Optimum Rate of Nitrogen Fertilizer for Garlic Production in Khun Yuam District, Mae Hong Son Province

อัตราปุ๋ยไนโตรเจนที่เหมาะสมสำหรับการผลิตกระเทียม ในอำเภอขุนยวม จังหวัดแม่ฮ่องสอน

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บทคัดย่อ: การศึกษาอัตราปุ๋ยไนโตรเจนที่เหมาะสมสำหรับการผลิตกระเทียม ได้ดำเนินการทดลองในพื้นที่ปลูกกระเทียมของเกษตรกรในอำเภอขุนยวม จังหวัดแม่ฮ่องสอน โดยวางแผนการทดลองแบบสุ่มสมบูรณ์ในบล็อก (randomized complete block design, RCBD) จำนวน 4 ซ้ำ 5 กรรมวิธีทดลอง ประกอบไปด้วยการใส่ปุ๋ยไนโตรเจนในอัตราที่แตกต่างกัน 4 กรรมวิธี คือ 62.50, 93.75, 125.00 และ 193.75 กก. N/เฮกตาร์ โดยมีกรรมวิธีที่ไม่ใส่ปุ๋ยเป็นชุดควบคุม จากผลการศึกษาพบว่า การใส่ปุ๋ยไนโตรเจนในอัตราที่แตกต่างกัน (62.50-193.75 กก. N/เฮกตาร์) ไม่ทำให้ค่าเฉลี่ยของความสูง จำนวนใบ เส้นผ่านศูนย์กลางหัว น้ำหนักแห้ง ปริมาณผลผลิต น้ำหนักต่อหัว ความเข้มข้นของธาตุอาหารหลักในหัวกระเทียม การสูญเสียน้ำหนัก และเปอร์เซ็นต์ความเสียหายของกลีบกระเทียมในช่วงเก็บรักษา แตกต่างกันอย่างมีนัยสำคัญทางสถิติ โดยการใส่ปุ๋ยไนโตรเจนอัตรา 125.00 กก. N/เฮกตาร์ ทำให้ปริมาณผลผลิตเฉลี่ย (20.8 ตัน/เฮกตาร์) เส้นผ่านศูนย์กลางหัวเฉลี่ย (41.25 มม.) และน้ำหนักต่อหัวเฉลี่ย (26.09 กรัม/หัว) ของกระเทียมสูงที่สุด อย่างไรก็ตามการให้ปุ๋ยไนโตรเจนอัตรา 62.50 กก. N/เฮกตาร์ เพียงพอต่อการผลิตกระเทียมสดและคุณภาพของกระเทียมเพื่อใช้เป็นหัวพันธุ์ โดยกระเทียมให้ผลผลิตเฉลี่ย 20.2 ตัน/เฮกตาร์ เส้นผ่านศูนย์กลางหัวเฉลี่ย 40.45 มม. น้ำหนักต่อหัวเฉลี่ย 23.31 กรัม/หัว เปอร์เซ็นต์การสูญเสียน้ำหนักและความเสียหายของกลีบกระเทียมเฉลี่ยในช่วงเก็บรักษาเฉลี่ยเท่ากับ 54.82% และ 4.73% ตามลำดับ

คำสำคัญ: กระเทียม ปุ๋ยไนโตรเจน การเจริญเติบโต ผลผลิต คุณภาพของกระเทียม

Abstract: The study on the optimum rate of nitrogen fertilizer for garlic production was conducted in farmer's field at Khun Yuam district, Mae Hong Son province. The experiment design was randomized complete block design (RCBD) with 4 replications and 5 treatments. The treatments consisted of 4 rates of nitrogen fertilizer (62.50, 93.75, 125.00 and 193.75 kg N/ha). Non-fertilized was used as a control treatment. The result revealed that application of nitrogen fertilizer at different rates (62.50-193.75 kg N/ha) were not significantly different on average plant height, the number of leaves, bulb diameter, dry weight, fresh yield, bulb weight, nutrient concentration, weight loss and the percentage of damage cloves. Application of nitrogen fertilizer at the rate of 125.00 kg N/ha produced the highest fresh yield (20.8 t/ha), bulb diameter (41.25 mm) and bulb weight (26.09 g/bulb). However, the results from this study suggested that application of nitrogen fertilizer at the rate of 62.50 kg N/ha was sufficient for producing good yield and bulb quality of garlic. The average fresh yield, bulb diameter, bulb weight, percentage of weight loss and damage cloves were as follows: 20.2 t/ha, 40.45 mm, 23.31 g/bulb, 54.82% and 4.73%, respectively.

Keywords: Garlic, nitrogen fertilizer, growth, yield, quality of garlic

Introduction

Garlic (*Allium sativum* L.) is a member of Alliaceae family which includes important vegetable crops such as onion, leek, chive and shallot. Garlic has been used throughout ancient history for culinary and medicinal purposes (Pandey, 2012). Worldwide garlic is grown about 1.5 million hectares with the total production of 26 million tons (FAO, 2015). Asia produces most of the world's garlic crop. The production of garlic in Thailand is cultivated over 90% of total area in the north with the total production of 70 thousand tons. (Office of Agricultural Economics, 2016). Good qualities of garlic like, large bulb size, long shelf-life and least damaged cloves are key factors influencing farmers' decision-making to use and purchase garlic. Normally, garlic is widely used for consuming and propagation. Therefore, improving garlic yield and storage quality are desirable attributes for growers and consumers. Nonetheless, the successful commercial production of garlic crop depends on several factors such as variety, nutrients, cultivation practices, climate, etc. Nutrient management plays an important role for growth, yield and quality (Singh *et al*., 2015). However, fertilizer requirements of garlic crop vary with fertility status of the soil, a variety of the crop and purpose for which the crop is grown (Diriba-Shiferaw, 2016). Innoi and Santasup (2016) reported that the nutrient uptake of garlic were 77.5 kg N/ha, 30.6 kg P_2O_5/ha, and 90.6 kg K_2O/ha, respectively.

Nitrogen (N) is an essential nutrient for plant growth and crop yield, being a constituent of protein, amino acids, chlorophyll, nucleic acid and cell wall (Neeteson, 1995). Nitrogen fertilization can have a significant effect on plant growth and development (Welbaum, 2015). According to a previous research, it was revealed that the appropriate nitrogen fertilizer rate could significantly improve the bulb size and yield of garlic (Kakar *et al*., 2002; Zaman *et al.,* 2011). Ebrahimi *et al.* (2014) reported that the maximum plant height, shoot dry weight and leaf number were achieved on the application of 125 kg N/ha and the highest bulb yield was obtained with application of 100 kg N/ha. Kilgori *et al.* (2007) suggested that the combined application of 120 kg

N/ha and 50 kg P_2O_5/ha could result in highest yield whereas higher dosage of 180 to 240 kg N/ha reduced the bulb yield. Zaman *et al*. (2011) observed that the maximum garlic yield was obtained from the treatment receiving 150 kg N/ha. Farooqui *et al*. (2009) recorded the highest growth and yield of garlic with the combination of 200 kg N/ha and 60 kg S/ha. Hore *et al*. (2014) noted that combination of 200 kg N/ha, 125 kg P_2O_5/ha, 150 K_2O/ha and 60 kg S/ha performed the maximum garlic yield. Although excess nitrogen stimulates the growth of foliage leaves but inhibits and delays bulb formation (Meredith, 2008). Shelf-life of garlic, garlic bulb pungency, total soluble solids and dry matter content rely on the correct level of fertilizer, soil types, the season of production and storage conditions (Diriba-Shiferaw *et al*., 2013). Nutritional compositions and allicin concentration of garlic depends on the environment, harvest time and cultivar (Somsu *et al*., 2016). Application of the nutrients over the optimum level would reduce bulb yield (Islam *et al*., 2012). Moreover, most garlic growers in the study area (Mae Hong Son province) attempt to increase productivity and quality of garlic by applying chemical fertilizer (125-187.5 kg N/ha (Kunasakdakul *et al*., 2015)). This may be due to unscientific cultivation which simply and increases production cost. Thus, it is necessary to evaluate the suitable rate of nitrogen fertilizer for successful garlic production and fertilizer use efficiency. Hence, the objective of this study was to examine the effect of nitrogen fertilizer levels on growth, yield and quality of garlic.

Materials and Methods

Study area and experimental design: The experiment was conducted on farmer's field at Khun Yuam district, Mae Hong Son province, northern Thailand during December 2014-April 2015. The initial soil properties at the experiment site were sandy loam (61% sand, 26% silt and 13% clay), pH 5.73, containing 2.2% of organic matter, 42.7 mg/kg of available phosphorus, 118.3, 553.5, 115.1 mg/kg of exchangeable K, Ca and Mg, respectively and 13.5 mg/kg of extractable S with an EC of 40.5 µS/cm. Compost (AG-5) (N=1.52%, P_2O_5=1.05%, K_2O=0.63%) was applied 6.25 ton/ha in the soil except for farmer practice treatment at 2 weeks before planting. The experimental plot size was 8 x 8 m. Cloves were planted in the spacing of 15 x 15 cm, then the plots were mulched with rice straw after planting. A local variety of garlic (softneck) was planted in a randomized complete block design with 4 replications. Five treatments were control (non-fertilized), three levels (62.5, 93.75 and 125 kg N/ha) of nitrogen fertilizer. P_2O_5 and K_2O fertilizers were applied at the rate of 75 kg P_2O_5/ha and 125 kg K_2O/ha and the fourth nitrogen level which was equal to farmer practice was applied at 193.75 kg N/ha (137.5 kg P_2O_5/ha, 137.5 kgK_2O /ha). Calcium nitrate (15-0-0), potassium sulfate (0-0-50) and other compound fertilizers (15-15-15, 25-7-7, 8-24-24) were used as N P and K sources in the experiment. Fertilizers were separated application 3 times, 20% of total fertilizer at basal application, 20% of total fertilizer at 30 days after planning (DAP) and 60% of total fertilizer at 60 DAP. Weed and pest controls were performed as necessary. A fresh yield of garlic was harvested at 110 DAP. Garlic yields were stored in the barn at ambient temperature as common farmers practise.

Data collection: Plant samples were randomly collected within the 0.25 m^2 for measuring plant growth at 30, 45, 60, 75 and 90 DAP. Plant height was measured from the ground level to the apex of a longest leaf, using a measuring tape. The number of leaves per plant was recorded by counting. Bulb diameter was determined by measuring the maximum width of garlic bulb using vernier caliper. Dry weight was measured by drying the garlic plant in a hot-air oven at 65-70° C till the constant weight obtained. At harvesting time, a fresh garlic was collected within the 16 m^2 for yield determination. Bulb weight, bulb diameter and dry weight of garlic were recorded, then concentration of nitrogen (N) (Novozamsky *et al*., 1974), phosphorus (P) (Walinga *et al*., 1995) and potassium (K) (Kalra, 1998) in garlic bulb were analysed. During 5 months of storage period, the percentage of total weight loss of garlic yield ((initial weight - measured weight) x 100 /initial weight) was determined monthly. At the end of the storage period, the percentage of damage cloves (weight of damage cloves x 100/total weight of cloves) was also recorded.

Statistical analysis: Data analysis was performed using Statistix 9.0. All data were analyzed using analysis of variance (ANOVA), followed by the least significant difference (LSD) at 5% level of probability.

Results

Plant growth

The results suggested that plant height of garlic was influenced by different rates of nitrogen fertilizer as shown in Table 1. All nitrogen fertilizer application treatments significantly increased plant height in comparison to control. However, increasing nitrogen fertilizer rates from 62.50 to 193.75 kg N/ha had no significant effect on plant height, plant heights were in the range of 35.25-36.57 cm, 46.08-46.76 cm, 56.63-57.80 cm, 64.08-64.79 cm and 66.62-67.79 cm at 30, 45, 60, 75 and 90 DAP, respectively. The minimum plant height was found in control treatment at all growth stages. The number of leaves per plant (Table 2) was not significant for all nitrogen fertilizer treatments at all growth stages. The maximum number of leaves per plant (10.4) was recorded with 125.00 kg N/rai and the lowest (8.0) was noted in control at 90 DAP.

The data were presented in Table 3 revealed that application of nitrogen fertilizer significantly increased bulb diameter in comparison to the control treatment. However, there was no significant difference among nitrogen fertilizer

Table 1. Effect of nitrogen fertilizer rates on plant height of garlic

Nitrogen fertilizer rates (kg N/ha)	Plant height (cm)				
	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP
Control	27.59 b	39.69 b	48.90 b	49.12 b	53.45 b
62.50	35.25 a	46.34 a	56.63 a	64.12 a	66.62 a
93.75	35.36 a	46.08 a	57.76 a	64.08 a	67.56 a
125.00	36.57 a	46.76 a	57.65 a	64.79 a	67.72 a
193.75	35.98 a	46.65 a	57.80 a	64.54 a	67.79 a
CV (%)	2.63	3.69	1.83	1.85	3.32
$LSD_{0.05}$	1.382	2.565	1.569	1.746	3.311

Means in each column followed by different letters indicate significant difference using least significant difference (LSD) at 5% probability level, ns = non-significant, DAP = days after planting

Table 2. Effect of nitrogen fertilizer rates on number of leaf of garlic

Nitrogen fertilizer rates (kg N/ha)	Number of leaves				
	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP
Control	4.5 b	5.0 b	5.8 b	7.1 b	8.0 b
62.50	5.1 a	5.8 a	6.8 a	7.9 a	10.1 a
93.75	5.1 a	5.8 a	6.6 a	8.0 a	10.3 a
125.00	5.1 a	5.8 a	6.6 a	8.0 a	10.4 a
193.75	5.1 a	6.0 a	6.6 a	8.0 a	10.0 a
CV (%)	5.12	5.01	3.87	4.50	3.76
$LSD_{0.05}$	0.389	0.437	0.385	0.539	0.565

Means in each column followed by different letters indicate significant difference using least significant difference (LSD) at 5% probability level, ns = non-significant, DAP = days after planting

Table 3. Effect of nitrogen fertilizer rates on bulb diameter of garlic

Nitrogen fertilizer rates (kg N/ha)	Bulb diameter (mm)					
	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP	110 DAP (At harvest)
Control	6.42 b	8.86 b	12.64 c	15.28 c	24.05 b	29.01 b
62.50	7.97 a	12.05 a	18.71 ab	27.99 ab	39.50 a	40.45 a
93.75	8.17 a	12.23 a	18.85 ab	27.03 b	40.33 a	41.05 a
125.00	8.07 a	12.26 a	18.91 a	28.76 a	40.58 a	41.25 a
193.75	8.08 a	11.96 a	18.01 b	28.05 ab	40.09 a	41.12 a
CV (%)	5.59	4.93	3.26	3.83	2.11	4.77
$LSD_{0.05}$	0.666	0.872	0.874	1.500	1.199	2.837

Means in each column followed by different letters indicate significant difference using least significant difference (LSD) at 5% probability level, ns = non-significant, DAP = days after planting

treatments, bulb diameter was in the range of 7.97-8.17, 11.96-12.26, 18.01-18.91, 27.03-28.76, 39.50-40.58 and 40.45-41.25 mm at 30, 45, 60, 75, 90 and 110 DAP, respectively. At 110 DAP (harvest stage), the maximum bulb diameter (41.25 cm) was obtained at 125.00 kg N/ha. Although increasing of nitrogen fertilizer from 62.50 kg N/ha to 125.00 kg N/ha tended to increase bulb diameter, however, application of nitrogen fertilizer at the high rate (193.75 N kg/ha) tended to reduce it.

Generally, the dry weight of garlic gradually increased until 60 DAP and thereafter rapid increase was observed during 75-110 DAP. The dry weight of garlic was significantly affected by different levels of nitrogen (Table 4). Increasing nitrogen fertilizer application rates from 62.50 to 193.75 kg N/ha resulted in the significant increase in dry weight compared to control. However, after 30 DAP, significant difference of garlic dry weight was not observed. The garlic dry weight was in the range of 0.44-0.50, 1.20-1.36, 2.76-3.02, 4.94-5.03, 8.18-8.29 and 9.38-10.31 g/plant at 30, 45, 60, 75, 90 and 110 DAP, respectively. The maximum dry weight of garlic (10.31 g/plant) was obtained from 193.75 kg N/ha treatment whereas the minimum dry weight was observed in the control at harvest stage.

Table 4. Effect of nitrogen fertilizer rates on dry weight of garlic

Nitrogen fertilizer rates (kg N/ha)	Dry weight (g/plant)					
	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP	110 DAP (At harvest)
Control	0.30 c	0.70 b	1.33 c	1.85 b	2.77 b	3.42 b
62.50	0.45 b	1.28 a	2.93 ab	4.94 a	8.18 a	9.38 a
93.75	0.44 b	1.20 a	2.96 a	4.97 a	8.26 a	9.47 a
125.00	0.44 b	1.29 a	3.02 a	4.99 a	8.29 a	10.11 a
193.75	0.50 a	1.36 a	2.76 b	5.03 a	8.29 a	10.31 a
CV (%)	6.93	13.45	4.46	15.66	6.12	10.18
$LSD_{0.05}$	0.045	0.242	0.179	1.051	0.675	1.339

Means in each column followed by different letters indicate significant difference using least significant difference (LSD) at 5% probability level, ns = non-significant, DAP = days after planting

Yield and bulb quality

The data in Table 5 showed that nitrogen fertilizer application rates increased garlic yield and bulb weight significantly in comparison to the control treatment. Different rates of nitrogen fertilizer from 62.50 to 193.75 kg N/ha had no significant effect on garlic yield and bulb weight. Fresh yield and bulb weight of garlic varied from 20.1 to 20.8 t/ha and 23.31 to 26.09 g/bulb, respectively. However, the maximum fresh yield (20.8 t/ha) and bulb weight (26.09 g/bulb) were recorded in 125.00 kg N/ha treatment, whereas the minimum fresh yield (7.50 t/ha) and bulb weight (6.19 g/bulb) were observed in control treatment. Application of nitrogen fertilizer significantly increased nitrogen concentration in bulb compared to the control treatment. However, there was no significantly difference among nitrogen fertilizer treatments, nitrogen content in bulb was in the range of 1.75-1.95%. The highest nitrogen content (1.95%) was noticed in the 125.00 kg N/ha treatment while the lowest nitrogen content (1.05%) was noted in control treatment. Moreover, the concentrations of phosphorus and potassium in the bulb were not significant. The concentrations of phosphorus and potassium were observed in the range of 0.31-0.33% and 1.14-1.26% respectively.

After garlic yield was kept the storage house, the weight of garlic decreased rapidly in the first month of storage and gradually decreased after 2 months of storage. The percentage of weight loss of garlic in storage was significantly affected by different rates of nitrogen fertilizer (Table 6.). At the first month of storage, the highest weight loss was recorded in 125 kg N/ha treatment (51.01%) and lowest weight loss was observed in 62.50 kg N/ha (45.44%). However, the total weight loss of all treatments including control was not significantly different after 5 months of storage (54.82-58.04%). The percentage of damage cloves was significantly influenced by different rates of nitrogen (Table 6). The highest damage clove (5.40%) was found in 193.75 kg N/ha treatment and the lowest damage clove (2.51%) was recorded in control treatment. However, increasing nitrogen fertilizer from 62.50 to 125.00 kg N/ha had no significant effect on damage cloves which was recorded in the range of 4.73-5.19%.

Table 5. Effect of nitrogen fertilizer rates on fresh yield, bulb weight and nutrient concentration in bulb of garlic

Nitrogen fertilizer rates (kg N/ha)	Fresh yield (ton/ha)	Bulb weight (g/bulb)	Nutrient concentration in bulb (%)		
			N	P	K
Control	7.50 b	6.19 b	1.05 b	0.33	1.19
62.50	20.2 a	23.31 a	1.78 a	0.33	1.14
93.75	20.1 a	24.16 a	1.87 a	0.33	1.16
125.00	20.8 a	26.09 a	1.95 a	0.32	1.15
193.75	20.4 a	25.24 a	1.75 a	0.31	1.26
CV (%)	11.58	8.60	9.03	6.70	6.90
$LSD_{0.05}$	3.174	2.781	0.233	ns	ns

Means in each column followed by different letters indicate significant difference using least significant difference (LSD) at 5% probability level, ns = non-significant

Table 6. Effect of nitrogen fertilizer rates on weight loss and the percentage of damage cloves during storage period

Nitrogen fertilizer rates (kg N/ha)	Weight loss (%)					Percentage of damage cloves (%)
	1 month	2 months	3 months	4 months	5 months	
Control	49.36 ab	52.41 a	53.99 a	54.91 a	58.04	2.51 c
62.50	45.44 c	45.26 c	47.15 d	48.12 c	54.82	4.73 b
93.75	47.05 bc	48.55 b	50.79 c	51.92 b	55.24	5.07 ab
125.00	51.01 a	51.47 a	52.79 ab	53.71 a	57.81	5.19 ab
193.75	49.45 ab	50.48 ab	51.84 bc	53.75 a	56.59	5.40 a
CV (%)	3.74	3.32	2.45	2.21	3.88	8.88
$LSD_{0.05}$	2.791	2.535	1.934	1.783	ns	6.626

Means in each column followed by different letters indicate significant difference using least significant difference (LSD) at 5% probability level, ns = non-significant

Discussion

This study demonstrated that increasing nitrogen fertilizer from 62.50-193.75 kg N/ha tended to increase plant height, the number of leaves, bulb diameter and dry weight of garlic and significantly increased the garlic growth in comparison to the control treatment. These results indicated the influence of nitrogen fertilizer on growth of garlic. Similar results were also reported by Kakar *et al.* (2002) and Zaman *et al.* (2011). Nitrogen promotes foliage growth that is responsible for the photosynthesis activities and accumulation of dry matter. In this experiment, the plant height of garlic was rapidly increased during 0-60 DAP and gradually increased at the growth stages of 60-90 DAP, as the bulb diameter immediately increased at the growth stages of 75-90 DAP. Similarly, the total dry weight accumulations sharply increased at the growth stages of 75-90 DAP. The obtained results were in conformity with Innoi and Santasup (2016) who observed that the leaf dry weight of garlic continued to increase until 90 DAP, meanwhile, the bulb dry weight was rapidly accumulated in the growth stage of 75-110 DAP. This might be due to the changes of growth stages from the vegetative phase to bulbing phase. Nevertheless, bulbing stage is strongly influenced by environmental factors, mainly temperature and photoperiod, on changes in the growth habits or phenological phase of garlic; similar conditions are not always required for overlapping or simultaneously occurring phases, as phase differences may depend on crop conditions (Lopez-Bellido *et al*., 2016). Although heavy nitrogen application stimulates the growth of foliage leaves but inhibits and delays bulb formation (Meredith, 2008).

The increase in fresh yield and bulb weight under different nitrogen application rates (62.50-125.00 kg N/ha) can be attributed to the positive effect of nitrogen on the growth parameters observed in this study. However, the high amount of nitrogen fertilizer (193.75 kg N/ha) reduced the garlic fresh yield. This result agrees with the finding of Kilgori *et al.* (2007) and Zaman *et al.* (2011). This might be an imbalance in plant nutrition that resulted in the reduction of yield. The result of the nutrient concentration in bulb showed that the nitrogen content obtained from the plant treated with nitrogen fertilizer was significantly higher than the control plot. Lacking of nitrogen in early bulb growth decreased the nitrogen content of the bulb (Bertoni *et al*., 1992) while phosphorus and potassium contents in bulb were slightly affected. This indicated that the phosphorus and potassium nutrition in the soil and received from fertilizer were adequate for growth of garlic. Moreover, nitrogen can increase phosphorus uptake in plant tissue. In case of high concentration of potassium, nitrogen can also increase potassium uptake in plant tissue (Fageria, 2001). A sufficient supply of nitrogen is associated with vigorous vegetative growth and more efficient use of available inputs, finally leading to higher productivity (Usman *et al.,* 2016).

Considering the quality of garlic yield during storage period, the percentage of weight loss was affected by different rates of nitrogen fertilizer. Generally, garlic farmers store garlic yield (whole plant) in the barn under ambient temperature conditions. This leads to an increase in the rate of respiration which enhance the weight loss. The highest weight loss was observed in control treatment (without fertilization). Similar results were reported by Diriba-Shiferaw *et al.* (2013). The lowest weight loss was observed in 62.50 kg N/ha treatment. However, nitrogen application higher than 62.50 kg N/ha tended to increase weight loss of garlic during storage. This result indicated that nitrogen fertilizer affected the quality and storage life of garlic, especially during the first month of storage. However, different rates of nitrogen fertilizer had no significant effect on the percentage of weight loss at 5 months after storage. This is attributed to water loss of the leaves of garlic in initial storage period. Bloem *et al.* (2011) revealed that water loss from intact bulbs was distinctly higher than water loss from cloves. The reason is that the drying process starts from the outer hulls to the cloves.

For garlic cultivation, separated clovers are used as a propagation plant part. Thus, the less damaged cloves are highly demanded by most garlic growers. The result from this study showed that the percentage of damage cloves tended to increase with the increment of nitrogen fertilizer rate. Therefore, the optimum rate of fertilizer application is necessary for producing good garlic propagation plant part. Appropriate nutrients are also significant for producing high dry matter. Conversely, later applications and excess nitrogen may delay maturity and reduce bulbs quality and storage life (Welbaum, 2015). Excessive fertilizer, especially nitrogen, can diminish diseases resistance. The pathogen that infects the crop can spread in the storage. During storage period of garlic, infection by pathogens and insect pests also contribute to deteriorating the bulbs and cloves. The postharvest quality of garlic depends upon the cultivar, growing conditions, harvest time and storage conditions (Meredith, 2008).

Consequently, the soil in the experiment had moderate level of organic matter (1.5-2.5%). Thus, the application of nitrogen fertilizer at the low rate (62.50 kg N/ha) did not significantly affect on the fresh yield of garlic in comparison to fertilizer rate of farmer practice (193.75 kg N/ha). According to the fertilizer management recommendation for allium crops in Thailand by the Department of Agriculture, the soil that consists of 1.5-2.5% of organic matter should receive 62.5 kg N/ha. This suggestion conforms to nitrogen fertilizer rate in this experiment and nitrogen requirement of garlic, 77.5 kg N/ha (Innoi and Santasup, 2016). In the soil that is high in available phosphorus (>40 mg/kg) and exchangeable potassium (>100 mg/kg), application of phosphorus and potassium fertilizer is rarely necessary for the crop. Based on this results, nitrogen fertilizer at the rate of 62.50 kg N/ha was sufficient for good production of garlic. Thus, application of urea (46%N) at the rate of 135 kg/ha or ammonium sulfate (21%N) at the rate of 300 kg/ha should be recommended. Moreover, adding compost at the rate of 6.25 t/ha to the soil (except for farmer practice and control treatment) has been used to maintain soil organic matter, thus supplying plant nutrient, improving the physical and biological properties of the soil and promoting the effectiveness of fertilizers. Hence, the low rate of nitrogen fertilizer application (62.50 kg N/ha) which had no significant effect on garlic yield suggested that available nitrogen in soil, inorganic nitrogen from applied chemical fertilizer and mineralized nitrogen from soil organic matter and added compost was sufficient for plant growth.

In this study, nitrogen removal by garlic was in the range of 71.8-84.8 kg N/ha when applied 62.50-193.75 kg N/ha (data not shown). Normally fertilizer is applied to the fields to supply the nutrient needs of the crop. However, it is not necessary to supply all these needs from fertilizer alone because the soil already contains some nutrient that are available for crop growth. Therefore, nutrient management ideally should provide based on crop removal and available nutrient in soil to balance between nutrient inputs and outputs for sustainable crop production. However, the amount of chemical fertilizer applied by conventional practice of farmer is generally higher than the actual nutrient requirements of garlic. This may imply an excessive use of fertilizer on garlic production, resulting in high production cost.

Conclusion

The study on the optimum rate of nitrogen fertilizer for garlic production in Khun Yuam district, Mae Hong Son province revealed that nitrogen fertilizer at the rate of 62.50-193.75 kg N/ha were not significantly different on plant growth, yield and quality of garlic. The application of 125.00 kg N/ha produced the highest bulb diameter, bulb weight, and fresh yield of garlic. However, nitrogen fertilizer at the rate of 62.50 kg N/ha was adequate for producing the good yield and bulb quality of garlic under the conditions of this experiment. In addition, this study indicated that the appropriate fertilizer application when considering soil fertility and nutrient requirements could produce the good yield of garlic and reduction in fertilizer usage.

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