Quantification of Dry-Matter Accumulation and Nutrient Uptake Pattern of Short Day Onion (*Allium cepa* L.)

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ABSTRACT

Understanding the physiology of dry-matter accumulation and nutrient uptake pattern of an onion crop is an essential criteria for optimizing fertilizer practices. An experiment was conducted to estimate the dry-matter accumulation and nutrient uptake pattern of short day onion. The dry-matter accumulation and nutrient uptake followed the sigmoid growth curve pattern. Uptake of nitrogen and potassium was slow for the first 15 days followed by rapid uptake from 15 to 60 days after transplanting and accounted for 76.2–78.2% of total uptake. Takeup of phosphorus, sulfur, manganese, zinc, and copper uptake was greater during 30 to 75 days after transplanting and accounted for 64.9–70.6% of total uptake. The deficiency of nutrients during these period reduces the crop yield significantly. The dry-matter accumulation and nutrient-uptake pattern reported in this study provide an opportunity for optimizing quantity and timing of nutrient application through fertilizers for short day onions.

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Introduction

Onion (*Allium cepa* L.), a member of the *Alliaceae*, is cultivated throughout the world for its nutraceutical value. Onion is a highly nutrient-responsive crop and application of plant nutrients through fertilizers is known to improve its bulb yield. As per existing practice, all the nutrients except nitrogen (N) are recommended as basal applications. Because less than 20 percent of total N, phosphorus (P), and potassium (K) uptake occurs during the first 4 weeks of planting, a basal application of fertilizer does not synchronize with the crop nutrient demand (Sitthaphanit et al. 2009). Onion is a shallow-rooted crop and the root system is restricted to the top 0–15 cm during the first 30 days of growth (Thangasamy, Sankar, and Lawande 2010). The excess nutrients applied as a basal dose are leached to the subsurface with percolating irrigation water beyond its active root zone (Sitthaphanit et al. 2009). Therefore, the fertilizer application should match crop nutrient demand to increase nutrient-use efficiency and crop productivity (Heckman 2003).

Understanding the physiology of crop nutrient demand is necessary to optimize the timing of fertilizer application for onion crops. Plant nutrient uptake and dry-matter accumulation are essential criteria for estimating crop nutrient demands during the crop growth period (Moustakas and Ntzanis 2005). The short day transplanted onion crop requires 90–95 kg of N, 13–15 kg of P, 40–45 kg of K, and 20–25 kg sulfur (S) to produce 40–45 t onion bulbs per hectare (AINRPOG 2012). The nutrient requirement and fertilizer-use efficiency of short day transplanted onion is different from long day onions. Additionally, physiology of nutrient uptake and dry-matter accumulation pattern of the short day onion is essential for developing a fertilizer-management program.
The literature relevant to dry-matter accumulation, total nutrient uptake, and uptake rate during the growth period is unavailable for this crop. Hence, quantification of dry-matter accumulation and nutrient-uptake pattern of this crop during the growth period is essential to optimize timing of fertilizer application. In this study, we quantified N, P, K, sulphur (S), zinc (Zn), manganese (Mn), and copper (Cu) uptake and dry-matter production throughout the growth period.

**Materials and methods**

**Experimental locations**

We conducted a field experiment on a clay loam soil (Typic Haplustept) for two years (2010–11 and 2011–12) at the experimental field of the Directorate of Onion and Garlic Research, Rajgurunagar, Pune (18.32° N and 73.51° E). The experimental location has a subtropical dry humid climate. Annual precipitation amounts received during 2010–11 and 2011–12 were 930 and 821 mm, respectively, of which 97–98% of total precipitation was received during the southwest monsoon (June–October). The maximum air temperature ranged from 24.0 to 40.0 °C and minimum varied from 4.6 to 23.1 °C during the growth period for both years. Soil samples were collected from the experimental field before transplanting and assessed for soil properties. The preplanting soil pH was 7.92 and electrical conductivity was 0.24 dS m⁻¹. Preplanting soil analysis data showed that the soils of experimental site had sufficient plant nutrients except soil available N. Soil available N in the experimental field was very low (156 kg ha⁻¹) (Table 1). Soybean (Glycine max L.) was the previous crop in the experimental field.

**Field experiment**

Onion crop was grown during the winter season for assessing nutrient uptake and dry-matter accumulation pattern. The field was irrigated before transplanting and onion cv. Bhima Kiran seedlings 45 days old were transplanted during the third week of December. The plot size was 6 × 2 m and consisted of 20 rows with 15-cm row spacing. The plant-to-plant spacing was 10 cm. Recommended fertilizers (150:50:80:50 kg NPKS ha⁻¹) and farmyard manure (FYM) (20 t ha⁻¹) were applied to the soil. Nitrogen, P, K, and S fertilizers were applied through complex fertilizer (10:26:26 NPK), urea, murite of potash (MOP), and bentonite sulfur. Full amounts of P, K, S, and FYM and 34% N were applied during transplanting. The remaining 66 percent of N fertilizer was applied at 30 and 45 days after transplanting (DAT). The field was irrigated as per crop requirements. Weed control consisted of pre-emergence application of oxyfluorfen 23.5% active ingredients (a.i.) emulsifiable concentrates (EC) and a hand weeding at 45 DAT.

| Soil properties | Initial values |
|-----------------|---------------|
| Soil texture    | Clay loam     |
| Soil pH         | 7.92          |
| Electrical conductivity | 0.24 dS m⁻¹ |
| Available N     | 156 kg ha⁻¹   |
| Available P (Olsen’s regent) | 23 kg ha⁻¹ |
| Available K (1 N NH₄Oac K) | 578 kg ha⁻¹ |
| CaCl₂ (0.15%)-extractable S | 35 kg ha⁻¹ |
| DTPA-extractable Fe | 2.56 mg kg⁻¹ |
| DTPA-extractable Zn | 0.65 mg kg⁻¹ |
| DTPA-extractable Mn | 7.53 mg kg⁻¹ |
| DTPA-extractable Cu | 0.54 mg kg⁻¹ |
Plant sampling and analytical methods

The seedlings were collected before transplanting, weighed for dry matter, and analyzed for N, P, K, S, Zn, Mn, and Cu. We collected ten plants per plot at 15-day interval from 30 DAT to harvest for dry-matter estimation and nutrient analysis. The collected samples were separated into leaves and bulbs after washing. The samples were chopped into small pieces and dried to a constant weight at 58–60 °C for determining dry weight. The samples were ground to pass through a 2-mm sieve and analyzed for nutrient concentration. The plant samples were digested using a diacid mixture of nitric acid (HNO₃) and perchloric acid (HClO₄) in the ratio of 9:4 and analyzed for P by vanadomolybdate method, K by flame photometry, and S by the turbidimetric method (Jackson 1967). Total N was determined by the Kjeldahl digestion method. Total Mn, Zn, and Cu were analyzed by atomic absorption spectrophotometry (Jackson 1967). The soil nutrients were analyzed as described by Page (1982). The plant nutrient concentration and dry weight were used for determining nutrient uptake.

Logistic growth model

The plant growth passes through three consecutive growth stages and follows a sigmoid growth curve. This can be explained by logistic equation (Robertson 1923)

\[ W = \frac{c}{1 + \exp\left(-a(x - b)\right)} \]

where W is dry-matter accumulation or nutrient uptake at time t, a is exponential growth rate, b is the age at the inflection point, c is the dry-matter accumulation or nutrient uptake constant, and x is days after transplanting. The logistic equation expresses the relationship between production and time. Hence, the growth rate (i.e., increase in production per unit time) was calculated from the first derivative of this equation.

Statistical analysis

The dry-matter accumulation and nutrient uptake data were fitted for the logistic equation using SAS JMP version 6.0 after testing the data for nonlinear logistic growth model (SAS Institute Inc. 2012). The data by year was analyzed by factorial design and the effect of year on the experiment was nonsignificant. Therefore, data for 2 years were pooled for analysis. Dry-matter accumulation and nutrient uptake curves were prepared by using the graph builder option. The correlation coefficient (r) between predicted and observed values is high (supplementary Table 1) and ensures statistical integrity of the curve.

Results and discussion

Dry-matter accumulation

The results showed that the pattern of dry-matter accumulation of short day onion during the growth period followed the S-shaped sigmoid curve (Figure 1). This crop growth curve fits well to a logistic function. A similar pattern of dry-matter accumulation was observed in flue-cured tobacco (Moustakas and Ntzanis 2005), okra (Moustakas, Akoumianakis, and Passam 2011), and maize (Karlen, Flannery, and Sadler 1988; Bender et al. 2013). The dry-matter accumulation curve in the leaves divided into three phases with the slow accumulation from transplanting to 15 DAT with dry-matter accumulation rate of 5.97 kg ha⁻¹ d⁻¹, indicating the slow adaptation of the plants to their new environment (Figure 2). The rapid dry-matter accumulation occurred during 15 to 60 DAT coincided with an active vegetative growth stage. The dry-matter accumulation decreased 60 DAT. This decrease in dry-matter accumulation in leaves was due to leaf abscission (Harper 1971; Rodriguez, Westfall, and Peterson 1990). However, the dry-matter accumulation rate in bulbs was slow up to 45 DAT with accumulation rate of 29.9 kg ha⁻¹ d⁻¹ followed by a rapid accumulation
phase after 45 DAT and reached maximum at 105 DAT. Total dry-matter accumulation followed a similar pattern in onion bulbs and leaves. The peak dry-matter accumulation in leaves recorded at 30 DAT with accumulation rate of 50.1 kg ha\(^{-1}\) d\(^{-1}\) and at 66 DAT with the accumulation rate of 66.9 kg ha\(^{-1}\) d\(^{-1}\) in bulbs (Figure 2). The growth pattern of the short day transplanted onion followed a similar trend to that of directly seeded onion (Sullivan et al. 2001; Halvorson et al. 2002). In directly seeded onion, the dry-matter accumulation in leaves increased during active vegetative growth stage and stabilized at 60 DAT while the dry-matter accumulation in bulbs continued until harvest.

### Nitrogen and potassium uptake

Nitrogen and K uptake during the crop growth period followed the sigmoid growth curve (Figure 3). The N and K uptake patterns followed the trend of dry-matter accumulation in the leaves. The accumulation of dry matter in leaves is closely related with N (Alva et al. 2002; Bender et al. 2013).
The N uptake curve was divided into three phases with slow N uptake from transplanting to 15 DAT with uptake rate of 0.63 kg ha\(^{-1}\) d\(^{-1}\). This period corresponds to slow plant growth period and demand for N during this period was 7.81 kg ha\(^{-1}\). The rapid N uptake (15–60 DAT) corresponds to the active vegetative growth stage. Onion crop removed 78.2% of the total N during this growth period, which showed that the demand for N was greatest during the active vegetative growth stage. The uptake rate was lowered after 60 days from transplanting and this stage coincided with bulb development and maturity stages. The N uptake from 60 to 120 DAT accounted for 7.85 kg ha\(^{-1}\).

Nitrogen content in the leaves decreased gradually from transplanting to harvest. This indicated that the N accumulated in the leaves during active vegetative growth stage was redistributed within the plant from the leaves to bulb during maturity (Harper 1971). The peak daily N uptake occurred at 40 DAT with the uptake rate of 1.74 kg ha\(^{-1}\) d\(^{-1}\) (Figure 4). The similar N uptake pattern was reported in directly seeded onion (Sullivan et al. 2001; Halvorson et al. 2002; Brewster 2008) and maximum N uptake was observed during the rapid vegetative growth phase.

Like N uptake and leaf dry-matter accumulation, K uptake was also divided into three growth phases with slow growth up to 15 DAT followed by a rapid growth phase from 15 to 60 DAT and

Figure 3. Cumulative N and K uptake curves of onion crop from transplanting to harvest.

Figure 4. Nitrogen and K uptake rate curves of onion.
plateau after 60 DAT (Figure 3). Onion crop removed 10.47 kg ha$^{-1}$ of K up to 15 DAT. The daily K uptake rate was slow up to 15 DAT and increased to a maximum at 33 DAT with the uptake rate of 1.52 kg ha$^{-1}$ (Figure 4). The uptake rate decreased sharply after attaining peak. Onion crop removed 76.2% of total K from transplanting to 60 DAT and greater K content was observed in leaves over bulbs. Potassium accumulated in the leaves during the vegetative growth period was translocated from leaves to bulbs at bulb development and maturity stages. Total K removed after 60 DAT to harvest was 7.9%.

The N and K uptake pattern showed that the demand for these nutrients was 10–15% up to 15 DAT. The greatest N and K uptake coincided with active vegetative growth stage (Karlen, Flannery, and Sadler 1988; Sullivan et al. 2001; Bender et al. 2013) and accounted for 76.2–78.2% of total uptake from 15 to 60 DAT. Application of these nutrients during this growth period is crucial for better onion production. Soil application of N and K after 60 days from transplanting is seldom effective in increasing bulb yields because the nutrient uptake from 60 to 120 DAT was 5–10%. During this period, the nutrients present in the leaves were translocated from the leaves to bulbs, which resulted in a reduction of the leaf nutrient concentration.

**Phosphorus, sulfur, manganese, zinc, and copper uptake**

Like N and K, the P, S, Mn, Zn, and Cu uptake pattern followed the sigmoid growth curve. Phosphorus uptake pattern was slightly different from N and P uptake patterns. Phosphorus uptake up to 30 DAT accounted for 18.3%, and uptake increased at a faster rate after 30 days, reached a peak at 49 DAT with the uptake rate of 0.25 kg ha$^{-1}$ d$^{-1}$, and declined sharply thereafter (Figures 5 and 6). The P uptake from 30 to 75 DAT was 70.6% of total P uptake and only 11.1% P was removed at bulb development and maturity stages, corresponding to 75–120 DAT. A similar P uptake pattern was observed in long day onion with 4% of total P uptake during onion seedling stage while about 91% P was removed during the rapid growth phase (Zhao et al. 2009). The S uptake was slow during the first 30 days from transplanting, increased rapidly after 30 DAT, and reached a maximum uptake at 75 DAT. The S uptake up to 30 DAT was 17.7% of the total required S (Figure 5). Maximum daily uptake rate was observed at 47 DAT with the uptake rate of 0.21 kg ha$^{-1}$ d$^{-1}$ (Figure 6), and total S uptake from 30 to 75 DAT was 69.4%. The uptake rate decreased gradually after reaching a maximum and uptake stabilized after 90 DAT, and the uptake during these periods accounted for 12.9%.

![Figure 5. Total P and S uptake curves of onion crop from transplanting to harvest.](image-url)
The Mn uptake was slow up to 15 DAT with the uptake rate of 1.88 g ha$^{-1}$ (Figure 7). Onion crop removed 17.1% Mn up to 15 DAT. The Mn-uptake rate increased to the greatest daily uptake rate of 3.39 g ha$^{-1}$ at 49 DAT. The uptake rate decreased after reaching the peak (Figure 8). The Mn uptake from 15 to 75 DAT accounted for 64.9% of total Mn uptake. The Mn uptake from 75 DAT to harvest was 18.0%. Zinc uptake from transplanting to 30 DAT was 9.85 g ha$^{-1}$ and the period of rapid Zn uptake started at 30 DAT and continued up to 90 DAT, accounting for 78.0%. Zinc-uptake rate was greatest at 64 DAT with uptake rate of 1.75 g ha$^{-1}$ (Figure 8). Zinc-uptake pattern followed the trend of P and S. The peak Cu uptake was recorded at 48 DAT with uptake rate of 0.18 g ha$^{-1}$ (Figures 9 and 10). The uptake rate decreased sharply after reaching peak rate. Total Cu uptake from 15 to 90 DAT accounted for 75.0% and uptake from 90 to 120 DAT was 1.31 g ha$^{-1}$. Total Cu uptake at harvest was 13.39 g ha$^{-1}$.

Phosphorus, S, Mn, Zn, and Cu uptake followed the similar trend of total dry-matter accumulation. Rapid accumulation of these nutrients occurred between 30 and 75 DAT with the peak absorption rate observed during 45–55 DAT for P, S, Mn, and Cu uptake that corresponds to late
Figure 8. Manganese and Zn uptake rate curves of onion.

Figure 9. Total Cu uptake curve of onion from transplanting to harvest.

Figure 10. Copper uptake rate curve of onion from transplanting to harvest.
vegetative growth and bulb initiation stages. The peak uptake for Zn occurred at 64 DAT. This showed that P, S, Mn, Zn, and Cu are essential for bulb initiation and development (Sullivan et al. 2001).

**Conclusion**

The dry-matter accumulation and nutrient uptake pattern of the nutrients reported in the study followed the sigmoid growth curve pattern. Nitrogen and K uptake followed similar uptake patterns, while P, S, Mn, Zn, and Cu have identical uptake patterns. The daily peak uptake rate of the essential nutrients reported in this study overlaps with active vegetative and bulb development phase of short day onions. The results of this study indicated that the basal application of nutrients not enough to match the periods of peak nutrient uptake. The information on dry-matter accumulation and nutrient-uptake pattern generated in this study is likely to provide the basis for optimization of quantity and timing of nutrient application through fertilizers for short day onions.

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