Effect of Unrestricted Nitrogen and Irrigation Application on Soil Carbon and Nitrogen Pools in Greenhouse Vegetable Systems

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In the north China plain, the amount of N fertilizer and irrigation application in greenhouse vegetable systems is about three to five times that in conventional cereal systems. Over a decade of shifting from the conventional cereal systems to greenhouse vegetables, the capacity for nutrient cycling within these greenhouse systems has fallen. Additionally, the content of inorganic C in the soil profile under greenhouse systems has shown a dramatic decline.

Storage of soil organic carbon (SOC) and carbonate carbon (IC) in agricultural land can be influenced by management practices such as tillage, fertilizer N inputs, and crop rotations (Russell et al., 2005). Indeed, long-term over-use of fertilizer N in agricultural systems has resulted in substantial NO_3^- leaching and soil carbonate has become depleted as a result of soil acidification (Ju et al., 2007). Hence, changes in SOC and carbonate content with N fertilization can affect soil C stability.

The natural abundance of stable isotopes can be used as a measure to reflect soil C and N cycling and storage (Lynch et al., 2006). Differences in plant $\delta^{13}C$ can be attributed to differences in photosynthesis between C_3 and C_4 plants and differences in soil $\delta^{15}N$ can result from discrimination against ^{15}N during the N loss process (Lynch et al., 2006). Thus, it is possible to quantify changes in soil C and N pools after long term changes in crop species and fertilizer regimes.

Soil organic matter (SOM) can be differentiated into soil active pools and passive pools. The active SOM fractions respond very sensitively to management practices and affect nutrient (including N) supply (Wander, 2004). The character of the active SOM can be denoted by particulate organic matter (POM), soil microbial biomass C and N (SMBC, SMBN), and dissolved organic matter (DOM) because these pools bring together the physical, biological and chemical functions of SOM (Wander, 2004).

Greenhouse vegetable production has played an important role in increasing farming incomes during the last two decades.

The shift to greenhouse vegetable systems has resulted in some concerns for soil quality and nutrient cycling.

In Shouguang County of Shandong Province, more than 65% of the arable land is now used for intensive greenhouse production, with an average of 2,220 kg fertilizer N/ha and 1,800 mm irrigation water applied each year to two successive crops (He et al., 2007). However, the effects of these excessive N rates application and massive irrigation on the C and N pools of the local soils, which are low in SOC, have not yet been determined.

Abbreviations: C = carbon; N = nitrogen; NO_3-N = nitrate N; Ca = calcium; Mg = magnesium; NH_4 = ammonium.

Table 1. Farm management, yields, and pH distribution in the soil profiles of the sampling sites.

System[1]	Site	Year started	Crop rotation3	Fertilizer/manure[3] kg N/ha/yr	Irrigation[3] mm/yr	Yield[3] t/ha/yr	pH at different depths (cm) in the soil profile					
							0-10	10-20	20-40	40-60	60-80	80-100
[2]G1	Yingli	1996	Tomato/Cucumber	1,634/1,300	1,400-1,700	171.0	7.71	7.87	8.07	8.13	8.05	8.14
C1	Yingli	1978	Maize/Wheat	600/0	<300	16.5	7.97	8.15	8.22	8.28	8.51	8.55
G2	Yingli	1996	Tomato/Cucumber	1,572/1,246	1,500-1700	175.6	7.38	7.67	8.20	8.17	8.15	8.11
C2	Yingli	1978	Maize/Wheat	600/0	<300	17.0	7.84	7.97	8.18	8.22	8.23	8.35
G3	Tianliu	1993	Tomato/Cowpea	1,829/1,318	1,300-1700	168.4	5.59	5.53	5.58	7.21	7.31	7.60
C3	Tianliu	1978	Maize/Wheat	500/100	<300	18.0	7.89	8.22	8.30	8.22	8.02	8.02
G4	Tianliu	1993	Tomato/Sweet pepper	1,620/1,866	1,400-1,600	150.0	6.87	6.90	7.26	7.45	7.56	7.56
C4	Tianliu	1978	Maize/Wheat	500/100	<300	18.0	7.89	7.99	8.11	8.24	7.96	7.83

[1]G, Greenhouse system; C, Conventional cereal system.
[2]Yield in greenhouse system refers to fresh weight and that in conventional cereal system to air-dried weight.
[3]Date of acquisition: April 2007. The amount of fertilizer/manure is the sum of chemical fertilizer or manure from both crops, respectively.

Table 2. Storage of soil organic C (SOC), soil inorganic C (IC), total carbon (TC) and total N (TN) in the soil profile (0 to 100 cm) of greenhouse (G) and conventional cereal (C) production systems.

	SOC, t C/ha		ΔSOC, t C/ha/yr	IC, t C/ha		ΔIC, t C/ha/yr	TC, t C/ha		ΔTC, t C/ha/yr	TN, t N/ha		ΔTN, t N/ha/yr
Site	G	C	G - C	G	C	G - C	G	C	G - C	G	C	G - C
Yingli 1	95.5	68.6	2.46	360.7	399.3	-3.51	456.2	467.8	-1.05	14.6	8.8	0.53
Yingli 2	109.5	88.9	1.87	343.2	433.8	-8.24	452.7	522.7	-6.37	12.4	9.1	0.12
Tianliu 1	89.8	89.3	0.07	15.1	34.7	-1.40	104.9	124.0	-1.33	9.9	9.2	0.08
Tianliu 2	109.1	85.4	1.69	5.0	23.1	-1.30	114.1	108.6	0.39	9.4	6.7	0.10

Shouguang County (36°41´-37°19´N, 118°32´-119°10´E) has a typical continental monsoon climate with annual average air temperature and precipitation of 12.4 ºC and 558 mm, respectively. Conventional maize/wheat rotations have been practiced since 1978 and greenhouse vegetable production has developed rapidly in place of the cereal rotation since the 1990s. The details of N fertilizer and irrigation in greenhouse systems and conventional maize/wheat rotation systems are shown in **Table 1**.

Paired soil samples were taken from four greenhouses and adjacent conventional cereal fields for direct comparison of the two production systems at the end of April 2007. Two pairs of samples were collected from Yingli village (118°48´N, 37°03´E) and two from Tianliu village (118°47´N, 36°59´E). The sampling distance between each greenhouse and the adjacent field was <50 m, with >200 m between greenhouses at each site. A single field sample was a composite of at least eight soil cores representing approximately 400 m^2 of area. The 100 cm deep sample cores were divided into 0 to 10, 10 to 20, 20 to 40, 40 to 60, 60 to 80, and 80 to 100 cm depth increments. A 100 cm soil profile of a conventional cereal system, either at Yingli or Tianliu, was taken to measure soil bulk density at these same soil depths. With increasing soil depth, bulk density was 1.42, 1.45, 1.47, 1.45, 1.43, and 1.43 g/cm^3 at Yingli. At Tianlie, bulk density was 1.48, 1.50, 1.46, 1.42, 1.41, and 1.50 g/cm^3. Contents of SOC, NO_3-N, IC, and soil bulk density were also determined at each depth increment as was the concentration and natural abundance of POM. The concentration of SMBC, SMBN, and DOM were determined at 0 to 10, 10 to 20, and 20 to 40 cm depth categories.

Soil samples for SOC analysis were soaked for 24 h in excess 0.3 mol/L HCl solution to remove calcium carbonate ($CaCO_3$). The wet soil was cleaned with deionized water until the solution pH was above 6 and oven-dried at 60 °C. POM was determined as described by Bronson et al. (2004). TN, SOC, POM-C, and POM-N of soil passed through a 0.15-mm mesh were determined with a CN analyzer (Vario Max CN, Elementar, Germany). Both $\delta^{13}C$ and $\delta^{15}N$ were determined with a mass spectrometer (Delta Plus XP, Thermo Finnigan, Germany). The $\delta^{13}C$ values were expressed relative to Pee Dee Belemnite and $\delta^{15}N$ to atmospheric N_2 for N.

Soil NO_3-N was extracted with 1 mol/L KCl at a soil:water ratio of 1:5 (W/V) and measured with a continuous flow analyzer (TRAACS 2000, Bran and Luebbe, Germany). SMBC and SMBN were determined by the $CHCl_3$ fumigation-extraction (FE) method. Their C contents were determined with a TOC analyzer (Phoenix 8000, Tekmar, USA) and N contents were determined by continuous flow analyzer (FIA Star 5000, Foss, Sweden) following Kjeldahl digestion. The calculation details of SMBC and SMBN were shown by Wu et al. (1990). DOC and DON were determined according to Cookson et al., (2007). Soil carbonate C was determined by the pressure calcimeter method.

Data are expressed on oven-dried soil basis. Student's t-test was used to assess differences at the 5% level between greenhouse and conventional cereal system. Data are reported in this paper as the mean ± one standard error of the mean (SEM).

Carbon and Nitrogen

The storage of TC in the soils of the greenhouse system was less than in the conventional cereal system with the exception of the Tianliu 2 site **(Table 2)**. The Yingli and Tianliu sites had distinctly different IC contents, but across sites, greenhouse soils commonly showed a large decline in IC **(Table 1)**. For example, greenhouse production at Tianliu 2 was responsible, in part through soil acidification, for a 78% loss in soil IC.

In parts of Shandong Province, more than 65% of arable land is now used for intensive greenhouse production.

Soil acidification was likely the result of nitrification of large, repeated applications of NH_4-based N fertilizer and the leaching of NO_3-N under unconstrained irrigation regimes (Ju et al., 2007). Over the four pairs of samples, SOC summed over the whole profile was significantly different between the two production systems ($p < 0.05$; greenhouse: 101.0 ± 9.9 t C/ha, conventional system: 83.0 ± 9.8 t C/ha), which may be attributable to the numerous different types of manure incorporated into the soil to maintain high vegetable crop yields (He et al., 2007). No significant difference in TN was observed between the production systems ($p > 0.05$; greenhouse: 11.6 ± 2.4 t N/ha; cereal rotation: 8.5 ± 1.2 t N/ha), but the higher concentrations of TN in the greenhouse system may have resulted from the very high N fertilizer and manure applications (He et al., 2007).

Nitrate-N

The concentration of NO_3-N in the greenhouse soil was much higher than in the conventional system and the difference was significant below the 20 cm soil depth ($p < 0.05$; **Figure 1**). Soil NO_3-N as a percentage of TN was 6.0 to 10.0% at the

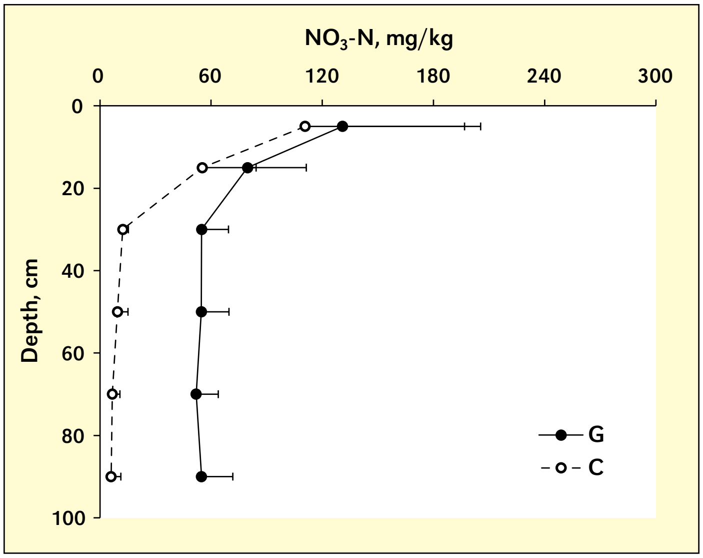

Figure 1. Concentrations of NO_3-N in the soil profile of a greenhouse (G) and a conventional (C) production system. Values at each depth are the mean of four sites considered as replicates. An asterisk represents a significant difference ($p < 0.05$) between greenhouse and conventional production systems.

0 to 100 cm depth in the greenhouse system and 1.2 to 8.1% in the conventional system. Soil NO_3-N summed over the whole profile in the greenhouse and conventional cereal system was 933 ± 265 and 339 ± 192 kg N/ha, respectively. Excessive NO_3-N leaching in the highly irrigated greenhouse system may have resulted in heavy pollution of groundwater, with the irrigation rate reaching 1,800 mm per year (He et al., 2007).

Active C and N Pools

Soil POM-C, POM-N, POM-C/SOC, and POM-N/TN in the top 40 cm of the soil profile were significantly higher in the greenhouse soil than the cereal soil (data not shown). Soil POM-C expressed as a percentage of SOC in the greenhouse system ranged between 24.3 and 52.4% and in the conventional system between 16.0 and 27.2%. Similarly, POM-N as a percentage of TN ranged from 14.0 to 31.7% and from 8.3 to 14.6%, respectively. The $\delta^{13}C$ of POM-C did not differ significantly between the two systems; $\delta^{15}N$ of POM-N was significantly higher in the greenhouses than in the cereal soil at the 0 to 20 cm depth ($p < 0.05$). Thus, the contribution of manure to POM-N was significantly greater ($p < 0.05$) than that to POM-C in the greenhouse system. Mendham et al. (2004) reported that a higher quality POM could lead to a decline in the net N mineralization rate. According to Wander (2004), the higher POM concentration in greenhouse system would indicate that manure application facilitated an increase in soil aggregation. However, for the greenhouse systems studied, the decline in soil carbonate discussed in **Table 2,** low SMBC/SOC, and low SMBN/TN (data not shown) all suggest that soil quality has deteriorated under these greenhouse crop production conditions.

Higher SOC and TN content combined with lower concentrations of SMBC and SMBN in the greenhouse system means that the capacity for nutrient cycling has decreased. Below the 10 cm soil layer, DOC/SOC in the conventional system was also significantly higher than in the greenhouse system (data not shown). The unrestricted manure applications and subsequent acidification of soil promotes the leaching of bridging cations (e.g. Ca^{2+}, Mg^{2+}) and further enhances the solubilization of organic matter (Zech et al., 1994).

Summary

The shift from the conventional cereal production system to intensive greenhouse vegetables has resulted in higher accumulation of NO_3-N, higher TN, and lower total C stocks due to a dramatic decline in carbonates in soil caused by intensive ammonium fertilization and unrestricted irrigation.Together this has lead to high nitrification rates and a large release of protons as well as a high potential for NO_3^- leaching. In both production systems, SOC in surface soil contained much more newly formed C sources (POM-C) and the $\delta^{15}N$ of POM-N responded sensitively to the effects of manure and chemical fertilizer application ($p < 0.05$). Soil quality may deteriorate in these greenhouse systems as measured by declines in SOC/TN ratios and SMBC/SOC and SMBN/TN ratios ($p < 0.05$). Besides, the high accumulation of NO_3-N presents a considerable danger for the quality of groundwater. BC

Taking soil samples to study changes.

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