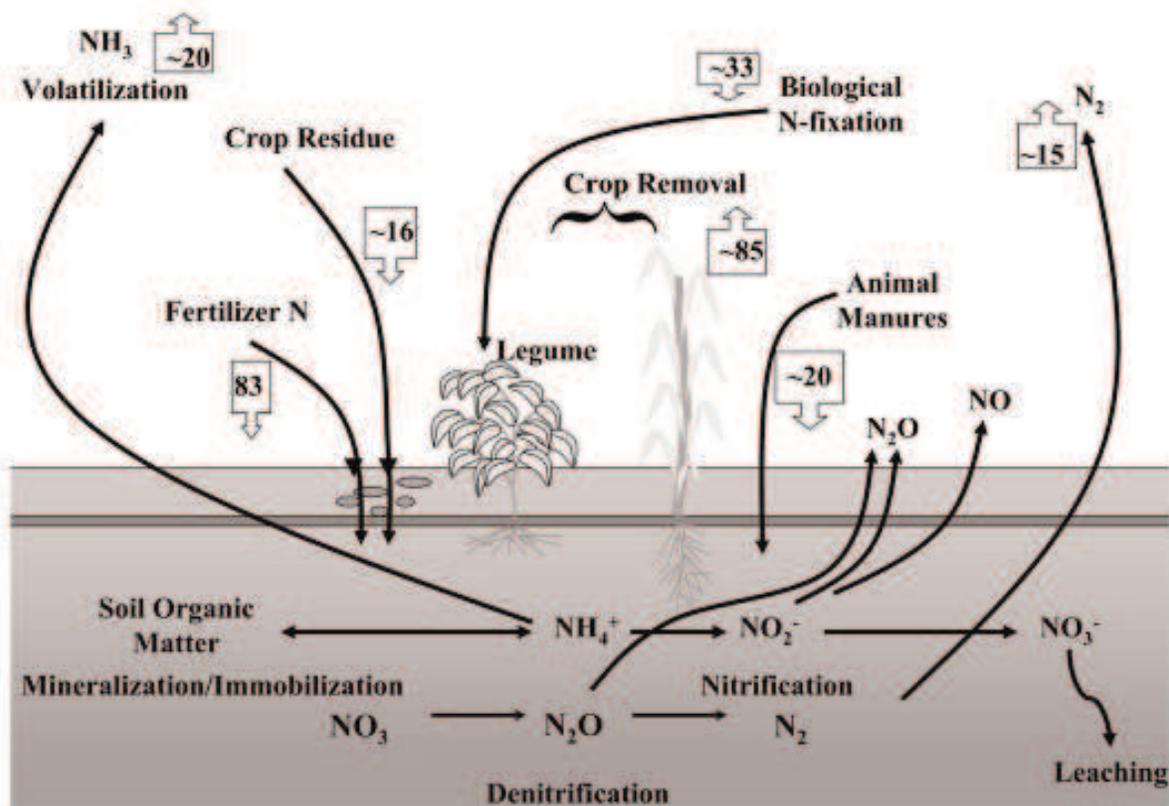


Fig. 1. A conceptual scheme on nitrogen loss in crop production(Tg N). By Mosier, 2004

## 2. Field conditions for Nitrate-N Leaching

Leaching refers to the movement of N in water moving downward through the soil profile and out of the rooting zone. As the key N form for uptake by most crops, nitrate (NO<sub>3</sub><sup>-</sup>) found in soil is usually used to indicate the abundance of N that can be taken up especially in well-aerated soils. As an anion, nitrate usually remains in the soil solution and therefore is relatively free to move with water flows. Drainage of excess water often drives NO<sub>3</sub><sup>-</sup> downward through the soil profile and out of the rooting zone, and thus nitrate leaching occurs. Most (usually >95%) of the N in soils is not susceptible to crop uptake until it is exchanged into available N as mineral N form (NO<sub>3</sub><sup>-</sup>, NH<sub>4</sub><sup>+</sup>) by soil microorganisms under many conditions such as some environmental factors (temperature, moisture availability, aeration status, etc.) and N types or amounts of organic N present in soils. That is to say, the importance of N losses by leaching varies greatly with factors that determine how much and when water flows downward through soils.

Two major inputs, including significant amount of NO<sub>3</sub><sup>-</sup> in the soil profile and sufficient precipitation or irrigation water are necessary when nitrate leaching occurs. Substantial N losses occur in systems where mineralization or fertilization results in high concentrations of NO<sub>3</sub><sup>-</sup> during periods when leaching is likely. Retained NO<sub>3</sub><sup>-</sup> in the soil profile usually comes

from many sources such as mineralization of SOM (soil organic matter) crop residues, manures and synthetic fertilizers application. There is also high nitrate leaching potential when rainfall and irrigation events in intensive agricultural systems due to the shallow root systems for cereal and vegetable crops with poor N fixation ability except for cover crop. Flows of excessive water inputs often increase the mobility by moving the soluble N from the soil surface to depths where crops roots cannot uptake and thus that leads to substantial storage capacity for  $\text{NO}_3^-$ -N in the soil profile.

It is difficult for growers to coordinate smoothly  $\text{NO}_3^-$  leaching control and economic benefits during the crop's active growth period with significant amounts of N input to the soil. Therefore, it is necessary for nutrient managers, soil and environmental scientists to develop the effective strategies to reduce nitrate leaching, which require to know detailed plans on nutrient, water and crop management considering N source, N application method, rate and timing, and others including soil properties and moisture, evapotranspiration, and crop systems for local conditions and specific sites. Best management practices (BMPs), which reduce N and irrigation inputs without lowering crop yields, are popular and major strategies to reduce nitrate leaching.

## 2.1 Fertilizer nitrogen management strategies

Applications of animal manures or commercial fertilizers often add more N than that is taken up by crops during a year in systems. The amount of N added for production of many field crops, for example, is the quantities of N expected to be taken up by the crop plus enough extra N to compensate for losses of N expected to occur (Stanford, 1973; Bock & Hergert, 1991).

### 2.1.1 Appropriate N application rate

Excessive N application is generally the universal reason for nitrate leaching. The remainder of N added usually remains in the soil at the end of the cropping season and is vulnerable to leaching. Many literatures reported that nitrate leaching increases rapidly with elevated N application rate (Zvomuya, 2003; Guo, 2006). Therefore, proper N input is the major consideration for nitrate leaching control. And producers are forced to use a rate that will give them an economic optimum return over the long run. However, most of the current recommendations for the crops requirements are generally at an excessive rate which will result in a marked increase in the loss of N leaching from the greenhouse vegetables (Fig. 2)

It is difficult to establish a nitrogen rate that will be appropriate for every year, since there are several biological reactions that influence the availability of nitrogen for crop use. The economical optimum nitrogen rates varied greatly between different growing seasons even if for the same field. Excess N use in crop production is often identified as a major contributor to  $\text{NO}_3^-$  enrichment of ground water. Little information is available to show the specific relationships between crop management systems and N fertilizer use on the amounts of  $\text{NO}_3^-$  lost by leaching. A study was conducted to determine the effect of several cropping systems and N rates, providing a range of N availability to corn (*Zea mays L.*), on soil water  $\text{NO}_3^-$  concentrations and leaching below the root zone. Four cropping-manure management systems were established in 1993 - 1994 (8-site years) at Arlington, WI, on a Plano silt loam. Ammonium nitrate (0 to 204 kg N ha<sup>-1</sup> in 34-kg increments) was broadcast at the time of corn planting. The results showed that nitrate N concentrations in the samplers increased as the amount of N applied in excess of the observed EONR increased.

Predicted soil water  $\text{NO}_3^-$ -N concentration at EONR was  $18 \text{ mg L}^{-1}$ . Average  $\text{NO}_3^-$ -N concentrations were  $<10 \text{ mg L}^{-1}$  where fertilizer N rates were  $>50 \text{ kg N ha}^{-1}$  below the EONR and  $>20 \text{ mg L}^{-1}$  where fertilizer N rates were  $>50 \text{ kg N ha}^{-1}$  above the EONR. An end-of-season soil  $\text{NO}_3^-$  test appears to be capable of evaluating corn N management practices and indicating the amount of excess N fertilizer applied that may be leached from the root zone. These results illustrate the direct relationship between  $\text{NO}_3^-$  loss by leaching and N application rates that exceed crop needs (Andraski, et al., 2000). Limiting the amount of inorganic N within the soil at the end of a crop's growing season and before the next crop has established an extensive root system is a key factor for reducing N losses. Therefore, although timing, method of N application, and accounting for mineralizable soil N are important for reducing potential  $\text{NO}_3^-$  leaching, it was concluded that the most important factor was to apply the correct amount of N fertilizer (Power & Schepers 1989).

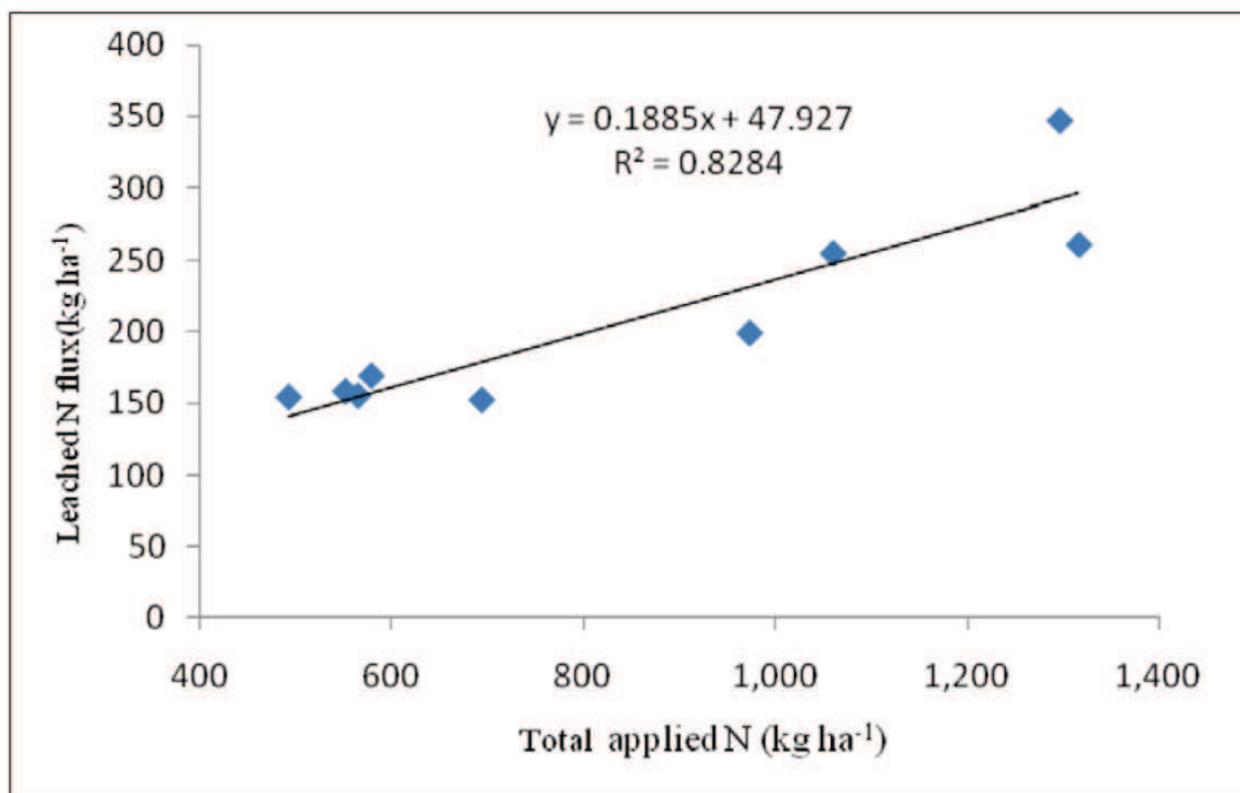


Fig. 2. A linear trend between total applied N and leached N flux.(from Song, 2009)

### 2.1.2 Timing N application in harmony with crop demand

It is necessary for BMPs development to consider timing of N supply and crop need, i.e., apply N at a proper phase that allows rapid crop uptake. For many crops, cumulative N demand usually follows an S-shaped curve, with slow uptake rate during establishment and an exponential utilization in the vegetative and reproductive phases. Splitting N application is thus recommended by applying N in phase with crop demand, providing high soil-N concentrations at different periods needed for crop growth while minimizing the time with leaching losses risk (Power et al, 1998). And it was reported that decrease in  $\text{NO}_3^-$  leaching and increase in anticipant yields for potatoes by adopting BMPs (Kelling, 1994; Errebhi, 1998; Waddell, 2000).

In summary, although some of the studies have emphasized the importance of BMPs, they do not provide a complete solution. The effects of these BMPs on reducing  $\text{NO}_3^-$  leaching are variable, ranging from no effect (Osborne & Curwen, 1990) to 30% reduction (Mechenich & Kraft, 1997). This indicates that BMPs should be carefully evaluated for specific conditions.

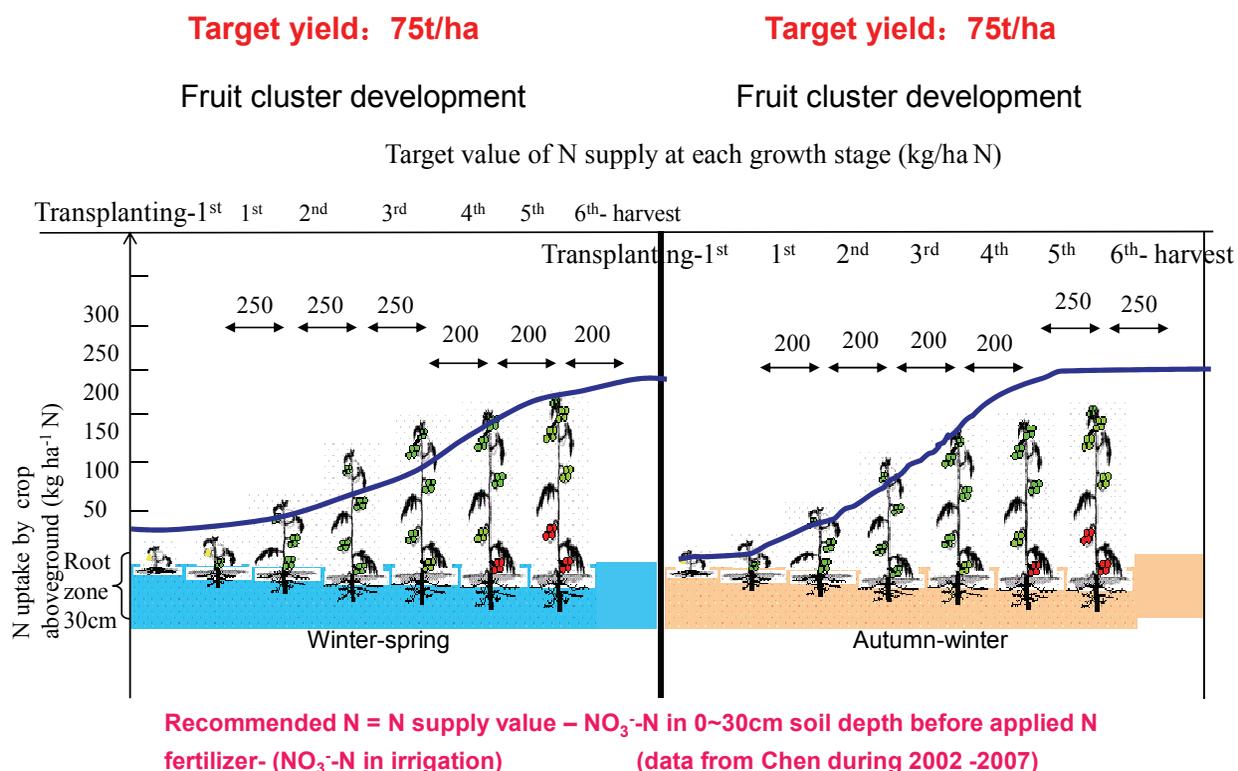


Fig. 3. Optimum N management based on plant N demand and soil N supply for greenhouse tomato cropping system. By Ren, 2009

In recent years in China, unreasonable nitrogen fertilization management in intensive vegetable production region always results in some serious environmental problems, which limit the sustainable development of local vegetable industry. Long-term field experiments were conducted in the six successive greenhouse tomato growing seasons in Shouguang, Shandong province from 2002 to 2007 (Fig.3). Compared with conventional N management, N fertilizer input with site-specific N management averagely reduced by 72% without any significant fruit yield reduction in all seasons. N agronomic efficiency of site-specific N management was 69 kg FW/kg N and value-cost ratio (VCR) was 27.8. According to fruit yield forming and N uptake pattern, the critical period for fertilization was carried out in April and October in winter-spring and autumn-winter growing season, respectively. During the critical periods of fertilization 3-4 events of side-dressing was needed with every 7 or 10 days at a rate of 50 kg N ha<sup>-1</sup>. With conventional N management, the yearly total N input, including Nmin residue in 0-90cm soil profile before transplanting, N from chemical fertilizer, manure and irrigation water, was 2917 kg N ha<sup>-1</sup>. However, the apparent N loss

was 1816 kg N ha<sup>-1</sup> through leaching, soil fixation, gaseous emission etc. In contrast to conventional N management, N use efficiency in site-specific N management increased by 7% and up to 25% while N input and apparent N loss reduced by 44% and 57% on average, respectively (Ren, 2009).

### 2.1.3 Slow release fertilizer and Nitrification Inhibitor application

The agronomic and environmental benefits by applying slow-release fertilizer and nitrification inhibitor have been reported with reducing NO<sub>3</sub> leaching and improving NUE (Zerulla, 2001; shaviv, 1993). However, the performance of these newly products depends on climate condition and soil type with temporal and spatial variation.

In contrast to traditional fertilization, nitrate nitrogen content in soil and yield factors of wheat-maize applied slow/controlled release fertilizer with different amounts and rates in North China was analyzed (Fig4, 5). The results indicated that nitrate nitrogen content still maintain high level during late growing period, and the yield traits such as panicle number, 1000 grain weight as well as actual yield keep high level if fertilized according to recommendation at the ratio of 6:4:2 at pre-sowing, reviving and jointing respectively (the treatment named as 100% UD). The formulated slow/controlled release fertilizer (CSR) showed lower nitrate nitrogen content in soil but had no influence on yields compared with 100% UD. CSR showed a positive impact on maize production, e. g. increased fertilizer use efficiency, decreased bare top length. The yield of 80% SCR is 18.3% higher than that of 100% UD (Table 1). Crop could absorb nutrient timely and fully with the application of SCR because the nutrient is released slowly and avoided of the loss risk by nitrate leaching. On the whole, further study on how to optimize SCR fertilization distribution during the wheat and maize growing season was needed for the purpose of increasing economic and environmental benefits simultaneously (Lu et al., 2011).

Recent years, researchers have tried their best to control nitrogenous fertilizer loss and its pollution to environment. The mixed nitrogen nutrition becomes one of the new methods to enhance the effectiveness of nitrogen utilization and reduce the nitrogen loss. In the field conditions, enhanced ammonium nutrition (EAN) by using the nitrification inhibitor in soil becomes a very good way to achieve the mixed nitrogen nutrition. Cotton is sensitive to nitrogen utilization. Meanwhile, due to growing in the hot season, the irrational nitrogenous fertilization utilization will lead to not only the poor cotton growth but also the larger nitrogen loss and environment pollution. With Bt-transgenic cotton 33B as experimental plant and Dicy anodiamide (DCD) as nitrification inhibitor, the effects of nitrogenous fertilizer strategies (including DCD and non-DCD treatment in different nitrogen levels) on the nitrogen accumulation in cotton field soil and cotton functional leaves were discussed. The results showed: 2% DCD treatment enhanced ammonium absorption (increased NH<sub>4</sub><sup>+</sup> - N from 0.70% to 112% in the main stem leaves and from 8.84% to 46.47% in the bearing stem leaves) and restrained nitrate absorption of cotton(decreased NO<sub>3</sub><sup>-</sup>-N from 0.20% - 22.68% in the main stem leaves and from 0.10% to 28.03% in the bearing stem leaves), the extent of influence is different from one growth stage or nitrogen level from another; at the same time, it reduced the content of rudimental total nitrogen(decreased extent from 0 to 14.39%) and maintained the higher content of ammonium nitrogen(increased extent from 1.11% to 17.83%) in cotton and enhanced the efficiency of nitrogen fertilizer as well as saved nitrogen resource. These above mentioned further showed that it was important to treat cotton with EAN from the physiological and ecological perspectives.

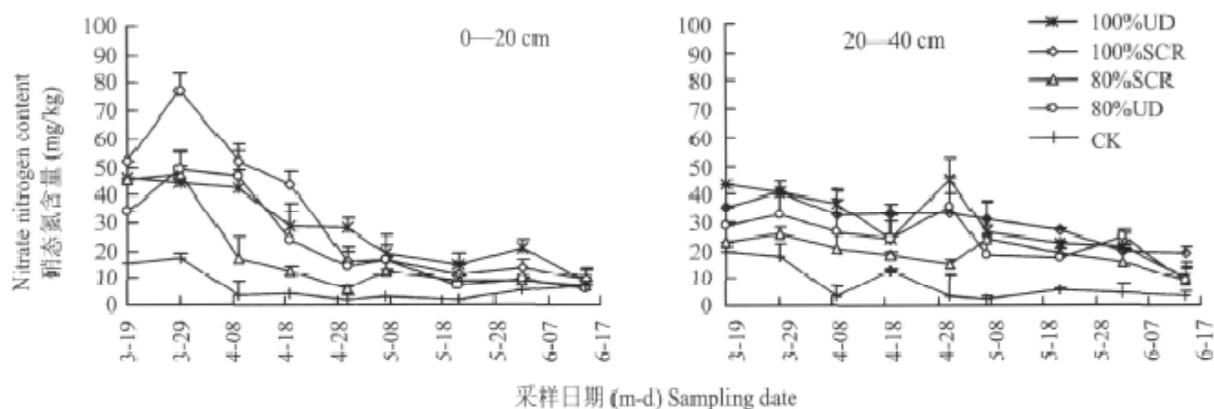


Fig. 4. Comparison of soil nitrate nitrogen content of coated urea, slow-releasing fertilizer and urea under the reduced application rate in winter wheat season

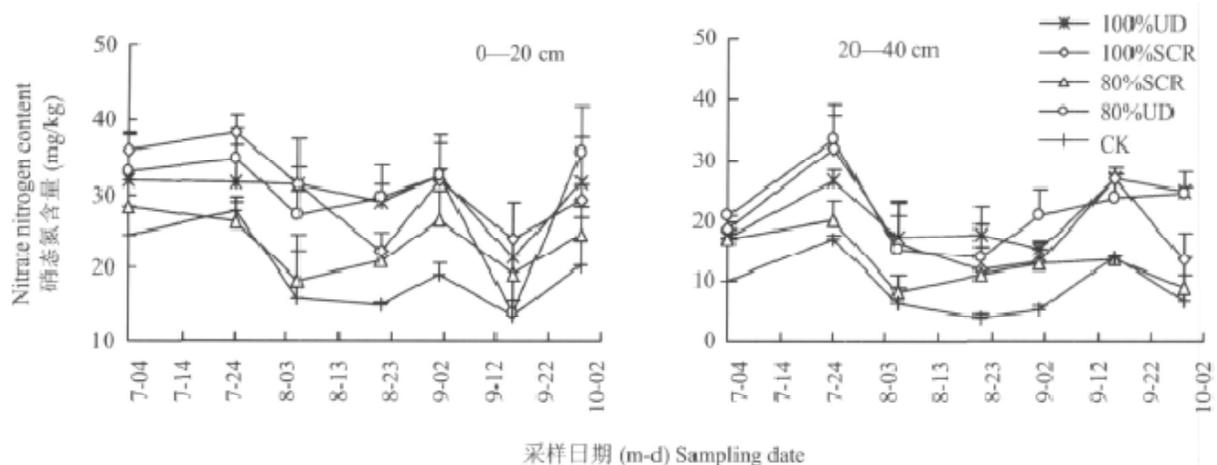


Fig. 5. Comparison of soil nitrate nitrogen content of coated urea, slow-releasing fertilizer and urea under the reduced application rate in summer maize season

Treatments	Winter wheat (kg ha <sup>-1</sup> )	Summer maize (kg ha <sup>-1</sup> )
100%UD	3705 a	7045 c
100%SCR	3525 a	7733 ab
80%SCR	3495 a	8336 a
80%UD	3150 a	7671 bc
CK	3225 a	6858 c

Note: Values followed by different letters within a column are significantly different at  $P < 0.05$  level. UD- local conventional fertilization; SCR-slow /controlled release fertilization; CK- no fertilization.

Table 1. Difference significance analysis for actual yields of winter wheat-summer maize system in different fertilizing treatments

## 2.2 Soil management strategies

### 2.2.1 On-site soil NO<sub>3</sub><sup>-</sup> test

Soil test is defined as "...rapid chemical analyses to the plant-available nutrient status, salinity, and elemental toxicity of a soil" a program that includes interpretation, evaluation,

fertilizer and amendment recommendations based on results of chemical analyses and other considerations" (Peck & Soltanpour, 1990). The purpose of soil test is to provide a basic parameter for soil management decisions usually for agricultural systems where yield and quality are the ultimate goals. Also it can be applied for other goals such as human health and environment protection. All modern soil testing programs generally have four basic components: (1) sample collection and handling; (2) sample preparation and analysis; (3) interpretation of analytical results; and (4) recommendations for action. For successful soil test, each component should be conducted properly without no error at each step. Soil test for nitrogen differs greatly between arid and humid regions. In most cases, samples for residual mineral N must be collected to deeper depths (60-200cm) than for standard soil testing (0-20cm) seldom. Due to it, a sample collected from the rooting zone shortly before the start of the growing season and analysed for residual mineral N ( $\text{NO}_3^-$ -N,  $\text{NH}_4^+$ -N) can precisely determine plant-available N, and thus N inputs are diminished accordingly. Soil samples are often only analysed for  $\text{NO}_3^-$ -N because it is usually the dominant form of inorganic N in most soils in China. Proper handling is critical to avoid changes during storage after sample collection. To avoid these problems, samples extraction of inorganic N should be rapidly done and usually accomplished by shaking some quantitative fresh samples for 30 min to 1 h with a salt solution [e.g., 2 M KCL, 0.01  $\text{CaCl}_2$ ], followed by filtration. Automated colorimetry is usually used to determine mineral N ( $\text{NO}_3^-$ -N,  $\text{NH}_4^+$ -N) in soil extraction at present, however, ion chromatography, steam distillation, ion electrodes, and micro-diffusion techniques are also applied for specific needs (Bundy & Meisinger, 1996).

The pre-sidedress soil nitrate test (PSNT) is a valuable method for soil N test and therefore is commonly used in many fields. It is originally developed for corn but now being investigated for wider range of agronomic and vegetable crops (Magdoff, 1984; Bock & Kelley, 1992). The PSNT was described and used to provide a timely monitoring of soil  $\text{NO}_3^-$ -N pool, get guidance for sidedress fertilizer N recommendations and evaluate the ability to nitrate leaching reduction (Bundy, 1994, 1999; Guillard, 1999). It was concluded that PSNT, compared with the conventional N-management system, could reduce fertilizer N, lower nitrate leaching, and diminish the potential for nitrate contamination to groundwater (Durieux, 1995). In China, Field experiments were conducted in a greenhouse of Shouguang city, Shandong province to validate integrated nitrogen management and PSNT techniques in monitoring nitrate dynamic in root zone and corresponding recommendation of sidedressing N fertilizer for greenhouse tomato in spring and autumn seasons in 2004. Considering the target yield level, FW 84 t ha<sup>-1</sup>, in spring, the rate of N supply (soil  $\text{NO}_3^-$ -N in root zone + N from irrigated water + sidedressed N) were N 300 kg ha<sup>-1</sup> of each sidedress at the first, second and the third cluster fruit expanding stage (CFES), and N 200 kg ha<sup>-1</sup> in the later growing stage. Similarly, when the target yield was FW 75 t ha<sup>-1</sup>, in autumn, the rate of N supply were N 200 kg ha<sup>-1</sup> of each sidedressing at the first, second third and the fourth CFES, and N 250 kg ha<sup>-1</sup> in the later growing stage in autumn season. Including organic manure application as conventional way, optimized N treatment reduced N application rate by 62% and 78% of total N fertilizer in spring and autumn season, respectively, compared to conventional treatment, because environmental N (N released from organic N pool and N from irrigated water etc.) contributed considerable N to tomato growth. Compared to conventional N treatment, apparent N loss in soil vegetable crop system significantly reduced in optimized N treatment while the yield was the same as that

of conventional treatment. It was concluded that integrated nitrogen management, together with PSNT technique, was very useful in increasing nutrient efficiency and reducing the risk of environmental pollution (He et al., 2006). For some open field vegetables, the same results are listed. Trials were conducted in 15 commercial fields in California in 1999-2000 to evaluate the use of presidedress soil nitrate testing (PSNT) to determine sidedress N requirements for lettuce production. In each field a large plot (0.2-1.2 ha) was established in which sidedress N application was based on presidedress soil  $\text{NO}_3\text{-N}$  concentration. Prior to each sidedress N application scheduled by the cooperating growers, a composite soil sample (top 30 cm) was collected and analyzed for  $\text{NO}_3\text{-N}$ . No fertilizer was applied in the PSNT plot at that sidedressing if  $\text{NO}_3\text{-N}$  was  $>20 \text{ mg kg}^{-1}$ ; if  $\text{NO}_3\text{-N}$  was lower than that threshold, only enough N was applied to increase soil available N to  $20 \text{ mg kg}^{-1}$ . The productivity and N status of PSNT plots were compared to adjacent plots receiving the growers' standard N fertilization. Cooperating growers applied a seasonal average of  $257 \text{ kg ha}^{-1}$  N, including one to three sidedressings containing  $194 \text{ kg ha}^{-1}$  N. Sidedressing based on PSNT decreased total seasonal and sidedress N application by an average of 43% and 57%, respectively. The majority of the N savings achieved with PSNT occurred at the first sidedressing. There was no significant difference between PSNT and grower N management across fields in lettuce yield or postharvest quality. At harvest, PSNT plots had on average  $8 \text{ mg kg}^{-1}$  lower residual  $\text{NO}_3\text{-N}$  in the top 90cm of soil than the grower fertilization rate plots, indicating a substantial reduction in subsequent  $\text{NO}_3\text{-N}$  leaching hazard. It was concluded that PSNT is a reliable management tool that can substantially reduce unnecessary N fertilization in lettuce production (Breschini & Hartz, 2002).

In practice, the PNST actually measures, that is to say, it is not the determination of residual inorganic N, but a field-based expression of the capacity to provide an adequate supply of mineral N during the growing season (i.e., of the soil N mineralization potential). The PNST has been successfully used to evaluated in amounts of field studies in many countries especially in the United States (Magdoff et al.,1990; Meisinger et al.,1992; Sims et al.,1995; Sogbedji et al., 2000). The general approach used to make N recommendation was summarized as follows (Tisdale et al, 1993):

$$N_{\text{fertilizer}} = N_{\text{crop}} - N_{\text{soil}} - (N_{\text{organic matter}} + N_{\text{previous crop}} + N_{\text{organic waste}}) \quad [1]$$

$N_{\text{fertilizer}}$  – amount of N needed from fertilizers, manures, biosolids, etc.

$N_{\text{crop}}$  – crop N requirement at realistic yield goal

$N_{\text{soil}}$  – residual soil inorganic N

$N_{\text{organic matter}}$  – N mineralized from soil organic matter

$N_{\text{previous crop}}$  – residual N available from previous legume crops

$N_{\text{organic waste}}$  – residual N available from previous organic waste use such as animal manures, biosolids wastewater irrigation, etc.

### 2.2.2 Tillage

Many literatures showed that tillage alter the soil environment and thus lead to elevated oxidation of SOM and mineralization of soil N (Randall, 1997a). Therefore Chinese farmers conventionally adopt tillage to manage soil N depending on tillage to release N for crop production. Effects of tillage on nitrate leaching control have been demonstrated in studies comparing no-till with conventional tillage in Iowa in USA (Kanwar, 1993; weed, 1996). It was concluded that despite having higher average  $\text{NO}_3\text{-N}$  concentration in drainage water,

tillage had less nitrate leaching losses than no-till under continuous corn systems due to its higher water retention capacity. Ploughless soil tillage impacts on yields and selected soil quality parameters is reviewed from the Scandinavian countries of Denmark, Finland, Norway and Sweden. The success of reduced tillage and direct drilling depends on the crop species as well as on the soil type and the climatic conditions. The best results seem to be obtained on the heaviest clay soils, which is the most difficult soils to prepare with conventional soil tillage methods. Satisfactory yields were obtained after ploughless tillage in winter wheat (*Triticum sp.*), winter oil seed rape (*Brassica sp.*) and late harvested potatoes (*Solanum tuberosum L.*). The influence of crop rotations and preceding crops in ploughless tillage systems for small grain cereals has received relatively little attention. Also, fertilization of reduced tilled crops has received too little attention, but it seems that nitrogen cannot compensate for sub-optimal tillage. One of the most striking effects of ploughless tillage is the increased density of the soil just beneath the depth of tillage. Nutrients and organic matter accumulated near the soil surface after ploughless tillage, and in the long run the soil reaction (pH) declined. Nearly all species of earthworms increased in number in ploughless tillage. The leaching of nitrogen seemed to increase with more intensive cultivation, particularly when carried out in autumn (Rasmussen, 1999).

Effects of tillage on N management have been demonstrated in studies comparing no-till with conventional tillage at several mid-western locations in America. In a long-term Minnesota study (Randall & Iragavarapu, 1995), residual soil NO<sub>3</sub> contents in the 0-1.5-m soil profile using were significantly higher with conventional tillage than N no-till for 5 out of 11 yr and were not significantly different for the other 6 yr. Average flow-weighted NO<sub>3</sub>-N concentrations were 13.4 and 12.0 mg L<sup>-1</sup> for conventional and no-till corn production treatments, respectively. Furthermore, while the no-till treatment had 12% greater subsurface drainage flow than the conventional treatment, NO<sub>3</sub> losses were marginally greater with conventional tillage. Although insignificant, these results suggest a minimal trend toward greater NO<sub>3</sub> losses with conventional tillage in this study. The authors concluded that NO<sub>3</sub> losses through tile drainage depend more on growing-season precipitation than on tillage. Recently, it was also concluded that NO<sub>3</sub> losses from agricultural fields are minimally affected by differences in tillage systems compared with N management practices (Randall & Mulla, 2001).

## **2.3 Crop management strategies**

### **2.3.1 Introducing cover crops**

Except for minimizing N losses, growing cover crops is another well-established method of managing nitrate leaching. The goal is to add crops to capture or recover residual N in the soil after main crop harvest. In recent years, the use of cover crops to reduce nitrate leaching has received much interest in many locations (Delgado, 1998; Logsdon, 2002) in addition to protecting soil from salinization. The choice of cover crops species depends on the cropping system, amount of fallow time, climate and soil type (Meisinger, 1991; Jackson, 1993). In general, shallow-rooted vegetable crops are vulnerable to higher nitrate leaching losses than deep-rooted vegetable crops. Cover crops thus can be introduced and act as scavengers that recover nitrate leached from the previous vegetable crop (Shrestha, 1998), and even reduce the NO<sub>3</sub><sup>-</sup> leaching losses that occurs in the next crop (Delgado, 1998; 2001a).

The influence on nitrate leaching of ryegrass (*Lolium perenne L.*) used as a catch crop in spring barley (*Hordeum vulgare L.*) was investigated during three successive years in a

lysimeter experiment on a sandy loam soil. Four treatments were included with combinations of time of tillage (November/March) and handling strategy of the aboveground ryegrass biomass (return/removal). Reference plots tilled in March were sown to spring barley alone. The ryegrass reduced nitrate leaching by 1.4–4.3 g N m<sup>-2</sup> year<sup>-1</sup> when incorporation took place in November. If incorporation was carried out in March, reductions in nitrate leaching were 2.1–5.6 g N m<sup>-2</sup> year<sup>-1</sup>. The herbage cut of ryegrass had accumulated 1.0–2.4 g N m<sup>-2</sup> year<sup>-1</sup> and 0.9–2.1 g N m<sup>-2</sup> year<sup>-1</sup> in November and March, respectively. Nitrate leaching losses increased with higher rates of N both with and without a catch crop. Grain yield and N uptake of the spring barley were unaffected by a catch crop and the management strategy did not interact with N fertility level. The study showed that growing a ryegrass catch crop repeatedly for three years was effective in reducing nitrate leaching losses, but the retained N did not have any immediate beneficial effect on spring barley grain yield (Thomsen, 2005).

Planting cover crops immediately after harvest or relay with main crop is important as it reduces fallow period and allows enough crop growth to accumulate soil N before winter NO<sub>3</sub> leaching (Fielder & Peel, 1992). For example, a rye cover crop planted on 1, 14 and 30 October in Maryland showed an increase in N accumulation and a decrease in soil NO<sub>3</sub>-N with early planting (Staver & Brainsfield, 1998). In a loamy sand soil, over-winter cover crops (e.g., wheat, *Triticum aestivum*) planted after early potato (Milburn et al., 1997); and wheat, rye, rapeseed (*B.napus*) seeded after sweet corn and incorporated in spring appeared to be most effective in recycling N to potato crop (Weinert et al., 2002).

A strategy of over seeding cover crops (e.g., oat) after 80 DAE of potato when N uptake is negligible can capture residual fertilizer N or soil N from late season mineralization. Relayed oat crop can capture unutilized N from potato, and rye can capture mineralized N from oat and residual N from potato, if there is any (Bundy & Andraski, 2005). Cover crops can be incorporated in winter just before soil freezes, which can recycle nutrients for succeeding crops.

Guo et al (2008) reported that total N uptake by sweet corn at harvest was 187 kg N ha<sup>-1</sup> in 2005 and 154 kg N ha<sup>-1</sup> in 2006 (Fig.6). Shoot N uptake by sweet corn was up to 42 and 56 kg N ha<sup>-1</sup> from sweet corn transplanting to 21 July in 2005 and 2006. During the later growth stages of sweet corn (from 20 July to the end of the harvest), the amounts of N removed by the sweet corn shoots were 131 and 112 kg N ha<sup>-1</sup> in 2005 and 2006. After three continuous cucumber growing periods with root zone N management, soil N<sub>min</sub> was lower at the beginning of the fallow period in 2006 than in 2005. In 2005 no significant difference was found in N<sub>min</sub> content between sweet corn cropping and the fallow treatment in the top 0.3 m of the soil profile. However, sweet corn cropping evidently depleted N<sub>min</sub> compared to the fallow treatment in 2006. In both years soil N<sub>min</sub> at 0.3–0.9 m depth was reduced by sweet corn cropping with root growth and N uptake occurring in contrast to the fallow period. At the sweet corn harvest less N<sub>min</sub> was retained in the top 1.8 m of the soil profile under sweet corn cropping compared with the fallow period (Fig. 8). Soil N<sub>min</sub> in the top 1.8 m of the soil profile was reduced by 333 and 304 kg N ha<sup>-1</sup> with sweet corn cropping compared to the fallow treatment in 2005 and 2006 and soil water content in the 0–1.8 m soil layer increased with or without sweet corn cropping in contrast to the beginning of the fallow period. No significant difference in soil water content was found between N<sub>mr</sub> and N<sub>mr+C</sub> treatments after the fallow period (Fig. 7).

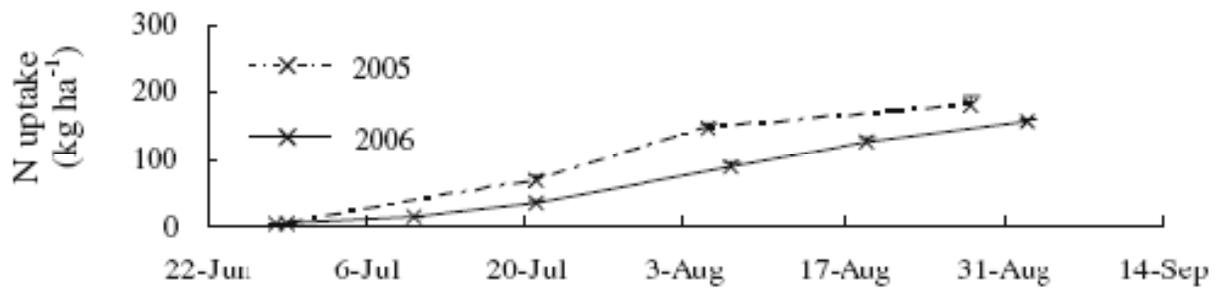


Fig. 6. Total N uptake by sweet corn at harvest. (from Guo et.al., 2008)

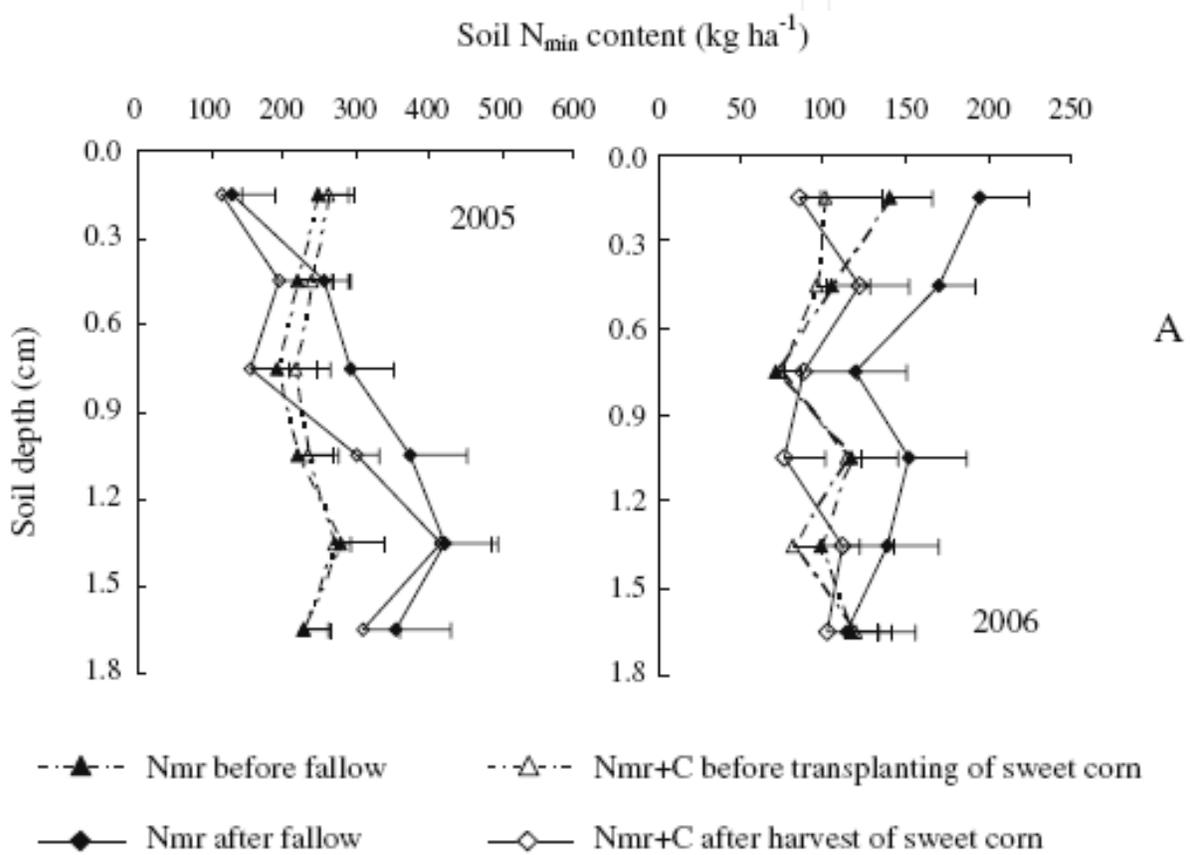


Fig. 7. Soil N<sub>min</sub> content throughout the top 1.80 m of the soil profile with or without sweet corn as catch crop in the summer fallow period in the greenhouse cucumber cropping system. Bars represent SD of means with three replicates per treatment. (From Guo et.al., 2008)

### 2.3.2 Manipulating diversified crop rotation

It was showed that change from continuous corn to diversified crop rotation is a better solution for soil residual N by planting crops or varieties with different rooting depths (Ju, 2007). Crop root depths were negatively correlated with NO<sub>3</sub><sup>-</sup> leaching, and thus rotations of potato with barley, winter wheat and cover crops were good choices of helping to improve NUE while reducing nitrate leaching (Delgado, 1998; 2007).

Factors contributing to differences in  $\text{NO}_3^-$  leaching potential for various crop rotations extend beyond fertilizer practices. Interactions between hydrology and tillage are very important because any residual  $\text{NO}_3^-$  that accumulates in the soil profile, whether from N fertilizer or microbial processes, can be leached if it is not assimilated by microbes decomposing crop residue or taken up by another plant. When a crop such as alfalfa depletes profile water content and the amount of precipitation is not sufficient to fully recharge the profile, the leaching potential will be minimal and very little water will be moving into subsurface drainage lines. Differences in residue and root decomposition relationships, as well as soil-plant-water dynamics, among various plant species also influence the leaching potential (Baker & Melvin, 1994; Randall, et al., 1997a; Malpassi, et al., 2000). The rate of N cycling is important because although N-fixing legumes can release large quantities of N to soils over time, organic N derived from plant and microbial residues is not as rapidly available to plants as inorganic N provided by most commercial fertilizers. Additionally, the gradual release of organic N often better synchronizes with subsequent plant needs and microbial population dynamics than point-in-time applications of N fertilizers. The large flush of available N following an inorganic fertilizer N application can often supply more N than can be assimilated by plants and microbes. When this pool is nitrified, large amounts of  $\text{NO}_3^-$  are susceptible to leaching and can potentially contaminate surface and ground water resources.

Better use of soil resources (nutrients and moisture) can also be done by including crops or varieties with different rooting depths (deep and shallow) in a crop rotation (Shrestha & Ladha, 1998). Rooting depths was positively correlated with N use efficiencies and the capability of crops to mine  $\text{NO}_3^-$  from ground irrigation waters (Delgado, 2001a). Crop root depths were negatively correlated with  $\text{NO}_3^-$  leaching. Commercial operations that used cover crops and crops that were rooted more deeply were able to increase the N use efficiency of their farm operations while minimize the amount of residual soil  $\text{NO}_3^-$  in the profile and  $\text{NO}_3^-$  leaching to groundwater (Delgado, et al. 2000; 2006). The deeper rooted crops acted as a biological filter that recovered  $\text{NO}_3^-$  from irrigated groundwater, helping to mine the  $\text{NO}_3^-$  (Delgado et al. 2007). Rotations of potato with barley, winter wheat and cover crops help to increase N use efficiency in the system while minimizing  $\text{NO}_3^-$  leaching (Delgado, 1998). Including alfalfa in a rotation especially in moderate sandy soil is also an effective approach in reducing leaching because of its deep rooting and high water usage (Owens, 1987).

### 2.3.3 Managing plant residues

As plant tissue is a primary source and sink for C and N, rational management of plant residues can affect N cycling in soils during the growing season and contribute to N immobilization and release in synchronization with crop demand. Plant residue decomposition proceeds depending on the C/N ratio, temperature, water content and other factors. Therefore, this was very important to understand the factors affecting plant residue decomposition and how to manipulated to reduce  $\text{NO}_3^-$  leaching potential with the availability of N to the main crop (Varvel, 1990; Gale, 2000; Dai, 2010).

The amount of crop residue N varies with the crop species, varieties, management practices, climate, and soil. Recovery of fertilizer N in potato is about 50% with current management practices. Distribution of fertilizer N recovery in potato averaged 24% in tubers, 9% in residue, 14% in soil, and 53% leached (Bundy & Andraski, 2005). This suggests that 23% of

residues and soil N could be returned to the soil, if properly managed. A study conducted in Canada with cauliflower, red cabbage and spinach residues incorporated in autumn and spring and mulched in autumn showed greater risk of  $\text{NO}_3$  leaching with autumn residue handling compared to spring handling (Guerette et al., 2002). Autumn handling of cauliflower residues and both incorporation treatments (spring and autumn) for red cabbage residues contributed significant amounts of N to the following wheat crop (equivalent to 27 to 77 kg N  $\text{ha}^{-1}$ ). Incorporation of crop residue with high carbon to nitrogen ratio should be encouraged to immobilize residual  $\text{NO}_3$  left in the root zone (Brinsfield & Staver, 1991).

Effects of different returning amount of maize straw on soil fertility and yield of winter wheat were studied using randomized block design in Loess Plateau in China (Zhang et al., 2010). The results showed that straw returning can increase soil organic matter content and reduce soil total nitrogen loss, enhance the capacity of soil microbial fixing and supplying C and N, increase C/N, and change the distribution of soil microbial community. Higher soil microbial C/N and redistribution of original soil microbial community was propitious to the soil organic transformation and mineralize carbon decomposition, as consequence, improve the soil nutrient supply. The results indicate that under condition of local study area, applying N 138 kg  $\text{ha}^{-1}$ , combined with returning amount of maize straw 9000 kg  $\text{ha}^{-1}$  can enhance soil fertility and increase yield by 7.47% significantly (Table 2 and 3).

Items	Treatments					
	Before sowing	ST0	ST6000	ST9000	ST12000	ST15000
BC/TC	1.07±0.03 c	0.76±0.02 d	1.08±0.03 c	1.37±0.04 a	1.14±0.03 b	1.15±0.03 b
BN/TN	2.23±0.07 d	2.82±0.14 c	3.04±0.14 bc	3.82±0.11 a	3.22±0.15 b	2.85±0.09 c

Note: Values followed by different letters within a row are significantly different at  $P < 0.05$  level. BC/TC-Microbial biomass C/Total C, BN/TN-Microbial biomass N/Total N.

Table 2. BC/ TC and BN/ TN of soil with different treatments

Treatment	Yield	Increase
ST0	6401.9±38.4 c	
ST6000	6528.7±44.7 b	1.98
ST9000	6880.2±68.8 a	7.47
ST12000	6508.9±45.6 b	1.67
ST15000	6263.3±31.3 d	-2.16

Note: Values followed by different letters within a column are significantly different at  $P < 0.05$  level.

Table 3. Wheat yield with straw into field treatment

#### 2.4 Water management strategies

Nitrate leaching is driven by water transport through the soil profile, so good irrigation strategies including proper amount at the right time, are greatly important to N leaching. N management alone cannot effectively reduce  $\text{NO}_3$  leaching, while N management scheduling, an important tool for water management, should integrate local factors such as soil moisture, infiltration, texture, crop water use and rainfall. Optimization measures on N and irrigation with frequent but little amounts can decrease  $\text{NO}_3$  leaching losses without yield reduction (Saffigna, 1977; Waddle, 2000). Many studies showed that drip irrigation

would be a useful choice in reducing N leaching with improving water use efficiency (Waddle, 1999; 2000). This subsurface irrigation system is effective in reducing NO<sub>3</sub> leaching due to its low irrigation amount since it delivers water directly to the root zone where N uptake is greatest (Starr, 2008).

Nitrogen management alone also cannot effectively reduce NO<sub>3</sub> leaching in sandy soils. It is a challenge to supply water to the crops on a sandy soil, which has low water holding capacity, while trying to minimize leaching. Good irrigation strategies (the right amount at the right time) are important as irrigation amount and timing are strongly related to leaching, especially in sandy soils (Cates & Madison, 1994). It was reported that 40% reduction in irrigation amount could help to reduce the risk of NO<sub>3</sub> leaching from potato without affecting yield (Waddell et al., 2000).

A recent study reported that water content within the center of the potato hill, where the greatest densities of roots occur, were greater under drip irrigation than those of sprinkler irrigation (Cooley et al., 2007). Therefore, management strategies targeted at wetting the hill center would likely improve water use efficiency (Starr et al., 2005).

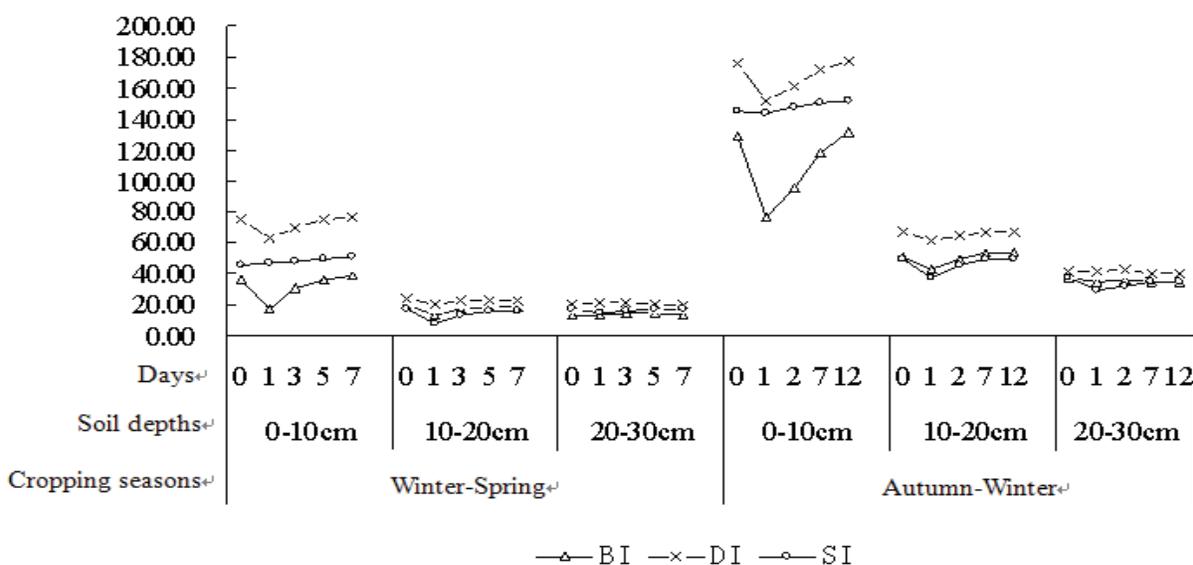


Fig. 8. Effects of different irrigation methods on nitrate nitrogen transport

Cropping seasons	BI	DI	SI
Winter-Spring	90.79 a	10.50 b	9.26 b
Autumn-Winter	117.52 a	18.94 b	8.08 c

Table 4. Effects of different irrigation methods on volume nitrate leaching

In order to reveal the effects of different irrigation methods on water distribution and nitrate nitrogen transport in solar greenhouse, border irrigation, drip irrigation and subsurface irrigation were evaluated by using cucumber *Jinyu No.5*(Fig.8). Irrigation water distribution, nitrate leaching, root zone nitrate nitrogen transport, yield and water use efficiency were conducted in the current study (Table 4). The experiments showed that the amount of leaching and evaporation decreased but transpiration increased under drip irrigation and subsurface irrigation. As the results, compared to border irrigation, the above irrigation

systems saved water by 25.9% and 32.0%, cucumber yield increased by 11.6% and 15.3% and water use efficiency (WUE) increased by 49.9% and 68.7%, respectively (Table 5). The drip irrigation and subsurface irrigation also reduced the amount of nitrate leaching, and it was important to protect groundwater (Wei et al., 2010).

Cropping seasons	Treatments	Economic yields (Kg ha <sup>-1</sup> )	WUE <sub>Y</sub> (%)
Winter-Spring	BI	110643 a	14.20 c
	DI	123771 b	21.96 b
	SI	128132 a	25.15 a
Autumn-Winter	BI	45526 b	10.31 b
	DI	50564 a	14.79 a
	SI	51858 a	16.20 a

Table 5. Effects of different irrigation methods on economic yield and water use efficiency (WUE<sub>Y</sub>)

### 3. Conclusion

Nitrate leaching is considered the major pathway for the loss of N from intensive agriculture systems in China. Therefore, it is of great importance for scientists to seek for efficient and economic strategies on controlling nitrate leaching. Although there is no quick fix for preventing nitrate leaching from the soil profile to groundwater, integrated use of various strategies can decrease nitrate leaching potential significantly by manipulating the N management practices on fertilizers and manures, soil, water and crop. The primary effect

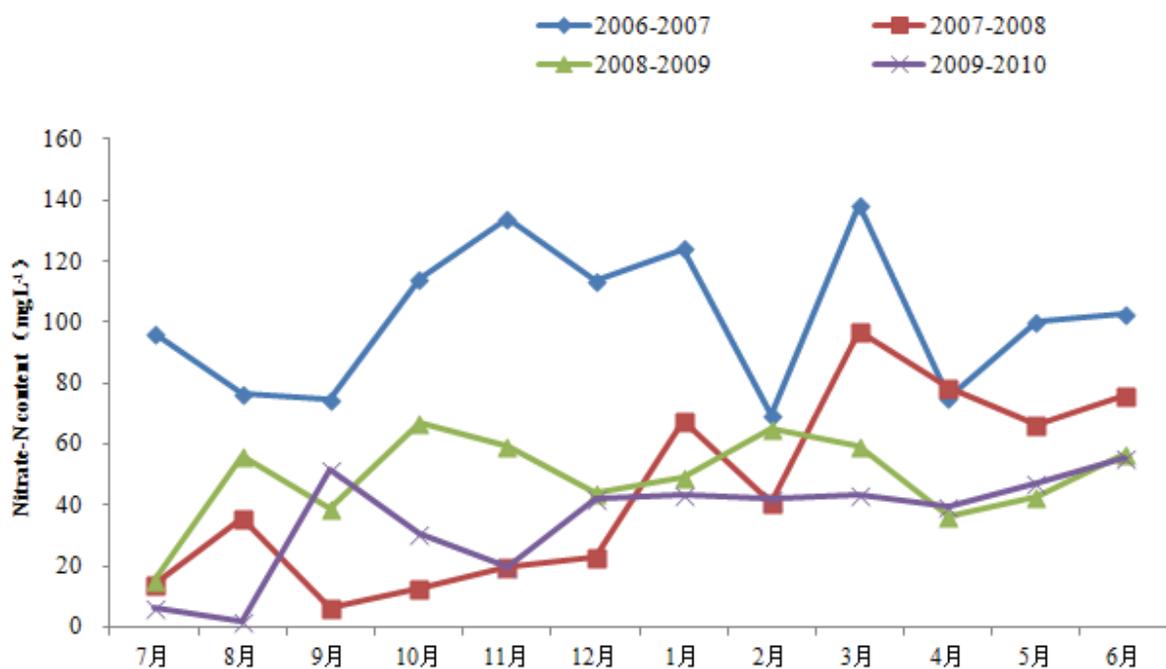


Fig. 9. Nitrate content monthly fluctuation curve within 4 years for a observation well by manipulating the N management practices. by Song, Unpublished data

has been found in a demonstration area (Fig.9). The local groundwater nitrate-N content decreased obviously from initial 101.67 mg L<sup>-1</sup> to present 35.36mg L<sup>-1</sup> by a monthly continuous monitoring on a fixed-point observation well within four years. However, that is not all for preventing nitrate contamination to groundwater, the ultimately desirable solution to minimize nitrate threats to water resources, is a better public recognition and implement on the above several different management practices in intensive agricultural production systems.

#### 4. Acknowledgment

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## **Soil Health and Land Use Management**

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Soils play multiple roles in the quality of life throughout the world, not only as the resource for food production, but also as the support for our structures, the environment, the medium for waste disposal, water, and the storage of nutrients. A healthy soil can sustain biological productivity, maintain environmental quality, and promote plant and animal health. Understanding the impact of land management practices on soil properties and processes can provide useful indicators of economic and environmental sustainability. The sixteen chapters of this book orchestrate a multidisciplinary composition of current trends in soil health. Soil Health and Land Use Management provides a broad vision of the fundamental importance of soil health. In addition, the development of feasible management and remediation strategies to preserve and ameliorate the fitness of soils are discussed in this book. Strategies to improve land management and relevant case studies are covered, as well as the importance of characterizing soil properties to develop management and remediation strategies. Moreover, the current management of several environmental scenarios of high concern is presented, while the final chapters propose new methodologies for soil pollution assessment.

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