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Correlations between soil physico-chemical properties and plant nutrient concentrations in bulb onion grown in paddy soil

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ABSTRACT

This study was carried out to evaluate the correlations between soil physico-chemical properties and onion (*Allium cepa* L.) plant nutrients in a long-term onion producing area over 30 years, during the growing season of 2010–2011. Soil and plant samples were collected from 16 onion growing fields. Each mineral content of onion plants showed different trends in conversion from the initial bulbing stage to harvest. Nutrient uptakes of leaf tissue decreased from the initial bulbing to harvest, while nutrient uptakes of onion bulb substantially increased. In soil, water content, nitrate-nitrogen (NO_3—N), and electric conductivity with high mobility decreased from the initial bulbing to harvest, but available phosphorus (av. P) or exchangeable cations with highly accumulated content did not change significantly. At the initial bulbing, soil N or NO_3—N and ex. K content were not positively correlated with each counterpart in leaf tissue, while av. P content was positively related with leaf P content. However, bulb N, P and K were not significantly correlated with each counterpart in the soil. Soil N or NO_3—N at the initial bulbing were negatively associated with bulb nutrients at harvest, especially Mg or soluble solid content. Soil av. P content at the initial bulbing showed strongly negative correlation with dry matter (DM), carbon (C), calcium (Ca), magnesium (Mg) and iron (Fe) at harvest. Soil ex. K content at the initial bulbing was solely positively related with the counterpart in bulb at harvest. Meanwhile, soil bulk density at the initial bulbing was positively correlated with DM, C, Ca, Mg, etc., in the bulb at harvest. In conclusion, the accumulated soil nutrients in a long-term onion growing area could negatively affect the bulb weight or mineral contents in bulb at harvest. Therefore, a new fertilizer recommendation program will be necessary for sustainable onion production.

1. Introduction

Onion (*Allium cepa* L.) is one of the most important vegetable crops grown in Korea, with 20,965 ha of production producing 1.20 million ton (Korean Statistical Information Service (KOSIS), 2012), and consumption has been increasing, due to awareness of the health benefits of onions. Intermediate-day onions planted in the fall have been introduced to temperate environments in the southern parts of Korea since the 1950s. The Korean onion has been producing more than 50 t ha^{-1} of bulb yield since 1989, and obtained the highest productivity all over the world (Food and Agriculture Organization (FAO), 2012). Onion productivity has been sustained by intensified cultural practices, including the use of transplants, high-density planting, polyethylene film mulches, and increased use of fertilizer, compost and synthetic chemicals. However, recently onion growers have been worried about various physiological disorders or diseases, and bulb yield reduction or deteriorated bulb quality of onions harvested or stored in historical onion growing areas.

Onion nutrient contents and bulb mineral uptakes were examined, to determine the nutritional status for optimum yield (Fink et al., 1999; Zink, 1966). Bosch Serra (1999) reported that the equilibrium N:P:K:Ca:Mg for bulb nutrient uptakes was 8:1:9:2:0.3 in bulb dry-matter yields around 11–13 t ha^{-1}. Many researchers contributed to determining N, P, and K fertilizer application rates suitable for optimum yield with minimum cost. Nitrogen fertilization was of great importance for onion production, but also, higher N rates did not accompany higher bulb yield (Boyhan et al., 2007; Halvorson et al., 2008). Phosphorus or K fertilizer applied to onions provided a slightly positive effect, or frequently no effects on bulb yield (Amin et al., 2007; Boyhan et al., 2007; Laughlin, 1989; Lee et al., 2011). In a paddy soil having 46.3 g kg^{-1} organic matter (OM) and 728 mg kg^{-1} available phosphorus (P), increased fertilizer beyond the recommended rates and delayed split application

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timings decreased bulb yield and accumulated soil electric conductivity (EC), OM, exchangeable potassium (K), and nitrate nitrogen (NO_3—N) in soil at harvest (Lee et al., 2012).

Long-term excessive application of chemical fertilizer accumulates nutrients in soil, which may result in increased susceptibility of onion root to high soil moisture content or water deficiency. Moreover, applied fertilizer or high soil nutrients content could not work, or could depress nutrient uptakes, as well as crop growth or yield. Therefore, this study was undertaken to evaluate the nutrient contents and uptake, soil mineral contents, and interrelationships between soil physic-chemical properties and plant nutrients in a long-term onion grown area.

2. Materials and methods

2.1. Field experiment

The present experiment was conducted in Changnyeong county (35°N, 128°E), in southeastern Korea, in 2010–2011 growing season. In the county, onions were grown on a total of 1152 ha (KOSTAT, 2012). Experimental sites came from 16 long-term onion growing fields. Fourteen F1 hybrid onion cultivars (Turbo, E-joeun, Premium gold, etc.) and two open-pollinated cultivars (Changnyeongjunggo, Chunjujunggo) were intermediate-day onions in bulb development, and mid or late maturing type in maturity. The onion seeds were sown from late August to mid September, transplanted from late October to early November at a plant density of 33.3 ± 2.3 individuals m^{-2}, and onion bulb were harvested from 3 to 9 June, when 80–100% of the plant tops had broken over at the neck.

2.2. Plant and soil sampling

Samplings for onion growth, plant nutrients and soil chemical analysis were performed from 26 to 28 April (at the initial bulbing stage), and from 3 to 9 June (at harvest). Ten plants were pulled at 3 replications from each field at the initial bulbing stage, and fifty plants were pulled at three replications at harvest. Soil samples were collected from the surface soil (0–20 cm) and the subsoil (20–40 cm), at the same site and date as the plant sampling.

2.3. Plant nutrient content and nutrient uptake analysis

All samples were separated into the bulb and green leaves, followed by the measurement of fresh weight (g/plant) and bulb weight (g/plant). Five representative bulbs and leaves were chopped into pieces approximately 2 cm square, and dried to a constant weight during 2 h at 105 °C, and 22 h at 60 °C. The dried samples were used to analyze dry matter and inorganic contents. Five other bulbs at harvest were selected, to analyze the soluble solid content (SSC), pyruvic acid (PA), and total phenolic compound (TP) of onion bulbs. Each bulb was cut longitudinally, and one half was immediately chopped into pieces approximately 2 cm square, and homogenized without water for 1 min in a blender (Food mix HMR-505, Hanil). The puree was poured into a filter paper (No. 6, Advantec), and placed in a plastic beaker, and allowed to filter. After approximately 60 min, the sample was stored in 15 ml cupped vial at −20 °C, until analyzed.

The dried samples were ground, weighed and dissolved in concentrated H_2SO_4 and concentrated H_2O_2. Carbon (C), nitrogen (N) and sulfur (S) was measured by elemental analyzer (vario Max, Elementar, Germany) using the ground samples. Atomic absorption spectrophotometer (novAA 300, analytikjena, Germany) was used to determine the K, Ca, Mg and Na content (Slavin, 1968). Phosphorus was measured colorimetrically with the ammonium–vanadate–molybdate method (Gericke and Kurmies, 1952). The SSC was determined with a hand reflectometer, and expressed as % Brix. The PA content was measured by the method of Yoo et al. (1995) and Yoo and Pike (1999). The concentration of PA was calculated from a standard sodium pyruvate curve. TP content was determined with the Folin–Ciocalteau assay (Singleton and Rossi, 1965). The content was expressed as mg gallic acid equivalents (GAE) kg^{-1} at the fresh weight basis.

2.4. Soil chemical analysis

The bulk density (BD) and water content (WC) were measured by gravimetric method, using a 100 ml sampling core. Fresh soil samples were analyzed for NO_3—N, and air-dried soil samples were analyzed for pH, electric conductivity (EC), organic matter (OM), nitrogen (N), sulfur (S), available phosphorus (av. P), and exchangeable cations. Organic matter, N and S contents were measured by elemental analyzer (vario Max, Elementar, Germany), and NO_3—N was identified by reflectometry (RQ plus, Merck). Soils for analyzing P and ex. cations were extracted using Morgan extractant (McIntosh, 1969). The extracted soil P was analyzed by spectrophotometer, and ex. cations were measured by atomic absorption spectrophotometer.

Soil pH was determined using a 5:1 DI water:soil ratio, and the EC was measured by conductivity meter.

2.5. Data analysis

Statistical analyses were performed using XLSTAT Pro 2013.1.01 (Addinsoft, USA). To assess the correlations between soil physicochemical contents and bulb nutrients values, the Pearson coefficient (r) was calculated, and presented in a rectangular correlation matrix.

3. Results and discussion

3.1. Plant mineral contents and uptakes

Fresh weight, P and S concentrations decreased in leaf tissue and increased in bulb at harvest, compared with the initial bulbing stage (Table 1). In contrast, Mg, Na and Fe concentrations increased in leaf tissue and decreased in bulb at harvest, from the initial bulbing stage. The yield, and N, P, K, S uptakes decreased in leaf tissue, while all elements in bulb increased at harvest, compared with the initial bulbing stage (Table 2). Total leaf-plus-bulb uptakes at final harvest were 119.8 kg ha^{-1} in K, 116.7 kg ha^{-1} in N, 32.7 kg ha^{-1} in S, 32.5 kg ha^{-1} in Ca, followed by 16.0 kg ha^{-1} in P, 11.6 kg ha^{-1} in Mg, 3.3 kg ha^{-1} in Na. The nutrient ratios of bulb to bulb plus leaf were 91.8% in P, 87.2% in S, 79.5% in N, 78.0% in K and 72.6% in Fe, and lower than 70% in other elements. The nutrient concentrations and uptakes depend on day length-induced cultivar type, maturity, soil fertility or fertilization methods (Lee et al., 2009; Salo et al., 2002; Yoldas et al., 2011; Zink, 1966). Zink (1966) reported that Southport White onions, spring-direct seeded cultivar removed 159.2 kg ha^{-1} of N, 28.0 kg ha^{-1} of P, 142.4 kg ha^{-1} of K, 89.7 kg ha^{-1} of Ca, 13.5 kg ha^{-1} of Mg, and 10.1 kg ha^{-1} of Na in 260 g of fresh weight, with 145 g kg^{-1} of dry matter at harvest. The higher N, K and Ca uptakes than our findings resulted from higher fresh weight and dry matter. Fink et al. (1999) summarized from studies related to nutrient contents that 60 t ha^{-1} of onion bulb took up 108.0 kg ha^{-1} of N, 21.0 kg ha^{-1} of P, 120.0 kg ha^{-1} of K and 9.0 kg ha^{-1} of Mg, while 5.0 t of harvest residues removed 15.0 kg ha^{-1} of N, 1.0 kg ha^{-1} of P, 9.0 kg ha^{-1} of K and 1.0 kg ha^{-1} Mg, which were similar to our studies.