**Journal of Plant Sciences**
2015; 3(6): 320-328
Published online December 5, 2015 (http://www.sciencepublishinggroup.com/j/jps)
doi: 10.11648/j.jps.20150306.15
ISSN: 2331-0723 (Print); ISSN: 2331-0731 (Online)

# Response of Potato (*Solanum tuberosum* L.) Yield and Yield Components to Nitrogen Fertilizer and Planting Density at Haramaya, Eastern Ethiopia

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**To cite this article:**
Alemayehu Tilahun Getie, Nigussie Dechassa, Tamado Tana. Response of Potato (*Solanum tuberosum* L.) Yield and Yield Components to Nitrogen Fertilizer and Planting Density at Haramaya, Eastern Ethiopia. *Journal of Plant Sciences*. Vol. 3, No. 6, 2015, pp. 320-328.
doi: 10.11648/j.jps.20150306.15

**Abstract:** To investigate the effect of nitrogen fertilizer and planting density on yield and yield components of potato crop (Bubu variety), a field experiment was carried out in Haramaya, Eastern Ethiopia during the rainy season of 2012. The experiment was a 4 x 5 factorial combination and a randomized complete block design with 3 replicates. Treatments included quantity of nitrogen fertilizer (0, 110, 165 and 220 kg N/ha) and planting density (4.17 plant $m^{-2}$ (80 cm x 30 cm), 4.44 plant $m^{-2}$ (75 cm x 30 cm), 5.56 plant $m^{-2}$ (60 cm x 30 cm), 6.67 plant $m^{-2}$ (60 cm x 25 cm) and 8 plant $m^{-2}$ (50 cm x 25 cm)). Increasing nitrogen level up to110 kg N/ha lead to more tuber yield, highest stem number, plant height, total dry biomass, total tuber number, large-sized tuber yield (59.01%) and marketable tuber yield. The highest foliar N concentration was recorded at 165 kg N/ha. Increasing planting density resulted in higher tuber yield; total tuber number, total dry biomass yield (%), marketable tuber yield and small-sized tuber yield (16.92%). Highest foliar N concentration was found at the lower planting densities of 4.17 and 4.44 plant $m^{-2}$. Yield of tuber per hectare was significantly and positively correlated with leaf area index, total tuber number, days to physiological maturity and total dry biomass yield. In conclusion, results of the experiment revealed that 110 kg N/ha and planting density of 6.67 plant $m^{-2}$ resulted in optimum total (35.50 and 35.66 t/ha, respectively) and marketable tuber yields of the Bubu variety in Haramaya, Eastern Ethiopia during the rainy season.

**Keywords:** Haramaya, Potato, Rain-Fed, Yield, Nitrogen Fertilization

## 1. Introduction

Potato (*Solanum tuberosum* L.) is one of mankind's most valuable food crops and mainstay in the diets of people in many parts of the world [1]. Ethiopia is endowed with suitable climatic and endemic conditions for potato production. However, the national average yield is very low (8.2 t $ha^{-1}$) compared to the world's average production (17.67 t $ha^{-1}$) [2]. The major production problems that account for such low yield are unavailability and high cost of seed tubers, lack of well adapted cultivars, poor agronomic practices, diseases, insect pests, inadequate storage, transportation and marketing facilities [3]. Low soil fertility is one of the most important constraints limiting potato production in Eastern Africa [4] and also [5] reported that nitrogen and phosphorus are deficient in most Ethiopian soils and thus application of these nutrients could significantly increase crop yields. Nitrogen has greater influence on growth and yield of crop plants than any other essential plant nutrient.

The blanket (general) recommended plant spacing and nitrogen fertilization for all potato varieties in Ethiopia is 75 cm by 30 cm between rows and plants, respectively and 110 kg N $ha^{-1}$ [6]. All varieties are recommended to be planted and fertilized with the above recommended spacing and nitrogen amount. However, farmers in eastern Ethiopia often use closer spacing due to the lack of sufficient land; the narrower spacing supposedly increases tuber number without compromising tuber size. However, research has demonstrated that the optimal response to N fertilizer and plant spacing differs by cultivar and soil fertility [7]. Many experiments have shown that total tuber yield and size of potato tubers increase with nitrogen [8]. [9] also reported that increase in nitrogen application raises tuber number, but that too much nitrogen has the opposite effect. Increasing planting density and nitrogen application up to a definite (160 kg N $ha^{-1}$ and 11 plant $m^{-2}$) point increases tuber yield, but beyond this point decreased them [10]. Also, [11] conducted a spacing trial on three improved and one local potato varieties grown in eastern Ethiopia at two locations. Inter-row spacing of 50 x 25 cm and 60 x 25 cm resulted in the highest tuber yields [11]. Still many potato producer farmers in the area frequently give less attention to optimal plant population due lack of sufficient land and high planting density supposedly yields more tuber number without considering it size of tuber. The possibility of securing high yields depends on the optimum number of plants per unit area [12]. Therefore, planting potato tuber with its optimal plant population is important to increase its yields and tuber size

One of the main problems on potato productivity in the area is improper (non optimal) use of nitrogen fertilization and planting density. To address this problem, the objective of this study was to investigate the effect of N fertilizer and planting density on yield and yield components of potato on Haramaya, Eastern Ethiopia.

## 2. Materials and Methods

### 2.1. Study Site

The experiment was conducted during the 2012 main growing season during the rainy season at the research field of the main campus of Haramaya University (42° 3' E, 9° 26' N, 2050 m a.s.l). The mean annual rainfall is 760 mm. The mean maximum and minimum annual temperatures are of 23.40°C and 8.25°C, respectively. The soil were neutral with high cation exchange capacity and low total N (0.12%) (Table 1). According to [13], the experimental soil has contents of low total N (0.12%).

***Table 1.** Physical and chemical properties of the experimental soil.*

| Parameter | Value |
|---|---|
| Moisture content | 8.34% |
| pH water, 1:2.5 | 7.86 |
| Electrical conductivity | 0.18 Ms/cm |
| Exchangeable sodium | 0.24 cmol (+)/kg soil |
| Exchangeable potassium | 0.98 cmol (+)/kg soil |
| Available phosphorus | 16.58 mg P/ kg soil |
| Organic carbon | 1.28% |
| Total nitrogen | 0.12% |
| Texture | |
| %Clay, Silt, and Sand | 52: 44: 4% respectively |

### 2.2. Experimental Set up

We used the Potato variety Bubu. The treatments consisted of the combination of four rates of N addition (0, 110, 165 and 220 kg N/ha) and five planting densities (4.17 plant $m^{-2}$ (80 cm x 30 cm), 4.44 plant $m^{-2}$ (75 cm x 30 cm), 5.56 plant $m^{-2}$ (60 cm x 30 cm), 6.67 plant $m^{-2}$ (60 cm x 25 cm) and 8 plant $m^{-2}$ (50 cm x 25 cm)). The entire rate of P and half rate of N fertilizers were applied at the time of planting. The remaining half of N was applied 45 days after planting of the tuber on June 22, 2012. Urea and Triple Super Phosphate (at the rate of 92 kg/ha) were used as fertilizer source for N and P, respectively.

The design was a 4 x 5 factorial experiment arranged in a randomized complete block, replicated three times. The plot size was 4 m x 3.6 m. Medium-sized and well-sprouted potato tubers were planted at the spacing distances mentioned above. Spacing between plots and replications were separated by 1 and 1.5 m, respectively. Cultural practices (weeding, cultivation and ridging) were done as per recommendation made for the crop.

### 2.3. Data Collection

Time to flowering was recorded when 50% of the population reached the flowering stage. Time to physiological maturity was recorded when 70% of plants leaves turned yellowish. Plant height was determined by measuring stem height from the base of the main shoot to the apex at full blooming. Number of stems per hill was recorded as the average stem count of five hills per plot during the flowering stage. Only stems arising from the mother tuber were considered as main stems. Leaf area index (LAI) was recorded from five plants in each plot. Individual leaf area of the potato plant was estimated from individual leaf length using the following formula developed by [14]. Total leaf area was calculated by multiplying the leaf area with the respective leaf number of the plant. LAI was calculated by dividing total leaf area to the respective land area occupied by the plants.

$$\text{Log10 (leaf area in cm}^2\text{)} = 2.06 \times \text{Log10 (leaf length in cm)} - 0.458$$

Total dry biomass (leaves, stem, roots, stolons and tubers) yield were recorded by taking the average dry biomass of five randomly selected plants at physiological maturity just before senescence. Samples were air dried and then oven dried at 70°C to constant mass. Size categories of tuber were recorded by taking all tubers from five randomly-selected plants and categorizing them into small (< 39 g), medium (39-75 g), and large (>75 g) according to [15] and each category was then expressed in percentage. Weight and number of marketable tubers yield were recorded as the weight and the number of marketable tubers that were free from diseases, insect pests, and greater than or equal to 25 g in weight [15]. These were taken from plants in the net plot area at harvest. Weight and number of unmarketable tubers yield were determined as the weight and the number of unmarketable tubers (culls) of each plot which included rotten, insect attacked and undersized tubers (less than 25 g) [15]. These were taken from plants in the net plot area at harvest. Total tuber number and yield were recorded as the sum of number and yield of marketable and unmarketable tuber. Harvest index was determined as the ratio of dry weight of the tubers to the dry weight of the total plant biomass measured from five randomly taken plants at harvest. Dry matter content of tuber (%) was taken from five fresh tubers randomly selected in each plot and weighed. Tubers were sliced and dried in an oven at 70°C until constant weight. Dry weight was recorded and dry matter percent was calculated according to [16] as:

$$\text{Dry matter (\%)} = \frac{\text{Weight of sample after drying}}{\text{Initial weight of sample}} x100$$

Nitrogen concentration in leaf tissues: Leaf samples were taken just before the start of tuber initiation. Fully grown mature leaves with petioles were randomly detached from the fourth node starting from the top of the plant. Leaf samples were dried at 70°C until constant weight and ground to pass through a 40-mesh screen. The dried and ground leaves of the plants were ashed at the temperature of 480°C. This material was treated with a solution of 1 volume of nitric acid ($HNO_3$) diluted in 3 volume of distilled water, and was analyzed for total nitrogen by modified Kjeldhal method [17].

### 2.4. Data Analysis

All crop data were subjected to analysis of variance, using SAS software version 9.1. Means that differed significantly were separated using the LSD procedure. Simple linear correlations between parameters were computed.

## 3. Results

### 3.1. Time to Flowering and Physiological Maturity

Interaction effect of planting density and nitrogen rates significantly influenced days required for flowering (Figure 1). Increasing N application from 0 to 220 kg N ha$^{-1}$ and planting density from 4.17 to 8.00 m$^{-2}$ prolonged the time required to attain 50% flowering from 42.67 to 49.00 days.

Nitrogen fertilization and planting density significantly influenced day required to attain physiological maturity in potato (Table 2). Increasing N application from 0 to 220 kg N ha$^{-1}$ prolonged the time required to attain physiological maturity by 6.8 days. When increasing planting density from 4.17 to 8.00 plant m$^{-2}$, the time required to reach physiological maturity shortened by 1.91 days.

### 3.2. Plant Height, Stem Number and Total Dry Biomass Yield

Nitrogen fertilization and planting density significantly influenced plant height, stem number and total dry biomass yield (Table 2). Application of 110 kg N/ha increased plant height, stem number and total dry biomass yield by 12 cm, 3.013 and 6.11 t/ha, respectively than without fertilization. Similarly, planting densities of 4.17, 4.44, and 5.56 resulted in the growth of significantly taller plants and highest number of stems than the planting densities of 6.67 and 8.00 plant m$^{-2}$. Increasing planting density from 5.56 plants m$^{-2}$ to 8.00 plants m$^{-2}$ significantly increased dry biomass yield by 4.5 t/ ha.

***Table 2.*** *Days to physiological maturity, stem number per hill, plant height per plant (cm) and total dry biomass yield (t/ha) as influenced by the main effect of nitrogen application and planting density.*

| Treatment | Days to physiological Maturity | Stem number per hill | Pant Height per plant (cm) | Total dry biomass yield (t/ha) |
|---|---|---|---|---|
| N fertilization treatment (kg N/ha) | | | | |
| 0 | 95.87$^{d}$ | 5.040$^{b}$ | 51.03$^{b}$ | 13.19$^{b}$ |
| 110 | 98.40$^{c}$ | 8.053$^{a}$ | 63.03$^{a}$ | 19.30$^{a}$ |
| 165 | 101.93$^{b}$ | 7.627$^{a}$ | 64.45$^{a}$ | 18.05$^{a}$ |
| 220 | 102.67$^{a}$ | 7.760$^{a}$ | 61.95$^{a}$ | 18.18$^{a}$ |
| Level of significance | ** | ** | ** | ** |
| Planting density m$^{-2}$ | | | | |
| 4.17 | 100.58$^{a}$ | 7.417$^{a}$ | 62.92$^{a}$ | 15.47$^{c}$ |
| 4.44 | 100.25$^{a}$ | 7.983$^{a}$ | 63.20$^{a}$ | 15.19$^{c}$ |
| 5.56 | 99.58$^{b}$ | 7.583$^{a}$ | 60.85$^{a}$ | 15.99$^{c}$ |
| 6.67 | 99.50$^{b}$ | 6.383$^{b}$ | 57.53$^{b}$ | 18.75$^{b}$ |
| 8.00 | 98.67$^{c}$ | 6.233$^{b}$ | 56.07$^{b}$ | 20.49$^{a}$ |
| Level of significance | ** | ** | ** | ** |
| CV (%) | 0.5 | 13.0 | 6.5 | 11.2 |

Means of the same main effect within a column followed by the same letter are not significantly different at 5% of probability level (LSD test); ** = Significant at 1 %.

### 3.3. Leaf area Index

The interaction effect of planting density and nitrogen fertilization significantly influenced leaf area index (Figure 1). The highest (5.897) leaf area index was recorded at the planting density of 6.67 plant m$^{-2}$ with nitrogen rate of 165 kg N/ ha and the lowest at 0 kg N/ha with low planting density of 4.17 (1.272) and 4.44 plant m$^{-2}$ (1.293) combinations.

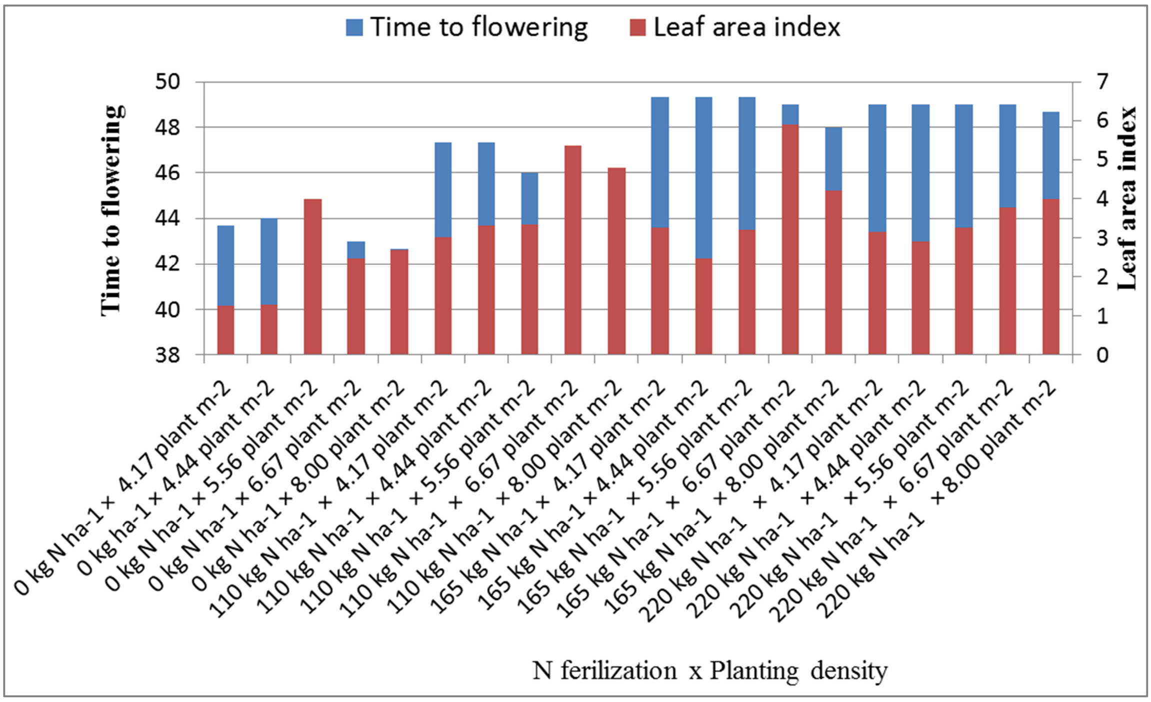


***Figure 1.*** *Time to flowering and leaf area index as influenced by interaction effect of nitrogen application and planting density.*

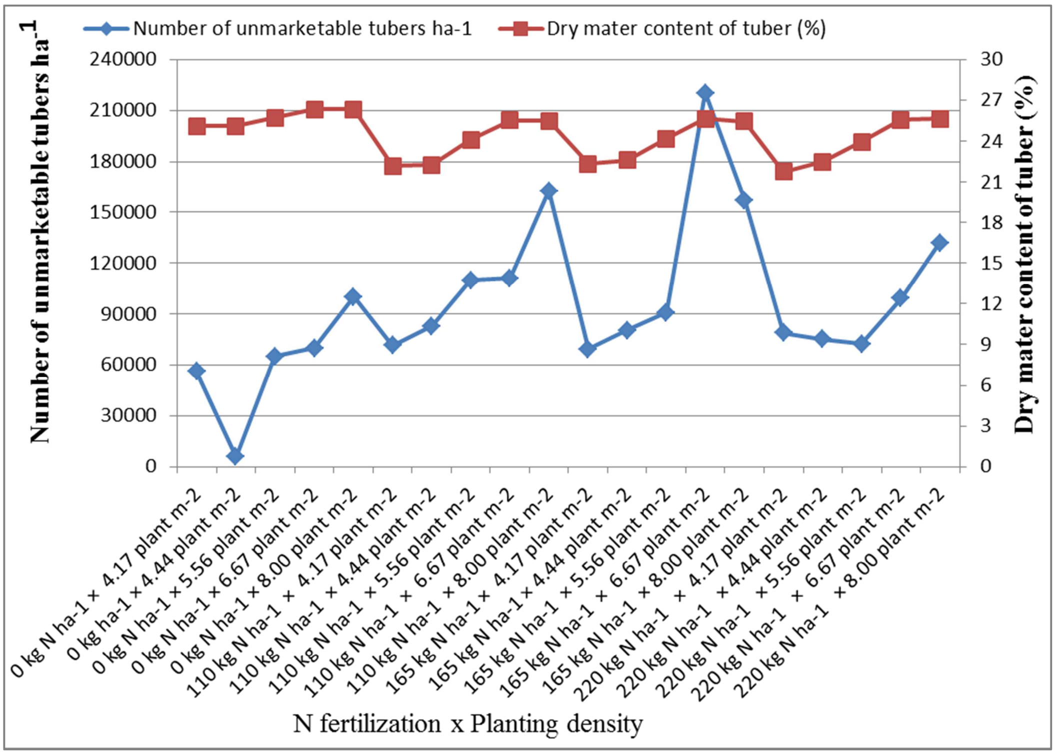


***Figure 2.*** *Number of unmarketable tubers per hectare and dry matter content of tuber (%) as influenced by interaction effect of nitrogen application and planting density.*

### *3.4. Total, Marketable and Unmarketable Tuber Numbers*

Nitrogen fertilization and planting density and its interaction effect significantly influenced total and marketable tuber number (Table 3) and unmarketable tuber number (Figure 2), respectively. However, planting density did not affect marketable tuber number. Application of nitrogen with the rate of 110 kg N/ha significantly increased total and marketable tuber number/ha by 141254 and 104137, respectively as compared to growing potatoes without application of nitrogen. The highest number of unmarketable tubers was produced in the treatment combination of the planting density of 6.67 plants $m^{-2}$ with 165 kg N/ha and the lowest were at 0 kg N/ha with 4.17 and 4.44 plants $m^{-2}$ combination. Increasing the planting density from 4.44 to 8.00 plants $m^{-2}$ significantly increased total tuber number/ha by 98221.

### 3.5. Total, Marketable and Unmarketable Tuber Yields

Nitrogen fertilization and planting density significantly influenced total, marketable and unmarketable tuber yield (Table 3). Application of nitrogen with the rate of 110 kg N/ha significantly increased both total and marketable tuber yield by 9 and 9.6 t/ha compared to without application of nitrogen. This shows that the optimum total and marketable fresh tuber yield was already attained at 110 kg N/ ha, and application beyond that level was supra-optimal and unnecessary. Yield of tuber per hectare was significantly and positively correlated with leaf area index (r =0.75**), total tuber number (r =0.85**), days to physiological maturity (r = 0.49**) and total dry biomass yield (r =0. 0.80**). The application of nitrogen rate of 110 kg N/ha resulted unmarketable tuber yield reduction by 0.7 t/ha. Similarly increasing planting density from 4.17 to 4.44 plants $m^{-2}$ did not change the total and marketable tuber yield. However, increasing the planting density from 4.44 to 6.67 plants $m^{-2}$ significantly increased total and marketable tuber yield by 5.21 and 4.67 t/ha, respectively. However, total and marketable tuber yields obtained in response to increasing the planting density from 6.67 to 8.00 plants $m^{-2}$ were in statistical parity. This result demonstrates that the optimum planting density for optimum total and marketable tuber yield was obtained at 6.67 plants $m^{-2}$. The highest unmarketable tuber yield was produced at the highest planting density of 8.00 plants $m^{-2}$, and exceeded the unmarketable tuber yield obtained at the lowest planting density of 4.17 plants $m^{-2}$ by 0.863 t/ha.

***Table 3.*** *Total and marketable tuber number, total, marketable and unmarketable tuber yield as influenced by the main effect of nitrogen application and planting density.*

| Treatment | Tuber number ($ha^{-1}$) | | Tuber yield (t/ha) | | |
|---|---|---|---|---|---|
| | Total | Marketable | Total | Marketable | Unmarketable |
| N fertilizer rates (kg N/ha) | | | | | |
| 0 | 389970$^{b}$ | 319412$^{b}$ | 26.60$^{b}$ | 24.30$^{b}$ | 2.303$^{a}$ |
| 110 | 531224$^{a}$ | 423549$^{a}$ | 35.50$^{a}$ | 33.90$^{a}$ | 1.603$^{b}$ |
| 165 | 536549$^{a}$ | 412750$^{a}$ | 34.77$^{a}$ | 33.17$^{a}$ | 1.600$^{b}$ |
| 220 | 505684$^{a}$ | 414071$^{a}$ | 34.95$^{a}$ | 33.39$^{a}$ | 1.568$^{b}$ |
| Level of significance | 31027.6 | 28668.3 | ** | ** | ** |
| Planting density $m^{-2}$ | | | | | |
| 4.17 | 448194$^{c}$ | 379167 | 30.34$^{c}$ | 28.91$^{c}$ | 1.422$^{d}$ |
| 4.44 | 446519$^{c}$ | 372444 | 30.45$^{c}$ | 29.02$^{c}$ | 1.431$^{d}$ |
| 5.56 | 494983$^{b}$ | 410357 | 32.98$^{b}$ | 31.25$^{b}$ | 1.734$^{c}$ |
| 6.67 | 519847$^{ba}$ | 394611 | 35.66$^{a}$ | 33.69$^{a}$ | 1.971$^{b}$ |
| 8.00 | 544740$^{a}$ | 405648 | 35.35$^{a}$ | 33.07$^{a}$ | 2.285$^{a}$ |
| Level of significance | ** | Ns | ** | ** | ** |
| CV (%) | 8.6 | 9.9 | 4.4 | 4.4 | 14.9 |

Means of the same main effect within a column followed by the same letter are not significantly different at 5% of probability level (LSD test); ns = non significant, ** = Significant at 1 %.

### 3.6. Dry Mater Content of Tuber (%)

The interaction effect of planting and nitrogen fertilization significantly influenced dry matter content of tuber (Figure 2). The highest tuber dry matter content was obtained at the treatment combination of 0 kg N/ha with high planting densities of 6.67 and 8.00 plants $m^{-2}$ and the lowest at 220 kg N/ha with 4.17 plants $m^{-2}$ combination.

### 3.7. Large, Medium and Small-Sized Tuber Yield (%)

Nitrogen fertilization and planting density significantly influenced large, medium and small-sized tuber yield (%) (Table 4) while planting density did not on medium sized tuber. Application of nitrogen with the rate of 110 kg N/ha significantly increased the proportion of large-sized tuber yield (%) by 22.76% where as the proportion of medium and small sized tuber yield (%) were decreased by 17.5 and 50.3%, respectively than without fertilization. Similarly increasing planting density from 4.17 to 4.44 and 5.56 plants $m^{-2}$ did not significantly affect the percentage of large-sized tubers produced. However, increasing the planting density from 5.56 to 6.67 plant $m^{-2}$ decreased the proportion of large-sized tubers produced by the potato crop by 14.06%. However, increasing planting density further from 6.67 to 8.00 plants $m^{-2}$ did not significantly change the proportion of large-sized tubers produced. Increasing the planting density from 4.17 to 4.44 plants $m^{-2}$ did not affect significantly the proportion of small-sized tubers produced. However, increasing the planting density from 4.44 to 6.67 plants $m^{-2}$ increased the percentage of small-sized tubers produced by 52.5%.

### 3.8. Harvest Index and Nitrogen Concentration in Leaf Tissue

Planting density significantly influenced harvest index while nitrogen fertilization did not. The highest harvest index was obtained at planting density of 4.17, and lowest at 8.00

plant m$^{-2}$. Nitrogen fertilization and planting density significantly influenced leaf tissue nitrogen concentration (Table 4). Increasing application of nitrogen from 0 to 110, 165 and 220 kg N/ha nitrogen concentration in the leaf tissue were increased by 1.02 %, 1.216% and 1.08%, respectively and reducing planting density from 8.00 to 4.17 plant m$^{-2}$ increased nitrogen concentration in leaf tissue from 3.87% to 4.49%.

***Table 4.*** *Large, medium and small-sized tuber yield (%), harvest index and nitrogen concentration in leaf as influenced by the main effect of nitrogen application and planting density.*

| Treatment | Large-sized tuber yield (%) | Medium-sized tuber yield (%) | Small- sized tuber yield (%) | Harvest index | Nitrogen concentration in leaf (%) |
|---|---|---|---|---|---|
| N fertilizer rates (kg N /ha) | | | | | |
| 0 | 48.07$^{b}$ | 34.71$^{a}$ | 17.21$^{a}$ | 0.7634 | 3.349$^{c}$ |
| 110 | 59.01$^{a}$ | 29.54$^{b}$ | 11.45$^{c}$ | 0.7860 | 4.369$^{b}$ |
| 165 | 58.03$^{a}$ | 30.35$^{b}$ | 11.62$^{c}$ | 0.7708 | 4.565$^{a}$ |
| 220 | 58.31$^{a}$ | 28.86$^{b}$ | 12.83$^{b}$ | 0.7753 | 4.429$^{ba}$ |
| Level of significance | ** | ** | ** | Ns | ** |
| Planting density m$^{-2}$ | | | | | |
| 4.17 | 58.76$^{a}$ | 30.32 | 10.92$^{c}$ | 0.7904$^{a}$ | 4.492$^{a}$ |
| 4.44 | 58.83$^{a}$ | 30.59 | 10.59$^{c}$ | 0.7755$^{ab}$ | 4.337$^{a}$ |
| 5.56 | 58.96$^{a}$ | 29.23 | 11.81$^{b}$ | 0.7721$^{ab}$ | 4.138$^{b}$ |
| 6.67 | 51.69$^{b}$ | 32.16 | 16.15$^{a}$ | 0.7696$^{b}$ | 4.052$^{bc}$ |
| 8.00 | 51.04$^{b}$ | 32.05 | 16.92$^{a}$ | 0.7620$^{b}$ | 3.870$^{c}$ |
| Level of significance | ** | Ns | ** | * | ** |
| CV | 5.2 | 9.6 | 7.6 | 2.9 | 5.6 |

Means of the same main effect within a column followed by the same letter are not significantly different at 5% of probability level (LSD test); ns = non significant, * = Significant at 5%, ** = Significant at 1%.

# 4. Discussion

The observed increment of total and marketable tuber yield in this study might be associated with of N fertilization ensures maintenance of photosynthetically active leaves for longer duration and formation of new leaves than no N supply as suggested by [23]. In agreement with the present finding, a significant increment in tuber yield in response to N application was reported by various authors [9, 20, 21, 35]. In the current study, N application beyond 110 kg/ha did not bring a significant yield advantage. This may be attributable to the fact that in such conditions, vegetative growth of the aerial parts can be increased and hence, prevented transferring of photosynthetic matters into the storage parts. Unmarketable tuber yield reduction due to N fertilization may be associated with the increment of both marketable and total tuber yield and also due to the increment of the proportion of large tuber yield percentage.

Increased total and marketable tuber yields obtained in this study, in response to higher plant population may be attributed with enhanced leaf area index and trapping of optimal radiation for production of photoassimilate. This result agrees with that of [9] and [10] who reported that increasing planting density of potato resulted in higher tuber yields due to more tubers being harvested per unit area of land. Also [11] who reported that closer spacing of 50 cm x 25 cm and 60 cm x 25 cm led to the production of higher marketable tuber yield than the wider spacing of 80 cm x 30 cm and 75 cm x 30 cm. The higher amounts of unmarketable tuber yield at higher planting density could be due to the fact that at the narrower spacing there is stiff inter-plant competition for growth factors, which result in the production of more numbers of undersized tubers. Consistent with the results of this study, [11] reported that closer spacing resulted in significantly higher unmarketable tuber yields than wider one.

The results of this study indicate that nitrogen fertilization and low planting density delayed flowering and prolonged the time required to reach physiological maturity. This result is also in conformity with the findings of [18, 19, 20, 21] who observed that high N fertilizer increased the leaf area which increases the amount of solar radiation intercepted and consequently, increases days to flowering, days to physiological maturity, plant height, and dry matter production of different plant parts. [22] reported that low planting density stimulates early tuber growth and earlier maturity in potato than high planting density treatments.

Stem number increase in response to N fertilization might associated with the influence of N on gibberellic acid biosynthesis which has direct influence on sprouting of tuber eye and lateral stem growth and development for potatoes. Decreasing of stem number in response to higher planting density might be due to stiffer competition for growths of lateral stems emerging from ground. In line with this study, [24] reported that widest spacing and high N fertilization results maximum number of stem per hill than closer spacing and unfertilized treatment.

Plant height increase in response to N fertilization and low planting density might be ascribed to the fact that nitrogen fertilizer stimulates vegetative growth and less competition among plants for growth factors than high densely populated ones. In line with the current investigation, [24] reported that N fertilization and wider spacing resulted in growth of taller plant than unfertilized and closer spacing.

The increase in dry biomass yield response to N fertilization indicates that the nutrient exerts a significant influence on biomass production and partitioning to the different parts. In line with this investigation, [10, 26] reported that with increasing plant density and nitrogen fertilization, plant dry matter accumulation in the canopy was increased per unit area in potato probably due to increase in new leaf formation and extended activity of older leaves and due to more number of plants exist at higher planting density.

Consistent with the results of this study on leaf area index, [28] reported that a high nitrogen supply is important for rapid leaf expansion and for obtaining a LAI between four and six, a value considered necessary for high tuber yields of potato. Significant increase in LAI with the increase in planting density from 4.17 up to 6.67 across the increasing N rate may be attributed to the increase in leaf area coverage of the soil surface until sufficient light became trapped for optimally enhanced production of photoassimilate. On the other hand, the observed reduction in LAI as planting density decreased from 6.67 with 110 and 165 kg N/ha to the maximum highest planting density (8.00 plants $m^{-2}$) with the same rate of N may be attributed to mutual shading as suggested by [29].

The observed tuber number increase in response to N could be attributed to an increase in stolon number through its effect on Gibberellins biosynthesis in the potato plant [32]. In agreement with the present finding, a significant increment in tuber number in response to N application was reported by various authors [9, 20, 35]. In contrast, however, there are reports indicating absence of strong relationship between rates of N application and tuber number in potato [33]. Tuber number increases with increase in planting density may be attributed to the increased number of main stems per unit area, each of which behave as an independent plant and produce larger numbers of tubers per unit area as suggested by [9, 15, 34].

Nitrogen fertilization and low planting density in general significantly reduced tuber dray matter content which might be associated with the influence of N on gibberellins biosynthesis activities which have direct influence on plant growth and dry matter accumulation. High levels of endogenous GA delay or inhibit tuberization [37] and impede the accumulation of starch and other tuber specific proteins [38]. In agreement to this study, [39] reported that increased N rates lowered the percent dry matter content in tubers. Tubers from high planting densities had higher dry matter percentage than tubers from low planting densities [40].

Nitrogen fertilization significantly increases large-sized tuber percentage whereas it decreases the medium and small tuber size categories. Consistent with the results of this study, [41] also demonstrated that nitrogen increased the quantity of larger-sized tubers. In contrast to the result of the current study, [42] observed that yield of tubers in the medium grades increased with increase in the applied nitrogen. This demonstrates that the largest proportion of small-sized tuber yield was obtained at nil application of nitrogen, followed by the highest (supra-optimal) rate of application of the nutrient.

Denser planting increased the production of larger yield of small-sized tubers than yields of large and medium-sized tubers possibly due to stiffer competition among the plants for growth factors. The result of the present result agreed with the findings of [22, 43] who reported that to produce smaller tubers, higher plant densities are needed than for the production of big tubers due to increased interplant competition in closer spacing.

In line with the current study in harvest index, [20] reported a non-significant difference in harvest index of potato due to nitrogen application. The yield increment in response to nitrogen application might be cultivars may possibly able to produce high carbon assimilates and maintain active growth later in the season there by giving high yield in spite of harvest index value and also might be due to proportional increment of total tuber and biomass yields. Planting density significantly influenced harvest index and lowest was observed at dense planting. Similar to this result, [9, 10] reported that as planting density deceased harvest index increased and density of 5.5 plant $m^{-2}$ resulted in the highest and densities of 7.5 and 11 plant $m^{-2}$ jointly produced lowest harvest index.

The observed leaf tissue nitrogen concentration increment as a result of increased nitrogen fertilization and decreasing planting density may be associated lower inter-plant competition for the uptake. The critical concentration of a nutrient in plant tissues is the concentration of the nutrient in a particular plant part usually a mature leaf sampled at a given growth stage (usually just before flowering or tuber initiation for potato) below which plant growth and yield are suppressed by 10 to 20 % [45]. Sufficient nutrient concentration in the leaf tissue is the one that leads to optimum yields. Sufficient concentrations of nitrogen in the dry matter of potato leaf blade sampled just before tuber initiation ranges between 5.0 and 6.5% [29]. The results of this experiment showed that plants grown in the treatments with 110 kg N/ha and above had approximately N concentration that approximated the abovementioned range. This means that plants attained at least 20% of their potential yield at 110 kg N/ha and above. The result of the present study is consistent with the findings of [46] that found that high N rates of 112-168 kg/ha maximized potato plant tissue N concentration.

In general, this study indicates that yield and yield components of potato variety Bubu can be improved/ manipulated with the application of N and proper use of planting density per unit area in the study area. The results have revealed that the current blanket recommendation rate of nitrogen for potato production (110 kg N/ha) is sufficient for optimum tuber yield of the crop variety, but the current research recommended spacing of 75 cm between ridges and 30 cm between plants (4.44 plant $m^{-2}$) is obsolete and should be revised for enhancing the yield of the crop. It could, thus be concluded that application of 110 kg N/ha and using the planting density of 6.67 plant $m^{-2}$ (60 cm x 25 cm) leads to optimum production of fresh tuber yields of the new variety in Haramaya district in eastern Ethiopia under rain-fed condition and on soils with similar physico-chemical characteristics of the experimental soil.

## Acknowledgments

The Authors acknowledge Haramaya University and Dilla University for the assistance during research period.

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