Reduced Nitrogen, Phosphorus, and Potassium Rates for Intermediate-day Onion in Paddy Soil with Incorporated Rice Straw plus Manure

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Abstract. The effect of nitrogen (N), phosphorus (P), and potassium (K) supply on the growth and nutrient uptake of intermediate-day onions (Allium cepa L.) was investigated in a double cropping system of rice and onion in which rice straw had been annually applied. The experiment consisted of three sets of treatments: N (0, 120, 240, 360 kg ha⁻¹ N), P (0, 18, 35, 52 kg ha⁻¹), and K (0, 67, 133, 200 kg ha⁻¹) with the addition of 8.0 t ha⁻¹ of decomposed pig manure. The rice straw was incorporated with tillage after harvest. Foliage weight of the onion plant was affected by N rate on 21 Apr. and on 23 May. Bulb weight was also influenced by N rate on 23 May and at harvest. The only difference (P = 0.05) in onion yield was observed between the zero N rate and all the other N levels. Soil pH was correlated with rate of N fertilization. Soil NO₃-N for 240 and 360 kg ha⁻¹ N rates ranged from 36.6 to 113.7 and 49.9 to 148.6 mg kg⁻¹, respectively, which was at least twice as high as that at 120 kg ha⁻¹ N rate. The highest fertilizer use efficiency of nitrogen was 36.0% at 120 kg ha⁻¹ followed by 240 kg ha⁻¹ at 28.0% and 360 kg ha⁻¹ at 20.6%. There was no clear effect of P or K rates on P or K concentration in the onion bulbs. K concentration and uptake in the onion leaf tissue increased with higher K rates. In conclusion, compost and rice straw provided sufficient P and K to grow onions without additional P and K fertilizer, and under these conditions, the fertilizer level of 120 kg ha⁻¹ N produced as much onion bulb yield as higher N levels.

Onion (Allium cepa L.) is one of the most important vegetable crops grown worldwide with 57.9 million tons produced annually (USDA, 2005). Onion production has been increasing in Korea owing to enhanced awareness of onion’s health benefits. Intermediate-day onions planted in the fall have been introduced to temperate environments in the last five decades and have become an important crop in the southern parts of Korea. Although onion has been grown continuously there for many years, onion productivity has been sustained in a double cropping system of rice followed by onions and by increased use of synthetic chemicals for pest control and fertilization. Onion growers have been under production pressure from imbalanced nutrients in soil, disease, storability issues, and under economic burden from the rising price of commercial chemical fertilizers.

Onions have a shallow, sparsely branched root system with most roots in the top 30 cm of soil. The shallow root system of onions is less effective than other crops at extracting soil nutrients (Brewster, 2008). Nevertheless, excess applications of N fertilizer should be avoided because it has little effect on yields but can increase bulb decay (Diaz-Perez et al., 2003). Onion productivity varies depending on climate, soil type, soil fertility, water management, and other agricultural practices (Westerveld et al., 2003). Optimum fertilizer requirement has been reported as 95 to 150 kg ha⁻¹ N as potassium sulfate.

The experiment consisted of three sets of treatments: 1) constant P and K with variable N rate; 2) constant N and K with variable P; and 3) constant N, P, and K rates were 240 kg ha⁻¹ N, 133 kg ha⁻¹ P, and 128 kg ha⁻¹ K, which were recommended fertilizer rates for intermediate-day onion in Korea. The N rates were 0, 120, 240, and 360 kg ha⁻¹ N applied as urea. The P rates were 0, 18, 35, and 52 kg ha⁻¹ P as fused phosphate fertilizer. The K rates were 0, 67, 133, and 200 kg ha⁻¹ K as potassium sulfate. Every treatment also received decomposed rice straw at crop maturity (Dobermann and Fairhurst, 2002). Straw incorporation into the soil returns most of the nutrients and helps conserve soil nutrients. However, when straw is either removed from the field or used as feedstuff or burned in situ, most of this recycling does not take place. Burning causes almost complete N and carbon loss and partial P, K, and other nutrient loss as well as atmospheric pollution. Incorporation of straw and stubble into wet (bunded) soil results in temporary immobilization of N (Li et al., 2006). Temporary N immobilization in rice straw reduces the N availability, but this is a temporary condition and later N becomes available by plants (Seneviratne, 2002). Yadavinder-Singh et al. (2004) suggested that rice residue is likely to have little adverse effects on N availability in the soil when it is allowed to decompose under aerobic conditions for at least 10 d before sowing the next crop. Rice straw contains 45% of its total K in a water-soluble form that is readily released in the soil on incorporation (Yadavinder-Singh et al., 2004). The purpose of the present study was to investigate onion growth, bulb yield, nutrient uptake, and soil properties affected by different N, P, and K fertilizer rates in the rice-onion cropping system in which rice straw was annually incorporated into the soil after rice harvest.

Materials and Methods

Field experiment and treatments. The present experiment was conducted twice in different areas of the same field during 2004–2005 and 2005–2006 growing seasons at the Onion Research Institute’s experimental farm, Changnyeongdong, Korea (long. 35°55′ N, lat. 128°47′ E). The experiment site has been under continuous cultivation by the double cropping system of rice followed by onion. Top soil texture was silt loam with an organic matter (OM) content of 16.5 g kg⁻¹, pH 6.9; and residual NO₃-N, available P, and exchangeable K were 5.3 mg kg⁻¹, 107 mg kg⁻¹, and 0.50 cmol+ kg⁻¹, respectively, before planting onion. Onion cv. Superball (an F₁ hybrid cultivar for fall transplanting) was sown onto a bare soil on 8 Sept. 2004 and 9 Sept. 2005 and transplanted into beds mulched with a sheet of transparent polyethylene on 6 Nov. 2004 and 8 Nov. 2005 with a spacing of 15 cm in row and 20 cm between rows with seven rows. The bed size was 12 × 1.4 m, accommodating 560 plants per plot. Harvesting was conducted after 80% of the tops had fallen down on 9 June 2005 and 13 June 2006.

The experiment consisted of three sets of treatments: 1) constant P and K with variable N rate; 2) constant N and K with variable P; and 3) constant N, P, and K rates were 240 kg ha⁻¹ N, 133 kg ha⁻¹ P, and 128 kg ha⁻¹ K, which were recommended fertilizer rates for intermediate-day onion in Korea. The N rates were 0, 120, 240, and 360 kg ha⁻¹ N applied as urea. The P rates were 0, 18, 35, and 52 kg ha⁻¹ P as fused phosphate fertilizer. The K rates were 0, 67, 133, and 200 kg ha⁻¹ K as potassium sulfate. Every treatment also received decomposed rice straw as pig manure.
Results and Discussion

Plant growth and bulb yield. Crop growth was very slow until March, but thereafter increased for all fertilization treatments (Table 2). Bulb weight was increased with N fertilizer on 21 Apr. and 23 May, but not on 12 Mar. or 11 June. Foliage weight was increased with N fertilizer on 21 Apr. and 23 May, but not on 12 Mar. or 11 June. In the case of P fertilizer, 18 kg ha⁻¹ P resulted in a significant increase for foliage weight on 12 Mar. and 21 Apr. By the time of harvest, there was no effect of P fertilizer. K levels did not affect foliage and bulb weight throughout the growing season except for bulb weight on 11 June.

Onion bulb TSS at harvest decreased with N application and was higher with 240 kg ha⁻¹ N than 120 or 360 kg ha⁻¹ N (Table 3). On the other hand, TSS was unaffected by P or K levels. Percent stand reduction was substantial at 360 kg ha⁻¹ N with a 7.7% reduction. It is likely to have been caused by the initial high salt concentration. Onion marketable bulb yield was lowest at the 0 N rate.

Chemical fertilizers N, P, and K on onions effectively enhance growth and yield up to a threshold level and are detrimental over this threshold (Amin et al., 2007; Greenland et al., 1992; Jilani et al., 2004). The thresholds vary depending on the soil conditions, fertility, and productivity as well as the local climate and varieties. Amin et al. (2007) reported that fertilizer application significantly increased bulb yield with N fertilizer over the no fertilizer treatment, but there were no differences between different N levels. This result was similar to our results.

Table 2. Changes in the average onion bulb and foliage weight of onion plants as affected by N, P, and K fertilizer levels.

| Levels (kg ha⁻¹) | 12 Mar. | 21 Apr. | 23 May | 11 June | 12 Mar. | 21 Apr. | 23 May | 11 June |
|------------------|---------|---------|--------|---------|---------|---------|--------|---------|
| N 0              | 1.3     | 10.5    | 72.6   | 102.9   | 1.7     | 19.5    | 23.1   | 6.2     |
| 60               | 2.0     | 10.5    | 74.2   | 107.1   | 2.1     | 20.0    | 23.4   | 6.8     |
| 120              | 2.3     | 12.5    | 120.7  | 167.2   | 2.4     | 33.0    | 46.7   | 10.6    |
| 240              | 2.6     | 14.2    | 145.1  | 165.8   | 2.4     | 34.5    | 54.2   | 9.4     |
| 360              | 2.8     | 13.9    | 122.3  | 171.9   | 2.0     | 40.6    | 64.2   | 12.5    |
| LSD (0.05)       | 0.2     | 2.2     | 3.3    | —       | 0.0     | 2.2     | 3.9    | NS      |

N = nitrogen; P = phosphorus; K = potassium; LSD = least significant difference; NS = non-significant.

Table 3. Onion soluble solid, stand reduction, and yield as affected N, P, and K levels.

| Levels (kg ha⁻¹) | TSS ('Brix) | Stand reduction (%) | Yield (t ha⁻¹) |
|------------------|-------------|---------------------|---------------|
| N 0              | 10.2        | 4.6                 | 26.1          |
| 60               | 9.4         | 2.8                 | 50.0          |
| 120              | 9.9         | 4.5                 | 52.8          |
| 240              | 9.3         | 7.7                 | 52.9          |
| 360              | 9.2         | 4.8                 | 52.9          |
| LSD (0.05)       | 0.2         | 2.2                 | 3.3           |

P = phosphorus; K = potassium; LSD = least significant difference; NS = non-significant.
to a study in the subtropical hilly region of Bangladesh (Mozumder et al., 2007). In other studies, fertilizing N rates from 0 to 200 kg ha\(^{-1}\) N showed that 120 kg ha\(^{-1}\) was best (Jilani et al., 2004), which was also supported by the findings of Ghaffoor et al. (2003). The stand reduction rate at very high N levels (360 kg ha\(^{-1}\)) was similar to findings of Mogren et al. (2008) who showed that onion seedling emergence was sensitive to soil N concentrations.

In some studies, P fertilizer applied to onions provided a slightly positive effect, resulting in an increase in bulb yield as compared with no P fertilization (Amin et al., 2007; Laughlin, 1989), whereas in others, there were no differences (Boyhan et al., 2007). In the cases of K fertilization levels, some researchers (Aisha and Taalab, 2008; El-Bassiony, 2006) reported that the highest bulb yield and quality were observed with increased potassium sulfate level in the clay or clay loamy soil of Egypt. However, most results showed that the increased K levels did not affect bulb yield (Amin et al., 2007; Boyhan et al., 2007).

In the present study, neither P nor K fertilizers influenced bulb yield significantly, perhaps as a result of the high level of nutrients in the organic materials applied to the experimental field, which were especially high in P in the pig manure compost and K in the rice straw (Table 1). The input of organic materials such as animal manure, compost, or crop residues can reduce chemical fertilizer doses and contribute to a build-up of soil nutrients (Prasad et al., 1999; Yaduvanshi, 2002). Gill and Meelu (1982) demonstrated that 12 t ha\(^{-1}\) of farm yard manure could substitute for 40 kg N as inorganic fertilizer in rice and gave residual effects equivalent to 30 kg ha\(^{-1}\) N and 13.1 kg ha\(^{-1}\) P in the following wheat crop. Shah and Ahmad (2006) showed that wheat fertilized with the integrated use of urea and farm yard manure (FYM) yielded better than the use of urea or FYM alone, although the level of applied N was the same. Prasad et al. (1999) have suggested that soil incorporation of rice or wheat residue is an ecofriendly practice without any adverse effects on crop yield and incorporated residue gradually improves soil fertility. Nguu (1987) has also observed that there were no significant differences in maize yield between 60 and 120 kg ha\(^{-1}\) N or 30 and 60 kg ha\(^{-1}\) P when crop residue of 4 t ha\(^{-1}\) was used as mulch and soil was not tilled.

![Graphs](image1.png)

**Fig. 1.** Effect of nitrogen (N) phosphorus (P), and potassium (K) treatments on the soil pH, NO\(_3\)-N, available P\(_2\)O\(_5\), and extractable K\(^+\) content during the growing season. Error bars represent the se.
Table 4. Effect of N, P, and K treatments on the nutrient concentration and total uptake in onion bulb and leaf tissue as well as fertilizer use efficiency at the end of growing season.

| Levels (kg ha⁻¹) | N | P | K | N | P | K | N | P | K |
|------------------|---|---|---|---|---|---|---|---|---|
| N                | 0 | 8.6 | 0.73 | 19.6 | 7.4 | 0.99 | 14.1 | 25.8 | 2.2 |
| 120              | 12.5 | 0.76 | 25.2 | 6.3 | 0.44 | 15.1 | 50.0 | 3.0 | 0.5 |
| 240              | 18.7 | 0.76 | 25.2 | 7.3 | 0.35 | 20.0 | 72.9 | 2.9 | 98.3 |
| 360              | 22.7 | 0.91 | 26.6 | 9.4 | 0.39 | 20.7 | 79.3 | 3.2 | 92.9 |
| LSD (0.05)       | 2.1 | NS | 1.3 | 0.5 | NS | 0.08 | 1.9 | 8.5 | 0.7 |
| P                | 0 | 18.7 | 0.98 | 28.1 | 6.7 | 0.32 | 15.2 | 65.0 | 3.4 |
| 18               | 20.2 | 0.99 | 27.1 | 8.0 | 0.35 | 14.1 | 68.2 | 3.4 | 91.3 |
| 35               | 19.2 | 0.93 | 27.4 | 8.5 | 0.36 | 26.8 | 66.8 | 3.2 | 95.5 |
| 52               | 18.4 | 0.96 | 24.0 | 9.3 | 0.43 | 26.1 | 60.6 | 3.2 | 78.8 |
| LSD (0.05)       | NS | NS | 1.3 | 0.9 | NS | 0.04 | 1.8 | NS | 5.2 |
| K                | 0 | 20.8 | 1.41 | 25.8 | 8.2 | 0.30 | 14.5 | 71.2 | 4.7 |
| 67               | 17.9 | 1.22 | 25.2 | 8.3 | 0.34 | 20.5 | 70.7 | 4.8 | 99.4 |
| 133              | 18.2 | 1.27 | 29.4 | 9.4 | 0.37 | 18.4 | 65.2 | 4.6 | 105.1 |
| 200              | 17.3 | 1.36 | 25.7 | 7.7 | 0.36 | 21.9 | 67.8 | 5.3 | 100.7 |
| LSD (0.05)       | 1.4 | NS | NS | NS | NS | 2.4 | NS | 8.0 | NS |

Fertilizer use efficiency (%) for N, P, and K treatments.

- LSD = least significant difference; NS = non-significant.

Soil chemical properties and nutrient uptake. The changes in soil pH and NO₃-N content were observed in soil available P and exchangeable K content, were affected by different N, P, and K levels (Fig. 1). There was an approximately decrease from 6.93 to 5.97 to 6.67 in soil pH for all N treatments until 125 DAT and thereafter there was a slow increase to 6.30 to 7.10 in pH. The soil pH lowered with the rate of N fertilization, in particular during early growth. On the other hand, P and K levels did not influence soil pH. Work by Barak et al. (1997) has shown that acid-forming N fertilizer applications over 30 years caused reductions in soil pH, accumulation of exchangeable acidity, decreases in exchangeable calcium and magnesium, and reduction of cation exchange capacity associated with the N fertilization rates. Hence, higher N fertilization rates eventually led to lower N fertilizer efficiency (Barak et al., 1997). In particular, soil pH is an important factor in the productivity of high-value crops such as onions, which ideally should be in the range of 6.0 to 6.5. When the soil pH of 5.20 was adjusted to 6.0 to 6.5, NO₃-N content but no significant influence that the differences in organic fertilizer application caused remarkable variations in soil NO₃-N content, with no significant influence on onion yields. Greenwood et al. (1992) indicated that in view of the sensitivity of onions to salinity, the severity of the depressive effect of fertilizer types depended on the concentration of nitrate in the rooting zone. Lee and Chung (2006) observed that lower NO₃-N content in the soil, which had compost applied, as compared with chemical fertilizer, led to increased growth rates and lettuce and nitrate accumulation in leaf tissue.

In the case of P and K, available P and exchangeable K in the soil were enhanced according to increasing P and K fertilizer rates (Fig. 1) and differences persisted to harvest. The onion bulb yield, however, was not significantly affected by higher P and K availability. Organic amendments provided all the P and K needed for maximum yield in this study. Applied P and K were unnecessary.

N concentrations and uptake in onion bulbs increased with added N fertilizer, whereas P and K uptakes in bulbs were lowest at the 0 N rate (Table 4). However, fertilizer use efficiency of N was 36.0% in the 120 kg ha⁻¹ treatment followed by 240 kg ha⁻¹ at 28.0% and 360 kg ha⁻¹ at 26.8%. On the other hand, increased P levels resulted in enhanced N, P, and K concentrations and uptake into onion leaf tissue but reduced K concentrations and uptake into the onion bulb. There was not a clear effect of higher P levels on the P concentration or total uptake into the onion bulb and P fertilizer use efficiency as well. K concentration and uptake in onion leaf tissue were increased with higher K levels. The K level of 133 kg ha⁻¹ resulted in the highest K uptake in onion bulb, but K fertilizer use efficiency was the highest at 67 kg ha⁻¹ level at 23.0% followed by 133 kg ha⁻¹ at 14.0% and 200 kg ha⁻¹ at 8.7%. Our results indicated that enhanced N and K uptake in onion bulbs was affected by higher N and K levels, respectively. This did not increase the N fertilizer use efficiency consistently and in turn did not increase onion bulb yield.

Onion root systems basically consist of superficial roots that are rarely branched and lack root hairs, requiring a much larger nutrient supply to compensate for this limited root system, but onion bulb yield responded little to fertilizer rates (Halvorson et al., 2008; Shock, 2007). The nutrient uptake of onions could be variable depending on fertilizer types, rates, application methods (Lee et al., 2009), and soil type (Mitsios and Rowell, 1987).

In conclusion, the annual application of compost and rice straw into the soil provided sufficient P and K to grow onions without additional P and K fertilizer while requiring a N fertilizer level of at most 120 kg ha⁻¹. The reduced chemical fertilizer required resulting from the compost and rice straw incorporation may be a better solution in terms of the environment and resource use as well as economic benefit than the annual application of chemical fertilizer.

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