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RESEARCH ARTICLE

N-catch crops affect soil profile nitrate-N accumulation during vegetable cultivation

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Abstract **To reduce nitrate leaching, the effects of three N-catch crops of sweet corn (*Zea mays* L.), amaranth (*Amaranthus* spp.), and sweet sorghum (*Sorghum* Linn.) on nitrate-N accumulation in the soil profile were examined using an incubation experiment. Results showed that the biomass and N absorbed by sweet corn were the largest compared with the other two N-catch crop treatments. Root length density for sweet corn, amaranth, and sweet sorghum in the 0–150 cm soil layer was 0.66, 0.34 and 0.46 cm/cm^3, respectively, and root dry weight was 0.065, 0.021 and 0.038 mg/cm^3, respectively. In the 0–200 cm soil layer, nitrate-N accumulation for fallow, mature sweet sorghum, amaranth, and sweet corn was 1124.7, 899.4, 867.4 and 794.2 kg/hm^2, respectively, where the treatment of sweet corn had the smallest N-accumulation. The nitrate-N leachability of fallow, sweet corn, amaranth, and sweet sorghum treatment was 3.6, 1.9, 2.4 and 2.6 kg/hm^2, respectively, indicating that cropping of sweet corn, amaranth, and sweet sorghum could reduce the leachability by 47%, 35% and 28% in comparison with fallow treatment. Therefore, the cultivation of N-catch crops can reduce nitrate leaching in seasonal soil, and the sweet corn might be the most suitable catch crop.**

Keywords N-catch crops, soil NO_3-N, leaching

Introduction

Greenhouse cultivation is a principal method of vegetable production in the northern region of China, and it is characterized by high investment and high output. Such intensive cultivation practices have led to the application of large amounts of chemical fertilizers, and in many regions, the application rate is even more than 1000 kg/hm^2 (Shen et al., 2005; Zhou et al., 2006). Excessive nitrogen fertilizer inputs can lead to NO_3-N accumulation in the root zone of crops after harvest (Liu et al., 2006) or the pollution of groundwater caused by nitrate leaching. According to the survey conducted by Jégo et al., (2008) and Zhang et al. (2007) in Dingzhou, Hebei, within greenhouse vegetable planting areas, the mean nitrate accumulation in the 200–400 cm soil layer was 354.2 kg/hm^2 (Ye et al., 2010; Yuan et al., 2010). Therefore, in order to maintain the sustainable development of intensive vegetable growing areas, it is necessary to prevent nitrates from leaching through the soil profile and to lower the nitrate content in groundwater.

The ‘N-catch crops’ refer to the crops planted in autumn after harvest in the temperate regions; such crops are not planted for economic output but for reducing nutrient loss and soil fertility (Thorup-Kristensen et al., 2003). Presently, with the excessive nitrogen application, nitrate leaching is getting more serious; thus, N-catch crops again have aroused the concern of researchers (Rodrigues et al., 2002; Thorup-Kristensen, 2003; Kristensen et al., 2004; Hasegawa et al., 2005; Guo, 2007; Yu and Zeng, 2007). The cultivation of N-catch crops after the main crop growing season can reduce leaching losses by 75% in one year (Gustafson et al., 2000). Sweet corn grows fast and has a large biomass, thus making it very suitable as a N-catch crop (Ren, 2003). Previous studies mainly focused on the selection of N-catch crops, biomass and N accumulation in the soil profile in terms of reducing the

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underground and soil solution NO_3-N concentrations. To determine the ability of various N-catch crops to accumulate excessive nitrogen from the soil prior to leaching, we studied three N-catch crops. We measured crop biomass, nitrogen uptake, root characteristics, soil NO_3-N accumulation and leaching volume of sweet corn, amaranth, and sweet sorghum, with fallow as control in a typical greenhouse in Hebei Province, northern China. This information will enable agronomists to advise farmers on the best practices in order to sustain production and reduce harmful nitrate infiltration of the groundwater.

Materials and methods

Experimental area

The experimental area was located at Beilingtou, Dingzhou city of Hebei Province, China, with an average elevation of 43.6 m. The annual sunshine and frost-free period in this area is about 2427.4 h and 208 d, respectively, and the average annual temperature is 13.0°C; the inter-annual temperature does not fluctuate greatly. The annual precipitation and evaporation are 523.3 mm and 1910.4 mm, respectively, while the actual precipitation from June 21 to September 30 in 2008 was 523.5 mm. Soil texture is of sandy loam or light loam.

Experimental design

Our experimental greenhouse is of general wall structure with an area of 256 m^2 (41.3 m×6.2 m), and the basic physical and chemical properties of soil are listed in Table 1. According to the classification of the Chinese agricultural nitrogen pollution assessment index proposed by Hou et al. (2008), the nitrate residue in the 0–100 cm soil layer in our experimental area was 1094.45 kg/hm^2. This value of more than 1000 kg nitrate per hm is 24 times as high as the value (45 kg/hm^2) set by Hou et al. as a "pollution potential intensity", and this represents a huge potential threat to the groundwater in this region.

Experimental processing and layout

Four treatments were set up using sweet corn, amaranth and sweet sorghum as N-catch crops with a fallow as control. Each treatment was performed in three repetitions with a plot area of 8 m^2. Both a soil solution extractor and a leakage leaching plate were buried in the 100-cm soil profile for each plot.

Planting and management

On June 20, 2008, stubble was removed after vegetable harvest. A sweet corn cultivar, "Golden Waxy No. 1," was used and sown at the rate of 22.5 kg/hm^2 with a row spacing of 30 cm × 50 cm and 3 seeds each hole with soil covering of 3 cm. Before sowing, seeds and pesticide were mixed at a ratio of 100 : 1–1.5. "Beijing Amaranthus No. 4" was sown at the rate of 18.75 kg/hm^2 and a row spacing of 20 cm × 20 cm. Sweet sorghum cultivar "Yajin 2" was planted at the rate of 12.45 kg/hm^2 and a row spacing of 20 cm × 50 cm. Crops were harvested on Sept. 28th. No fertilizer or irrigation was used during the growing period, and weeds were removed by hand.

Sampling

Before sowing, the soil, from depth of 0 to 200 cm (at each 20 cm), was sampled to measure the basic physical and chemical properties. During the growing season, soil samples from 0 to 120 cm (spacing 20 cm) were collected. At harvest, soil samples were taken as per pre-sowing, 0–200 cm (spacing 20 cm). During the growing season of the crops, the soil solution was all collected by pump not only in the soil solution extractor but also in the leakage leaching plate, at intervals of 15 d, or after rain. All collected liquid samples were kept in a minus 20°C freezer before analysis. After harvest, fresh weights for all aerial parts of the crops such as stalk leaves, grain, cob and husk in collecting sub-plot (1 m × 1 m) were determined. The biomass was then air-dried for some time, further dried at 70°C and weighed. A root drill of 10 cm high and 10 cm in diameter was used to collect root and soil samples of sweet corn at a distance of 5 cm between corn

Table 1 Physical and chemical properties of the field experimental soil

Soil layers (cm)	pH (H_2O) (1 : 1)	NO_3-N (kg/hm^2)	Olsen-P (mg/kg)	NH_4Ac-K (mg/kg)	Mechanical composition sand/silt/clay/%	Bulk density (g/cm)	Field capacity (%)
0–20	7.50	222.8	275.7	222.4	54/34/12	1.37	23.71
20–40	7.85	216.4	100.3	146.3	48/39/13	1.50	22.10
40–60	8.12	59.1	25.4	140.2	49/40/12	1.49	22.56
60–80	8.31	51.2	10.5	138.9	52/36/11	1.50	21.71
80–100	8.30	53.7	7.6	120.8	48/38/13	1.34	24.30

rows at harvest, with a drilling for each district and sampling depth of 150 cm.

Sample analysis

Soil texture was determined by pipette method. Soil bulk density was determined by ring-blade method. Soil organic matter content was determined by dichromate volumetry-heating method. Soil available P content was determined by 0.5 mol/L $NaHCO_3$ extraction - spectrophotometry method. Soil available K content was determined by 1 mol/L NH_4Ac flame photometry, and soil pH value was determined by potentiometer (soil:water 1:2.5). The content of nitrate-N in the soil solution was determined using a continuous flow analyzer (TRAACS-2000).

Determination of total nitrogen in plants was as follows: Dried crop samples after crushing were first sieved over a 0.25-mm mesh, and finally, total nitrogen was determined by ordinary Kjeldahl method.

Determination of root length density and dry weight was conducted by placing the samples taken from the root drill in a 0.25-mm sieve, washing with water and picking out the root pieces. These were then scanned by the ordinary office letter scanner, and then the root length density was calculated and analyzed by using the WinRHIZO software, which simultaneously determined the root dry weight.

Data analysis

Variance analysis of data was conducted by using Excel. SAS 6.1, ANOVA package was used to test LSD.

Results

Biomass and nitrogen uptake of N-catch crops above ground

Biomass can accurately reflect the nitrogen uptake by N-catch crops and the nitrate leaching. Generally, the larger the biomass, the more nitrate-N uptake from the soil. The total biomass of sweet corn was 12939.1 kg/hm^2, which was significantly higher than that of amaranth or sweet sorghum (Table 2). N uptake for each of the three N-catch crops is more than 150 kg/hm^2, showing a strong nitrogen absorption capacity of the three crops. The N uptake of sweet corn was the largest followed by amaranth and sweet sorghum. There was a significant difference between sweet corn and sweet sorghum. Although the N uptake of amaranth was lower than that of sweet corn, the difference was insignificant due to the high nitrogen content of amaranth leaves and stems.

Catch crops root distribution in soil profile

As shown in Fig. 1, the roots of catch crops reached to 150-cm soil layer. Moreover, the root length density was related to root dry weight, that is, both decreased with the soil depth. The sweet corn root length density and root dry weight were significantly higher than those of sweet sorghum and amaranth in 0–40 cm soil layer. Root length in 0–40 cm of sweet corn, amaranth and sweet sorghum accounted for 64%, 55% and 53% of 0–150 cm, respectively. There was no significant difference in root length between sweet corn and sweet sorghum in 40–80 cm soil layer, but both, in root length, were significantly different from that of amaranth in the soil. Below 80 cm, root length density and root dry weight of three N-catch crops had no significant difference.

Nitrate-N accumulation in soil profile after harvest of N-catch crops

The nitrate-N accumulation in various soil profile levels, after harvest of N-catch crops, is shown in Table 3. Compared with fallow, the treatments significantly reduced the nitrate content through the entire soil profile, particularly in 0–60 cm soil layer. There was a significant difference between fallow and N-catch crops; further, in the upper soil, sweet corn had a greater potential to reduce nitrate. The nitrate-N accumulation occurred in 60–200 cm. indicating whether it is fallow or N-catch crops, the upper nitrate-N was leached down, and nitrate-N leaching of the fallow was the largest. There were no significant differences between fallow and sweet sorghum. In 0–200 cm soil layers, only nitrate accumulation of fallow was higher than the preplant, which indicated nitrate-N leaching obviously increased in the condition of fallow.

Table 2 Above ground biomass and N uptake in different N-catch crops

N-catch crops	Biomass (kg/hm^2)					nitrogen concentration (g/kg)				N uptake (kg/hm^2)
	Straw	Seeds	Corncob	Bract	Total	Straw	Seeds	Corncob	Bract	
Sweet corn	6090.9	5515.7	752.7	579.8	12939.1 a	11.6	22.4	12.5	15.0	212.0 a
Amaranth	3692.2	–	–	–	3692.2 c	46.9	–	–	–	174.0 ab
Sweet Sorghum	6782.8	478.7	–		7261.5 b	23.2	12.4	–	–	163.0 b

Note: The different letters in the same column indicate a statistically significant difference at $P = 0.05$.

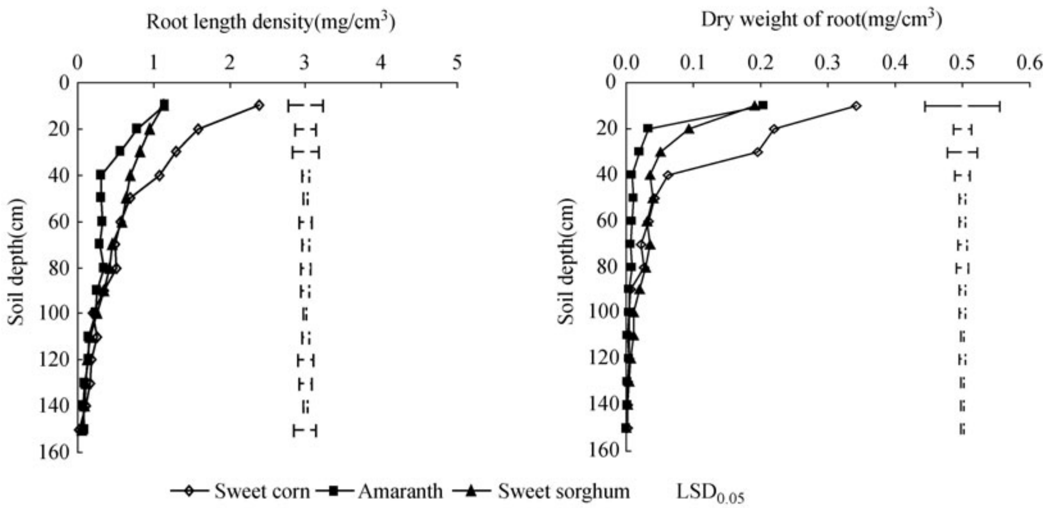

Figure 1 Root length density and dry weight of different catch crops.

Table 3 The measured amount of NO_3-N in soil profile before and after catch crops harvest (kg/hm^2)

Soil depth (cm)	before sowing	Fallow		Sweet corn		Amaranth		Sweet sorghum	
		After harvest	Total accumulation	After harvest	Total accumulation	After harvest	Amount accumulation	After harvest	Total accumulation
0–20	222.77	74.05	−148.72b	46.73	−176.04 c	102.06	−120.71a	44.84	−177.93c
20–40	216.38	119.66	−96.72a	36.88	−179.5c	67.46	−148.92b	52.4	−163.99c
40–60	59.09	97.15	38.06a	37.2	−21.89c	27.86	−31.23c	47.88	−11.21b
60–100	104.81	57.14	47.93a	56.22	48.59a	64.15	40.66b	95.66	9.15c
100–200	344.85	681.11	336.26a	519.94	175.09c	524.55	179.70c	640.28	295.43b
0–200	947.90	1124.71	176.81a	794.15	−153.76c	867.39	−80.51b	899.36	−48.55b

Note: The different letters in the same column indicate a statistically significant difference at $P = 0.05$.

Effect of N-catch crops on soil nitrate-N at 100 cm depth

Nitrate-N concentration at 100-cm soil profile is shown in Fig. 2. The concentration of nitrate nitrogen of fallow in 100-cm soil was the highest, followed by amaranth, and there was no significant difference between sweet corn and sweet sorghum in the concentration of nitrate nitrogen there. There was a peak for all samples at the 60th day (August 19), which may be due to 90 mm of rainfall in August 13–14, leading to strong nitrate N leaching from the top. In the later growing period of the crops, nitrate N concentration of soil solution for all samples decreased, possibly because of the reduced rainfall and the intercept of N-catch crop roots.

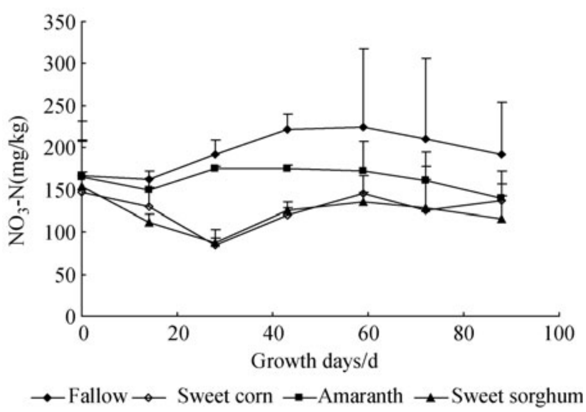

Figure 2 Dynamics of NO_3-N in 100 cm soil profile.

Nitrate-N leachability in soil profile

Nitrate-N leaching loss in 100-cm soil layer is shown in Fig. 3. Leaching losses of nitrate-N for fallow, sweet corn, amaranth and sweet sorghum are 3.6, 1.9, 2.4, and 2.6 kg/hm^2, respectively. Compared with fallow, they were

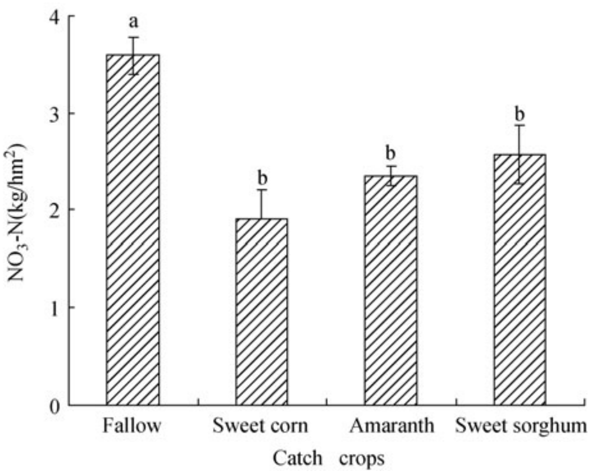

Figure 3 NO_3-N seepage in 100 cm soil profile.

decreased by 47%, 35% and 28%, which indicates that the N-catch crops can reduce leaching of nitrate N in soil. Among them, the leaching loss of nitrate-N for sweet corn was the lowest.

Discussion

Phytoremediation of the soil environment can reduce the leaching risk. The theory on how the catch crops may decrease nitrate N leaching is N concentration in soil water decreases in the soil when N-catch crops absorb N. Compared with fallow, the treatments significantly reduced the nitrate content through the entire soil profile, particularly in 0–60 cm soil layer. There was a significant difference between fallow and N-catch crops; further, in the upper soil, sweet corn had a greater potential to reduce nitrate. Under long-term traditional water and fertilizer conditions, nitrate accumulation in the 0–60 cm soil layer for fallow, sweet corn and amaranth was less than that before sowing, but significantly higher than that before sowing in the 90-cm soil layer (Ren, 2003). N accumulation in 0–180 cm soil layer for sweet corn planted in 2005 and 2006 was decreased by 333 and 304 kg/hm^2, higher than nitrogen uptake of the sweet corn (Guo, 2007).

The environmental demand of N-catch crops is to reduce nitrate-N leaching; therefore, the nitrogen absorption capacity and root growth characteristics of crops are important factors. In our study, the three N-catch crop roots grew to 150-cm soil layer which was much deeper than previous studies, with the N uptake of 212.0, 174.0 and 163.0 kg/hm^2, respectively. Studies have shown that the utilization of 15 N labeled nitrate by sweet corn in 20, 40, 60 and 80 cm of soil was 23.1%, 6.1%, 2.8% and 0.8%, respectively (Kristensen et al., 2004). Roots of summer planted sweet corn in Beijing extended to 105 cm, but were mainly in the 0–60cm top soil layer, and N uptake reached to 182 kg/hm^2 (Guo, 2007). Another study showed those of sweet corn and amaranth roots could extend to 1 m, and the N uptake was up to 207–247 and 184–256 kg/hm^2 (Ren, 2003).

During the growing of N-catch crops, nitrate-N content of soil solution in the 100-cm soil for fallow and N-catch trend line in the experiment varied during the growth of N-catch crops, low in the pre- and post-growth and high in the mid-growth, but the value of the fallow treatment was lower than that of other treatments with Nitrate-N leaching in 100-cm soil layer reaching 1.9, 2.4 and 2.6 kg/hm^2, respectively, reduced by 47%, 35% and 28% compared with that for fallow. Therefore, N-catch crops can effectively decrease nitrate-N content in the certain soil profile and reduce leaching loss.

The continuous cultivation of N-catch crops for 3–7 years could reduce nitrogen leaching loss by roughly 50% in field (Gustafson et al., 2000). The long-term cultivation of the crops would significantly increase organic N in soil (Thomsen et al., 1999). The N-catch crop cultivation was studied with vegetable cultivation in one year, and therefore, further study is needed on nitrate-N leaching and the future vegetable production in the long-term cultivation of N-catch crops.

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