Effects of Nitrogen Management on Garlic Yield, Economic Benefit and Soil Apparent Nutrient Balance

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ABSTRACT

An experiment was conducted on garlic (Allium sativum L.) to investigate the effects of nitrogen management on yield, economic benefit and the soil apparent nutrient balance, in the region of Laiwu town in Shandong province, China. The treatments included control (no N fertilizer), urea at 300 kg/ha, urea at 240 kg/ha, combined urea and commercial organic fertilizers at 120 kg N /ha each, and controlled-release nitrogen fertilizer at 192 kg N /ha. Results showed no significant difference both for garlic bulb yield and economic benefits between the urea treatments at different N application rates. The effect of the combined use of urea and organic fertilizer was similar to that of the urea application at the same N application rate. However, garlic bulb yields in the treatment of controlled-release nitrogen fertilizer were significantly higher than in the other fertilizer treatments, even the N application rate was lower. The net income from garlic in the treatment of controlled release fertilizer was also significantly higher than those in the other treatments. There was N surplus after the garlic growth season when urea was applied at 300 kg/ha, while there was N, P and K deficit when the controlled-release N fertilizer at 192 kg/ha was used to produce more garlic. It is suggested that use of controlled release N fertilizer combined with a supplement of other nutrients would be a sustainable strategy for fertilizer management in garlic production.

Keywords

Garlic bulb; Garlic bolt; N fertilizer application; Economic benefit; Nutrient balance

Academic Discipline And Sub-Disciplines

Agriculture; Soil Science; Plant Nutrition

SUBJECT CLASSIFICATION

Fertilization application

TYPE (METHOD/APPROACH)

Original research work; Field experiment; Nutrient balance

INTRODUCTION

Garlic, classified under the alliaceae family, is a widely consumed condiment vegetable. It has high nutritional value (Naruka and Dhaka, 2001), and is rich in vitamins A and C. Garlic also contains antibiotic substances which makes it valuable for medical benefits (Bayan et al., 2014). Statistics in publications show the global importance of garlic, with about 19 million hectares planted and an overall annual production of nearly 327 million tonnes (Samavatean et al., 2011). About 80 thousand hectares of garlic are planted in China each year.

N fertilizers are often over-applied in an attempt to achieve high garlic yields. According to the survey, N fertilizer application rates in China are about 900-1500 kg/ha. A large amount of applied N has now accumulated in the soil due to this high level of N application, resulting in low N use efficiency (Jiang et al., 2013). Furthermore, surplus N can be lost to the atmosphere and the groundwater (Lee et al., 2012; Olfati et al., 2014; Savci, 2012). For example, the average concentration of nitrate in groundwater was up to 34.7 mg/L in the garlic production area in Jinxiang Town in China (Zhang et al., 2008). High N fertilizer applications have also caused soil stalinization and acidification (Qian et al., 2014; Yu et al., 2015), potentially inhibiting garlic growth and resulting in low yield with poor quality and lower economic benefits. Optimum N management practices are therefore urgently needed to increase N use efficiency, achieve good yield and economic benefits, and maintain soil quality.

The aims of this study were to examine the effects of nitrogen fertilizer management on garlic yield, economic benefit and the soil apparent nutrient balance. Our results will provide the direct evidence needed by farmers to apply N fertilizer for garlic production in an economically and environmentally rational manner.

MATERIALS AND METHODS

Experimental site

The field experiment was conducted on a typical vegetable production farm at Weiwangxu town, Laiwu city, Shandong Province, China (36°17 N, 117°27′ E). The region has a typical warm and semi-humid continental monsoon climate. Mean annual temperature was 13.0 °C, and the lowest and highest mean monthly temperatures were -14.5 °C in January and 36.7 °C in July, respectively. The average annual frostless period was 202 days. The average annual rainfall was 695 mm, concentrated in the summer. The study site was a field that had been under vegetable cultivation for decades. Soil samples from 0-20 cm depth showed the soil to be a Brown earth, with a pH (H_2O) of 7.03, organic matter of 14.3 g/kg, and available N, P, and K of 156, 112, and 181 g/kg soil, respectively.

Experimental design and crop management

The field experiment consisted of five treatments, each in triplicate, with a randomized block design. Treatments included control (CK, no N fertilizer), urea at 300 kg/ha (FP), urea at 240 kg/ha (OPT), combined urea and commercial organic fertilizers at 120 kg/ha each (OM-CF), and controlled-release nitrogen fertilizer at 192 kg/ha (CRF) (Table 1). Fertilizers were applied three times in each of the FP, OPT and OM-CF treatments: 60% as a basal fertilizer, 25% as garlic bolt elongation fertilizer, and 15% as a garlic bulb expansion fertilizer (Table 1). In the Treatment CRF, thermoplastic resin-coated urea containing 4% coated material and 42% N, was applied only once as a basal fertilizer. This urea was a product of the Shandong Kingenta Ecological Engineering CO., LTD, China. Synthetic phosphate and potassium fertilizers were applied as basal fertilizers at rates of 90 kg P_2O_5 /ha and 270 kg K_2O /ha, respectively, in all the treatments except Treatment FP, which had a fertilizer application at a rate of 120 kg P_2O_5 /ha and 255 kg K_2O /ha. Garlic (*Allium sativum L.*) was cultivated in 7.0 m × 7 m field plots. Garlic seed was sowed on 25th September 2012. Other traditional practices, including seedling management and pesticide use for growing garlic, were followed.

Table 1. Fertilizer application in the experiment（kg/ha）

Treatments	Base fertilizer			Supplemental fertilizer (Garlic bolt elongation)	Supplemental fertilizer (Garlic bulb expansion)	The total N applied
	N	P_2O_5	K_2O	N	N	
CK	0	90	270	0	0	0
FP	180	120	255	75	45	300
OPT	144	90	270	60	36	240
OM-CF	144	90	270	60	36	240
CRF	192	90	270	0	0	192

CK= no N fertilizer, FP= urea at 300 kg/ha, OPT= urea at 240 kg/ha, OM-CF= combined urea and commercial organic fertilizers at 120 kg/ha each, CRF= controlled-release nitrogen fertilizer at 192 kg/ha.

Sampling and Analysis

Soil samples (0–20 cm depth) were collected before the fertilizer application in September 2012, air-dried, homogenized, and sieved through a 2-mm sieve for physical and chemical analyses. Garlic bolt and garlic bulb were harvested on 5th May 2013 and 28th May 2013, respectively. The plant samples were washed with tap water, rinsed with deionized water, dried at 80°C, pulverized, and digested with H_2SO_4 and H_2O_2 to determine N, P, K concentrations in the samples. Soil survey laboratory methods were used for these analyses (Lu, 1999; Zhang and Gong, 2012). In brief, soil pH was determined through a suspension sample with a water to soil (w/w) ratio of 2.5:1, and measured with a pH meter. Soil organic matter (SOM) was determined by the potassium dichromate method. The total nitrogen (TN) in plant, and the available nitrogen in soil, were measured using the Kjeldahl digestion–distillation method, and the alkali solution diffusion method, respectively. Total phosphorus (TP) and available phosphorus were determined by the molybdenum blue colorimetric method. Total potassium (TK) and available potassium were measured by flame photometry.

Data analysis

Nutrient inputs included N, P, K from organic and inorganic fertilizers, and nutrient outputs included N, P, K uptaken by crops. The soil apparent nutrient balance was calculated by: soil apparent nutrient balance (kg/ha) = nutrient inputs (kg/ha) - nutrient outputs (kg/ha).

Statistical analyses were performed using SPSS 13.0 for Windows. An analysis of variance (ANOVA) test was used to determine the treatment effects on the measured variables. A paired t-test and a least significant difference (LSD) multiple-comparison test were used to identify statistical differences among the treatments. For all analyses, a probability level of <0.05 was considered as statistically significant.

RESULT

Effect of N application on the yield of garlic and garlic bolt

The mean garlic bulb yields of each treatment were shown in Table 2. Compared with no N application (CK), garlic bulb yields in the Treatment FP, OPT, CRF, and OM-CF increased by 31%, 29%, 55%, and 18%, respectively. All these increases were statistically significant ($P<0.05$). In addition, garlic bulb yields in Treatment CRF were 18%, 20%, and 30% higher than in the Treatments FP, OPT, and OM-CF, respectively. Compared with the yield from the Treatment OM-CF, the increases due to the application of CRF were significant ($P<0.05$), but there was no significant difference for garlic bulb yields among Treatment FP, OPT, and OM-CF. There was no significant difference for garlic bolt yields between Treatment CK and Treatment FP, OPT (Table 2). Garlic bolt yields were lowest in Treatment CRF, while highest in Treatment OM-CF. The garlic bolt yields in Treatment OM-CF were 15%, 22%, 16%, and 35% higher than those in Treatment CK, FP, OPT, and CRF.

Table 2. Garlic and garlic bolt yield in different fertilization treatments

Treatments	Garlic bulb (kg/ha)	Garlic bolt (kg/ha)
CK	27963±1437 c	5510±445 b
FP	36671±385 b	5204±270 bc
OPT	36006±3020 b	5442±328 b
OM-CF	32896±2929 a	6327±160 a
CRF	43208±2474 b	4694±353 c

CK= no N fertilizer, FP= urea at 300 kg/ha, OPT= urea at 240 kg/ha, OM-CF= combined urea and commercial organic fertilizers at 120 kg/ha each, CRF= controlled-release nitrogen fertilizer at 192 kg/ha.Values marked with different letters in the same column are significantly different ($P<0.05$).

Effect of N application on garlic economic benefits

The cost of garlic seed, pesticide, and agricultural film was the same in all treatments. The lowest labor cost was in Treatment CRF (Table 3), as the fertilizer was only applied once as a basal fertilizer. The fertilizer cost in all treatments was in the following decreasing order: OM-CF > FP > OPT > CRF > CK. The total revenue and net income of garlic in all treatments followed the order of CRF > FP ≈ OPT ≈ OM-CF > CK, when the price of garlic in 2013 was considered. The net income of garlic in Treatment CRF was 61%, 20%, 22% and 35% higher than those in Treatment CK FP, OPT, and OM-CF, respectively. The increase in income from the use of CRF was statistically higher than from the other fertilizers. The ratio of net income to cost was lowest in Treatment CK while highest in Treatment CRF. There was no significant difference in the ratio of net income to cost between Treatment CK and OM-CF, and between Treatment FP and OPT.

Table 3. Average annual evaluation of economic benefit of garlic in different fertilizer treatments (costs and garlic price based on those in Shandong in 2013)

Treatments	cost (Yuan/ha)			Total income (Yuan/ha)	Net income (Yuan/ha)	Net income/cost
	Seed, pesticide, agricultural film	Labor cost	Fertilizer			
CK	24000	15900	2424	128384 c	94160 c	3.75 c
FP	24000	15900	3369	162296 b	127127 b	4.61 b
OPT	24000	15900	3099	160350 b	125451 b	4.59 b
OM-CF	24000	15900	5149	150563 b	113613 b	4.07 c
CRF	24000	15150	3047	186915 a	152819 a	5.48 a

CK= no N fertilizer, FP= urea at 300 kg/ha, OPT= urea at 240 kg/ha, OM-CF= combined urea and commercial organic fertilizers at 120 kg/ha each, CRF= controlled-release nitrogen fertilizer at 192 kg/ha.Values marked with different letters in the same column are significantly different ($P<0.05$).

Effect of N application on soil apparent nutrient balance

The N and P uptake in garlic was highest in Treatment CRF and lowest in Treatment CK (Table 4). There was no significant difference for nutrient uptake between Treatment FP and OPT. The apparent N deficiency in soil was 86 kg N /ha in Treatment CRF, while the apparent surplus N in soil was 50 and 21 kg N /ha in Treatment FP and OM-CF, respectively. Apparent P deficiency in soil occurred in all treatments. Apparent K deficit in soil was 20 kg K /ha in

Treatment CRF, while the apparent surplus K from fertilizers in soil was 59, 25 and 10 kg /ha in Treatment CK, OPT and OM-CF, respectively.

Table 4. Soil nutrient balance in different fertilization treatments

Treatments	Nutrient input (kg/ha)			Nutrient output (kg/ha)			Nutrient net balance (kg/ha)		
	N	P	K	N	P	K	N	P	K
CK	0	39	224	191d	80d	165c	-191	-41	59
FP	300	52	212	250b	106ab	213b	50	-54	-1
OPT	240	39	224	240b	98bc	199b	0	-59	25
OM-CF	240	39	224	219c	89cd	214b	21	-50	10
CRF	192	39	224	278a	112a	244a	-86	-73	-20

CK= no N fertilizer, FP= urea at 300 kg/ha, OPT= urea at 240 kg/ha, OM-CF= combined urea and commercial organic fertilizers at 120 kg/ha each, CRF= controlled-release nitrogen fertilizer at 192 kg/ha.Values marked with different letters in the same column are significantly different ($P < 0.05$).

DISCUSSION

Garlic growth is affected by soil characteristics, climate, species, fertilizer type and the amount of fertilizer used. Compared with the nutrient level standard developed from the national soil survey, available nutrients in the soil in this study area were rich (National Soil Survey Office, 2002). The controlled-release N fertilizer had the best effect on garlic growth among all treatments, even when the N application rate was lowest. A similar result was reported by Li (Li et al., 2003). This reflects the high N use efficiency of controlled release N fertilizer, with the N released from the controlled-release fertilizer matching the N needed by garlic growth during critical periods (Zebarth et al., 2012). However, the garlic bolt yield in Treatment CRF experienced the lowest effect from the fertilizer, possibly due to insufficient N supply through the bolting period. Therefore, the addition of N during that critical growth period could increase the yield of garlic bolt. The economic benefits in Treatment CRF was best, due to the low rate of N fertilizer application and labor costs.

Compared with conventional N fertilization (ie. the Treatment FP), a 20% reduction of N use will not significantly affect garlic bulb and garlic bolt yield and its economic benefits. However, the ratio of net income to the cost of Treatment OM-CF was significantly lower than Treatment FP and OPT, due to the expensive of organic fertilizer. Nevertheless, an organic and chemical fertilizer combination can improve the quality of garlic, as observed by other others (Assefa et al., 2015; Liu et al., 2008; Zhang et al., 2013). In addition, long-term organic fertilizer applications can maintain soil fertility and promote garlic yield (Zhang et al., 2013). Applications of sulfur, zinc, and selenium can also enhance garlic yield (Assefa et al., 2015; Poldma et al., 2011; Zaman et al., 2012), assist with formation of alliin and other active substances, and increase the preservation time of garlic (Bloem et al., 2011; Imen et al., 2013).

Nutrient deficiency and surpluses in soil depended on the input of fertilizers and nutrient uptake by garlic, which determined the soil sustainable production capacity. The results in the study indicated that conventional N application (ie. the treatment FP) could maintain garlic growth, resulting in a N surplus in soil. P deficit in soil was observed in all treatments, indicating that P fertilizer needs to be adequately increased to maintain an optimum P level in soil. It is noteworthy that the controlled-release N fertilizer can produce high yields of crop, at the expense of plant excessive uptake of soil nutrients. It is suggested that P and K fertilisers be applied when controlled release fertilizer is used to maintain soil nutrient balanced. Improvement of the controlled release fertilizer should supply N at the critical period of garlic growth.

CONCLUSION

N surplus occurred in the conventional N application treatment when the N was applied at 300 kg N /ha. Compared with the conventional N application, a 20% reduction of N fertilizer did not significantly affect garlic yield and its economic benefits. A 36% reduction of N fertilizer, using controlled release N fertilizer, could increase garlic yield and its economic benefits, but would result in nutrient deficit soil which would affect long-term soil nutrient balance. It is suggested that controlled release N fertilizer combined with supplement of other nutrients would be a sustainable plan for fertilizer management in garlic production.

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