Response of Improved and Local Potato (Solanum tuberosum L.) Cultivars to Nitrogen Fertilizer (Study in Haramaya, Eastern Ethiopia)

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Abstract: A field experiment was conducted on a research field of Haramaya University during the 2012 main cropping season to determine the relative agronomic and tuber quality performances of potato varieties in response to nitrogen (N) application. The treatments consisted of four N rates (0, 55, 110 and 165 kg N ha⁻¹), and two improved (Bubu and Zemen) and three local (Batte, Daddafa and Jarso) varieties. The experiment was laid out as RCBD with a factorial arrangement and replicated three times. Plot size was 4.5 m x 3.6 m (16.2 m²) accommodating six rows of plants at the spacing of 75 cm between ridges and 30 cm between plants. Net plot area was 3 m x 3 m (9 m²). The results revealed that increasing the rate of N from 0 to 55 kg N ha⁻¹ significantly increased most of the measured parameters. However, increasing N beyond this level did not affect most of the parameters. Variety also significantly influenced many parameters. The interaction effects of N and variety were not significant on all parameters. Positively and highly significant associations were found for a number of the measured parameters. In conclusion, the results revealed that the optimum performances of all varieties occurred at the N rate of 55 kg N ha⁻¹. In addition, improved variety Bubu, followed by Zemen, was superior to the other varieties in terms of tuber productivity.

Keywords: Varieties, Yield, Nitrogen Level & Growth.

1. INTRODUCTION

Research findings have indicated that potato could be one of the most important crops to be introduced in the area where the population experiences recurrent malnutrition due to heavy dependence
on cereal crops and poor crop productivity provided that appropriate agronomic practices are applied (Zelalem et al., 2009). Potato is regarded as a high-potential food-security crop because of its ability to provide a high yield of high-quality product per unit input with a shorter crop cycle (mostly < 120 days) than major cereal crops like maize (Hirpa et al., 2010). It has been stated by John J. Burke (2017) that at least six major potato roles can be assigned to the potato tuber. These include hunger-relieving crop, food (either fresh, processed), animal food, propagule (from which to produce the next crop), feed stock in industry for starch and alcohol, an item of commerce, and a resource of biodiversity. He also detailed that potatoes are grown and eaten in more countries than any other crop; they are grown in all the continents except Antarctica. In the global economy they are the fourth most important crop in total production and the fourth largest contributor to human caloric consumption, after the three cereals, rice, wheat and maize.

About more than 1.13 million farmers are potato growers in Ethiopia; and this crop added 29.84% of the area to the total root crop, and contributed 21.24% to the total root crop production (CSA, 2017/2018). Hirpa et al. (2010) indicated that potato is grown in four major areas in Ethiopia. These areas include the central, the eastern, the north-western and the southern regions (mainly located in the Southern Nations’, Nationalities’ and Peoples’ Regional State and partly in the Oromiya region). In this study they also stated that these areas together cover approximately 83% of the potato farmers.

Mulatu et al. (2008) pointed out that potato is the second most advantageous crop next to khat (Chata edulis) in supporting farmers’ welfare with 759% increase in income over sorghum (Sorghum bicolor (L.) Moench) which is the main staple cereal crop grown in Hararghe. Compared to the other areas of potato production, this area is characterized by export market oriented production particularly to Djibouti and Somalia (Hirpa et al., 2010). Similarly, Mulatu et al. (2005) stated that the development of potato culture in Hararghe, like other vegetables, is due to the presence of an export and cross-border market outlet to Djibouti and Somalia; it is also due to the presence of a domestic market in the major urban settlements of Hararghe, including Dire Dawa, Harar, Jigjiga, Asebe Teferi and several other towns. Most farmers grow local potato varieties namely, Batte, Jarso, Samune, Daddafa, Mashena dima, etc. throughout the year using irrigation and rainfalls (Anonymous, 2011). However, Mulatu et al. (2005) reported that some farmers targeted by research and extension as well as those involved in nongovernmental organization (NGO) seed programmes have access to improved varieties released by Haramaya University. Despite the use of local varieties, the productivity of potato in this area is equivalent to the productivity in the central area; this might be due to good farm management practices triggered by farmers’ market orientation.

The optimal response to N fertilizer application differs by cultivar (Kleinkopf et al., 1981; Johnson et al., 1995) and soil type. Similarly, the other finding indicated that nutrient elements efficiency is the relative yield of one genotype in a poor soil as compared to its yield in a favourite nutritional condition. Maximum efficiency of nutrient element use is obtained while its concentration is near to critical level, because without excessive amounts of element in plant tissues, the highest yield is gained. In view of that, the release of new potato cultivars requires additional revision to develop best management recommendations for N fertilization of potato and for optimization of tuber yield and quality (Saeidi et al., 2009).

Nitrogen is the mineral nutrient most commonly deficient in agricultural soils. As a result, in developed countries, farmers apply relatively high rates of N fertilizers. Soil-plant system inefficiencies prevent complete utilization of the N, leaving residual N in the soil, which is a waste of natural resources and cause for environmental concern (Hopkins et al., 2008). Worldwide, crops do not directly utilize about half of the applied N and the overall N use efficiency has declined with increasing N fertilizer use (Dobermann, 2005). On the other hand, as compared to the developed countries, in developing countries such as Ethiopia, Kenya and Uganda, the amounts of fertilizers applied to the potato crop are very low. For example, in a study conducted by Gildemacher et al. (2009), the amounts of FYM, N, and phosphorus applied to potato crop were estimated to be only 4 t ha\(^{-1}\), 43 kg N ha\(^{-1}\), and 101 kg P ha\(^{-1}\) in Kenya, 3 t ha\(^{-1}\), 30.6 kg N ha\(^{-1}\), and 33.4 kg P ha\(^{-1}\) in Ethiopia, and 2.2 t ha\(^{-1}\), 37.6 kg N ha\(^{-1}\), and 46.9 kg P ha\(^{-1}\) in Uganda, respectively.
A blanket recommendation of 110 kg N ha\(^{-1}\) (165 kg urea ha\(^{-1}\)) and 90 kg P\(_2\)O\(_5\) ha\(^{-1}\) (195 kg DAP ha\(^{-1}\)) has been promoted in Ethiopia for a long time, without any formulation of the amount of farmyard manure to be used for production of the crop (Institute of Agricultural Research, 2000). An experiment conducted at Haramaya on clay soil indicated that application of 87 kg N ha\(^{-1}\) and 46 kg P\(_2\)O\(_5\) ha\(^{-1}\) is needed for optimum potato production (Getu, 1998). Hence, fertilizer requirement varies across locations due to reasons such as difference in soil types, nutrient availability of the soil, economic factors of the area, moisture supply and variety (Zelalem et al., 2009). Although many potato varieties have been released in the country, there is lack of clear information regarding N fertilizer requirement, management of the individual cultivar for optimum tuber yield. This necessitates a continuous research towards the establishment of appropriate fertilizer rates for the newly released varieties for specific location. According to Atkinson et al. (2003), newer potato cultivars are becoming more widely grown because of improved characteristics such as earliness, yield, quality, and storability, and increased resistance to insects, pathogens, and other environmental stresses. Therefore, this experiment was carried out with the objective of evaluating the response of improved and local potato varieties to different rates of N fertilizer at Haramaya area.

2. MATERIALS AND METHODS

2.1 Description of the study site

The experiment was conducted during the 2012 main growing season under rain-fed condition at research field on the main campus of Haramaya University. Haramaya is located at 9°26’N latitude, 42°30’E longitude and at an altitude of 1980 meters above sea level. The site received mean annual rainfall of 780 mm, with the mean minimum and maximum temperatures of 8.25°C and 24.4°C, respectively (Mohammed et al. 2013). The soil of the experimental site is a well drained deep alluvial with a sub-soil stratified with loam and sandy loam (Tamire, 1973). Analysis of the chemical and physical properties of the soil indicated that it has organic carbon content of 1.15%, total N content of 0.11%, available phosphorus content of 18.2 mg kg\(^{-1}\) soil, potassium content of 0.65 cmol kg\(^{-1}\) soil (255 mg K Kg\(^{-1}\) soil), pH of 8.0, and percent sand, silt, and clay contents of 63, 20, and 17, respectively (Simrat, 2010). These results indicate that the soil is low in organic carbon and total N, high in exchangeable potassium, and medium in available phosphate (Landon, 1991; Ryan et al, 2001).

2.2 Description of experimental material

Two improved potato varieties (Zemen and Bubu) that were released by Haramaya University and three local varieties (Daddafa, Jarso and Batte) were used. Bubu was released in 2010 (Tekalign, 2011). It is recommended for the highlands of eastern and western Hararghe zones with an altitude ranging from 1650-2330 meter above sea level. Zemen was released in 2001 (Ethiopian Agricultural Research Organization, 2004). It is adapted to east and west Hararghe with an altitude of 1700-2000 meter above sea level that receives an annual rainfall of 700-800 mm.

2.3 Field experiment set up

The experiment was laid out in randomized complete block design (RCBD) in a factorial arrangement with four treatments and three replications. Treatments were 0, 55, 110 and 165 kg N ha\(^{-1}\), assigned to each plot randomly. The land was cultivated by a tractor and pulverized by human labour. The number of plots was 60, and the size of each plot was 4.5 x 3.6 m wide.

2.4 Soil sampling and analysis

Soil samples were taken randomly in a W-shaped pattern of the entire experimental field before planting. Five samples were taken using an augur from each arm of the W-shaped lines to the depth of about 0-30 cm from the top soil layer, and combined to a composite sample. This composite was air-dried, pounded and sieved through a 2 mm sieve. From this mixture, a sample weighing 1 kg was prepared, and finally analyzed. Soil pH was determined from the filtered suspension of 1:2.5 soils to water ratio using a
glass electrode attached to a digital pH meter (Page, 1982). Soil texture was determined by modified Bouyoucos hydrometer method as described by Singh (1980). The sample was analyzed for total N, available phosphorus, potassium, and organic carbon contents. Organic carbon content of the soil was determined based on oxidation of organic carbon with acid dichromate medium following the Walkley and Black method as described by Dewis and Freitas (1970). Total N was determined using Kjeldhal method (Jackson, 1975). Available phosphorus was determined by extraction with 0.5 M NaHCO₃ according to the methods of Olsen et al. (1954), and potassium was determined with a flame photometer after extracting exchangeable K from the soil with 0.5 N Ammonium-acetate at pH 7 (Hesse, 1971).

2.5 Planting and fertilizer application

Medium-sized and well sprouted potato tubers were planted on the ridges at a spacing of 30 cm between plants and 75 cm between rows. The tubers were planted at a depth of 10 cm and covered with soil (Ngungi, 1982). One row consisted of 12 plants, and one plot consisted of 6 rows. The spacing between plots and blocks were 1 m and 1.5 m, respectively. Net plot area was 3 m x 3 m (9 m²). The plants were fertilized equally with Urea (46% N) as source of Nitrogen and triple superphosphate (46% P₂O₅) as source of phosphorus for all the plots. Nitrogen (110 kg N ha⁻¹) in the form urea, was applied at the specified rates in three splits (one fourth at plant emergence; half of it two weeks after emergence; and one fourth at the initiation of tubers/start of flowering) as topdressing. However, triple superphosphate (46% P₂O₅) was applied as basal fertilizer at the rate of 90 kg P₂O₅ ha⁻¹ at planting.

Other cultural activities such as weed control, earthing-up and fungicide application were equally applied for the whole experimental area. Controlling of weeds was performed by hoeing and by hand pulling/uprooting. Earthing-up was done to prevent exposure of tubers to direct sunlight, for promoting tuber bulking and for easily harvesting. Fungicide, Ridomil MZ 65% WP at a rate of 1.5 kg/ha which is diluted at a rate of 40 g per 20 litre water, was sprayed once a week for the control of potato late blight (Phytophthora infestans). It was sprayed two times during wet season when the plants were at vegetative growing stage. Fungicide, Ridomil MZ 65% WP (1.5 kg ha⁻¹ which is diluted at a rate of 40 g per 20 litre water) was sprayed two times once a week to control potato late blight (Phytophthora infestans).

2.6 Data collection

All data for growth parameters were taken up on randomly selecting 5 plants from central rows in each plot. Days to flowering was recorded at about 50 percent flowering of plant population in each plot. Days to maturity was recorded when 50 percent of the plants of different treatments were ready for harvest as indicated by senescence of the haulms. Plant height was determined by measuring the height from the base to the apex of plants. To determine leaf area, plants were selected at 50 percent flowering; then leaf area index was estimated from individual leaf length via the formula developed by Firman and Allen (1989).

\[
\log_{10} (\text{leaf area in cm}^2) = 2.06 \times \log_{10} (\text{leaf length in cm}) - 0.458.
\]

Leaf area index was obtained by dividing the value of leaf area by the area of land occupied by the plant using the formula: Leaf area index (LAI) = LAₘ x N /A. Where: LAₘ = mean leaf area; A = area (cm²) occupied by one plant in the cropping area; N = number of leaves on the plant

Number of main stems per hill was taken (when plants about to initiate flower bud) by counting the number of stems emerging from each tuber (per hill) from below the soil. The weight of fresh aboveground biomass was measured just at flower initiation before tuber set. Then, oven-dried at about 65°C until constant weight was obtained, and dry weight was determined. Underground fresh and dry biomass was determined just before senescence by weighing both fresh and dry weight (oven-drying similar to aboveground biomass). Finally, total fresh and dry biomass was calculated from the sum of shoot and underground biomasses.

 Marketable tuber yield was calculated by taking the average weight of tubers (at harvest) from plants in the central rows of each plot. To do this, stand count per plot was also taken to enable us calculating yields per hectare. Tubers free from diseases, insect pests, and greater than or equal to 25 g in weight were
considered as marketable, while diseased and small-sized (< 25 g) tubers were considered as unmarketable. Unmarketable tuber yield was recorded at the same time. Afterwards, the total tuber yield per plot was recorded by adding up the weights of marketable and unmarketable tubers. Similarly, both marketable tuber number and unmarketable tuber number were taken at harvest by counting, and then total tuber number was obtained by adding up the number of marketable and unmarketable tubers. At the same time, mean tuber weight was determined at harvest by dividing the weight of all tubers by the total number of tubers. Finally, the proportional weight of tubers sizes were categorized into small (25-39 g); medium (40-75 g), and large (> 75 g) according to Lung'aho et al. (2007). Then each of these categories was counted, and the proportion of the weight of each tuber category was expressed as a percentage. Harvest index was determined from 5 randomly taken plants in the central rows of each plot just at physiological maturity, washed with water, and sliced into thin (about 3 mm) pieces. The sliced tubers were pre-dried in the sun by thinly spreading in an open air to dissipate excess moisture, and the partially dried tubers were wrapped up in paper and dried overnight in an oven at about 65°C until constant weight was obtained. Haulms, leaves, and all other plant parts were also dried in the same way. Then, harvest index was computed by dividing the dry weight of the tubers by the dry weight of the total biomass. In other ways it is the ratio of economic yield to biological yield which characterizes the movement of dry matter to the economic part of the plant. Tubers specific gravity was determined by the weight in air/weight in water method. Five kg tubers of all shapes and sizes were randomly taken from each plot. The selected tubers were washed with water, first weighed in air and re-weighed by suspending in water. Finally, specific gravity was calculated via the formula (Kleinkopf et al., 1987):

\[
\text{Specific gravity} = \frac{\text{Weight in air}}{\text{(Weight in air} - \text{Weight in water)}}
\]

Tuber dry matter content was determined based on five medium-sized fresh tubers which were randomly taken at harvest from each plot. The tubers were weighed, sliced and dried overnight in an oven at about 65°C until a constant weight was obtained. Finally, the dry matter percent was calculated according to Williams and Woodbury (1968) as follows.

\[
\text{Dry matter (\%) = } \frac{\text{Weight of sample after drying (g)}}{\text{Initial weight of sample (g)}} \times 100\%
\]

Plant tissue analysis was done by taking leaf samples from plants just before the start of tuber initiation (when plants about to initiate flower bud). Sixty fully grown mature leaves with petioles were randomly taken from the fourth nodal insertion from top of the plant (middle of stem) from each plot. The leaf samples were dried at about 65°C to constant weight, ground, and analyzed for total N by the modified Kjeldhal method as described by Jackson (1975).

2.7 Data analysis
Data were subjected to analysis of variance (ANOVA) using the Generalized Linear Model of the SAS statistical package (SAS, 2002) version 9.1. All significant pairs of treatment means were compared using Least Significant Difference (LSD) test at 5% level of significance. Correlation analysis was done to detect linear relationship between parameters where needed.

3. RESULTS AND DISCUSSION
3.1 Effects of N and Variety on Growth Parameters
Effect of N and its interaction effect with each variety did not significantly influence days to flowering and days to physiological maturity. However, the main effects of variety highly significantly influenced days to flowering and days to physiological maturity. The results revealed that prolonged days
to flowering (about 51 days) and days to maturity (about 109 days) were observed for Batte (local variety). However, earlier dates of flowering and maturity were observed for the improved varieties (Bubu and Zemen) as well as the local varieties Daddafa and Jarso compared to the local variety Batte (Table 1). The observed differences in days to flowering and days to physiological maturity of these cultivars may be due to their inherent genetic characteristics. This difference could be due to certain factors (Shunka et al., 2016), some of which genetic, agro-ecological variation, soil fertility status, etc. A positive and highly significant association between days to flowering and days to physiological maturity was observed. In line with this study, Birhuman and Kang (1993) reported a medium association between days to flowering and days to physiological maturity.

Plant height as well as leaf area index were significantly and highly significantly affected respectively, by the main effects of N and variety. However, there was no significant effect regarding the interaction of the two factors on the above parameters. As shown in Table 1 increasing the rate of N application from 0 to 55 kg ha$^{-1}$ increased plant height by 15% and leaf area index by 29%. However, increasing the rate of N supply beyond this level did not change the magnitude of both parameters. On the contrary, Anabausi et al. (1997) reported that application of N increment (0, 125, 250, or 350 kg N ha$^{-1}$) on potato resulted in a significantly increase in plant height. Also, Jatav et al. (2017) stating that application of N showed significant effect on all the growth parameters up to 150 kg ha$^{-1}$. Bubu and Daddafa produced significantly taller plants than the other three varieties. Batte, Bubu, and Daddafa had significantly higher leaf area index than Jarso and zemen. Kleinkopf et al. (1981) and Dwelle et al. (1981) reported that a high N supply is important for rapid leaf expansion and for obtaining a LAI between 4 and 6, a value considered necessary for high tuber yields of potato. However, in this study leaf area index of 4.00 or above was attained by neither of the varieties. Consistent with this proposition, Marschner (1995) stated that, as a rule, the crop yield increases until an optimal value in the range of 3-6 is reached, the exact value depending on plant species, light intensity, leaf shape, leaf angle and other factors. The author further explains that, at a high LAI, mutual shading usually becomes the main limiting factor, and when the water supply is limited, however, drought stress and corresponding negative effects, particularly at the sink sites, can decrease the optimal LAI to values far below those resulting from mutual shading. Batte, Bubu and Daddafa had significantly higher leaf area index than Jarso and Zemen. In this study, plant height positively and highly significantly correlated with leaf area index. Consequently, increase in these parameters may result in increased yield (Tables 1 & 3). This reveals that plants manufacture their food on the canopy and later be translocated to the other parts of the plant to be utilized or stored. According to Lalonde et al. (2004), Sugars and amino acids are generated in plants by assimilation from inorganic forms; and these assimilated forms cross multiple membranes on their way from production sites to storage or use locations. Hence, both the above parameters contributed to the yield increment.

The effect of N as well as the interaction effect of variety with N supply did not significantly affect the number of main stems produced per hill which is contrary to Kolodziejczyk (2014). However, highly significant differences were observed among the varieties. Related to the present study, Assefa (2005) reported that the absence of N effect could be due to the case that the trait responsible for stem number was not influenced much by mineral nutrition, as the stem number is the indication of storage condition, physiological age of the seed variety and tuber size. The highest number of main stems per hill was achieved by Bubu (improved variety) whereas the lowest was attained by Jarso (local variety) as in Table 1. Thus, number of main stem of Bubu exceeded that of Jarso by about 100%. Consistent with the results of Morena et al. (1994), the number of stems per hill was influenced by variety. Association of stem number with marketable tuber yield and total tuber yield was positive and highly significant. Corroborating the result of this study, Allen (1978) stated that an increase in stem number per hill resulted in increased total and graded tuber yields. On the other hand, Yibekal (1998) reported that there was weak association between stem number and tuber yield. Moreover, Goodwin et al. (1969) reported absence of relationships between yield and the number of main stems for the same above ground density; which implies that tubers with many main stems and those with single/or few main stems have produced similar yields.
Table 1. The main effects of N and variety on days to flowering and physiological maturity, plant height (cm), leaf area index, and number of main stems per hill.

<table>
<thead>
<tr>
<th>Treatment( kg ha⁻¹)</th>
<th>days to flowering</th>
<th>days to physiological maturity</th>
<th>plant height</th>
<th>leaf area index</th>
<th>number of main stems per hill</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>48.67</td>
<td>106.67</td>
<td>54.80ᵇ</td>
<td>2.17ᵇ</td>
<td>5.85</td>
</tr>
<tr>
<td>55</td>
<td>46.53</td>
<td>104.53</td>
<td>62.92ᵃ</td>
<td>2.79ᵃ</td>
<td>6.63</td>
</tr>
<tr>
<td>110</td>
<td>46.80</td>
<td>104.80</td>
<td>60.99ᵇ</td>
<td>2.89ᵇ</td>
<td>6.04</td>
</tr>
<tr>
<td>165</td>
<td>46.27</td>
<td>104.27</td>
<td>61.52ᵃ</td>
<td>2.97ᵃ</td>
<td>6.35</td>
</tr>
</tbody>
</table>

Significance Level ns ns * * ns
LSD (5%) -- -- 5.51 0.57 --

Means within a column followed by the same letter are not significantly different at 5% level of significance; ns = non significant; * = significant at 5%; ** = significant at 1%; *** = significant at 0.1% probability levels.

Fresh biomass was not significantly affected by the effect of N. Similarly, the interaction effect of N and variety did not significantly affect all of the components of the shoot and underground biomass. But, shoot dry biomass was significantly affected by the main effect of N while the rest of all components of the biomass were highly significantly affected by the main effects of N and variety. In agreement with this result, Assefa (2005) revealed that increasing N application from 0 to 55 kg ha⁻¹ increased underground fresh and dry biomass yield, total fresh biomass, and shoot dry biomass. However, increasing the N supply beyond this level did not influence any of the biomass components produced by the potato crop. Besides, Millard and Marshall (1986) and Saluzzo et al. (1999) reported that N fertilization increased dry matter accumulation in canopy, underground biomass, and total dry biomass, respectively, from 656.7 to 880.0 g/hill, 919 to 1226 g/hill, 51.89 to 65.11 g/hill, 164.1 to 218.6 g/hill, 216.0 to 283.6 g/hill. In line with this result, the finding of Blumenthal et al. (2008) showed that N is often the most limiting factor in crop production; hence, application of N fertilizer results in higher biomass yields and protein yield and concentration in plant tissues. In addition, Barakat et al. (1991) noticed that potato shoots fresh weight was increased with each N dose increment. The highest shoot fresh biomass yield was produced by Bubu and Daddafa, followed by Batte and Zemen while the lowest was produced by Jarso. Thus, the shoot fresh biomass produced by the improved variety Bubu exceeded that of Jarso, Batte and Zemen, by 122, 50, and 43%, in the order listed here. Similarly, the highest underground fresh biomass yield was produced by Bubu, followed by Daddafa and Zemen. The lowest underground fresh biomass yield was produced by Batte and Jarso. Thus, Bubu produced 59, 43, and 42% more underground fresh biomass than Jarso, Zemen, and Batte, respectively. Bubu and Daddafa produced the highest total fresh biomass yield, followed by Zemen and Batte. However, Jarso produced the lowest total fresh biomass yield. Total fresh biomass yield produced by Bubu exceeded that produced by Jarso, Batte, and Zemen by 73, 44, and 25%, respectively (Table 2). However, in terms of dry biomass production, Bubu exceeded all varieties. Thus,
the shoot dry matter produced by Bubu was the highest, followed by that produced by Daddafa and Batte. Jarso and Zemen had the lowest shoot dry biomass production. The shoot dry matter produced by Bubu exceeded that produced by Jarso, Zemen, Batte, and Daddafa by 131, 79, 42, and 26%, in the order listed here. Similarly, the underground dry biomass yield produced by Bubu was superior to the underground dry biomass yields produced by all other varieties, and its underground dry biomass yield exceeded the underground dry biomass yields produced by Jarso, Batte, Daddafa, and Zemen by 127, 67, 53, 40%, in the order listed here. The varieties also differed significantly in total dry biomass yield produced per hill. The highest total dry biomass yield was produced by Bubu, closely followed by Batte, Daddafa and Zemen. The lowest total dry biomass yield was produced by the local variety Jarso. Thus, total dry biomass yield produced by Bubu exceeded those produced by Jarso, Batte, Zemen, Daddafa by 128, 61, 48, 46%, respectively (Table 2).

Table 2. The main effects of N and variety on shoot and underground fresh biomass (g/hill), and shoot and underground dry biomass (g/hill).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Shoot fresh biomass</th>
<th>Underground fresh biomass</th>
<th>Total fresh biomass</th>
<th>Shoot dry biomass</th>
<th>Underground dry biomass</th>
<th>Total dry biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen( kg ha⁻¹)</td>
<td>0</td>
<td>262</td>
<td>656.7a</td>
<td>919b</td>
<td>51.9b</td>
<td>164.1b</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td>315</td>
<td>848.0a</td>
<td>1163a</td>
<td>60.9b</td>
<td>215.2a</td>
</tr>
<tr>
<td></td>
<td>110</td>
<td>319</td>
<td>928.7a</td>
<td>1248a</td>
<td>65.2a</td>
<td>236.0a</td>
</tr>
<tr>
<td></td>
<td>165</td>
<td>346</td>
<td>880.0a</td>
<td>1226a</td>
<td>65.1a</td>
<td>218.6a</td>
</tr>
<tr>
<td>Significance Level</td>
<td>ns</td>
<td>***</td>
<td>***</td>
<td>*</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>LSD (5%)</td>
<td>98.8</td>
<td>146.4</td>
<td>10.3</td>
<td>23.3</td>
<td>30.3</td>
<td></td>
</tr>
<tr>
<td>Variety</td>
<td>Batte</td>
<td>273.0b</td>
<td>713.3c</td>
<td>986c</td>
<td>61.5b</td>
<td>183.1c</td>
</tr>
<tr>
<td></td>
<td>Bubu</td>
<td>409.0a</td>
<td>1015.0a</td>
<td>1424a</td>
<td>87.1a</td>
<td>306.2a</td>
</tr>
<tr>
<td></td>
<td>Daddafa</td>
<td>400.0a</td>
<td>924.2ab</td>
<td>1324a</td>
<td>68.9b</td>
<td>200.4bc</td>
</tr>
<tr>
<td></td>
<td>Jarso</td>
<td>183.9c</td>
<td>638.3c</td>
<td>822c</td>
<td>37.7c</td>
<td>134.6d</td>
</tr>
<tr>
<td></td>
<td>Zemen</td>
<td>286.9b</td>
<td>850.8b</td>
<td>1138b</td>
<td>48.5c</td>
<td>218.1b</td>
</tr>
<tr>
<td>Significance Level</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>LSD (5%)</td>
<td>74.2</td>
<td>110.5</td>
<td>163.7</td>
<td>11.5</td>
<td>26.1</td>
<td>33.8</td>
</tr>
<tr>
<td>CV (%)</td>
<td>28.9</td>
<td>16.1</td>
<td>17.4</td>
<td>22.9</td>
<td>15.1</td>
<td>15.2</td>
</tr>
</tbody>
</table>

Means within a column followed by the same letter are not significantly different at 5% level of significance; ns = non significant; * = significant at 5%; *** = significant at 0.1% probability levels.

3.2 Effects of N and Variety on Yield Components and Yield

The effect of N was highly significant on all parameters of tuber number while the effect of variety was highly significant on marketable as well as unmarketable tuber numbers. But, the interaction effect of the two factors on all the components of tuber number was not significant; also, the main effect of variety was not significant on total tuber number. The results showed that increasing N application from 0 to 55 kg ha⁻¹ increased marketable tuber number produced per hill by 33%, unmarketable tuber number by 58%, and total tuber number by 40%. However, increasing the application of N from 55 to 110 and 165 kg ha⁻¹ did not affect all tuber number parameters. In line with the results of this study, significant increases in tuber number in response to increased application of N was reported by Lynch and Rowberry (1997) and Sparrow et al. (1992). However, it was observed by Morena et al. (1994), and Sharma and Arora (1987) that there was no strong relationship between N application rates and tuber number. On the other hand...
Kołodziejczyk (2014) found that the share of the number of stems per 1 m² as well as the number of tubers per stem showed significant contribution in the yield increment within the rate of N application.

The varieties Bubu and Zemen produced the highest marketable tuber numbers. However, Bubu also produced the lowest unmarketable tuber number per hill. This was followed by the tuber numbers produced by Batte and Zemen. These varieties produced also the highest number of unmarketable tubers. The lowest marketable tuber number was produced by Jarso and Daddafa. These two varieties also produced the highest unmarketable tuber numbers (Table 3). Thus, Bubu produced 23, 19, and 17% more marketable tuber number than Jarso, Daddafa, and Batte, respectively.

Marketable, unmarketable and total tuber yields were highly significant influenced by the effects of N and variety. However, there was no significant effect with regard to the interaction effect of the two factors on tuber yield. An increase N application from 0 to 55 kg ha⁻¹ increased marketable tuber yield by 25%, total tuber yield by 27%, unmarketable tuber yield by 53%. However, increasing the rate of N from 55 to 110 and 165 kg N ha⁻¹ did not affect marketable and total tuber yields as well as unmarketable tuber yield (Table 3).

The highest marketable and total tuber yields were obtained from the improved Bubu variety whereas the lowest marketable and total tuber yields were obtained from the local Jarso variety. The varieties Zemen, Daddafa and Batte lay in the intermediate range in terms of marketable and total tuber productivity. Thus, Bubu produced 54, 25, 22, and 14% more marketable fresh tuber yield than Jarso, Daddafa, Batte, and Zemen, respectively. In terms of production of total tuber yield, Bubu was superior to all other varieties except Zemen, which produced total tuber yield that was in statistical parity with the former. The lowest total tuber yield was produced by Jarso. The total tuber yield of Bubu exceeded that of Jarso, Daddafa and Batte by additional increments of 43, 19, and 16%, in the order listed here. The least unmarketable tuber yield was produced also by Bubu (Table 3). Berga et al. (1994) reported that unmarketable tuber yield might be controlled more importantly by manipulating other factors such as disease incidence, harvesting practice, etc. rather than mineral nutrition.

The differences in yield among these varieties could be related to their genetic makeup in the efficient utilization of inputs like nutrients; it is one of the four major categories of factors affecting yield (soil, genetic, climatic and management practices) as reported by (Downs and Hellmers, 1975; Tisdale et al.,1995). Hence, as reported by Hammes and De Jager (1990) and Gawronska et al. (1990), variation in tuber yield of these varieties may be due to differences in the rate of photosynthesis and dry matter production. In this study, there was strong positive association of plant height with marketable and total tuber yield. This means, the higher the height the higher the yield with an increase in N rate. Also, there was an increase in leaf area index which could indicate the responsibility of leaf for the subsequent yield increment (Tables 1 & 3). Parallel to this, Singh and Singh (1987) found that the correlation between plant height and tuber yield was positive and strong. In contrast, as reported by Sidhu et al. (1980), plant height was slightly important for tuber yield; however, Gopal (2001) found the absence of significant association between plant height and tuber yield.
Table 3. The main effects of N and variety on marketable and unmarketable tuber number (count/hill) and marketable and unmarketable tuber yield (tonnes/ha).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Parameters</th>
<th>Tuber number</th>
<th>Tuber yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (kg ha⁻¹)</td>
<td></td>
<td>marketable tuber number</td>
<td>unmarketable tuber number</td>
</tr>
<tr>
<td>0</td>
<td>6.46b</td>
<td>2.36b</td>
<td>8.81b</td>
</tr>
<tr>
<td>55</td>
<td>8.60a</td>
<td>3.71a</td>
<td>12.32a</td>
</tr>
<tr>
<td>110</td>
<td>8.37a</td>
<td>3.24a</td>
<td>11.61a</td>
</tr>
<tr>
<td>165</td>
<td>8.35a</td>
<td>3.89a</td>
<td>12.24a</td>
</tr>
</tbody>
</table>

Significance Level: *** *** *** *** ** ***
LSD (5%) 0.81 0.72 1.21 2.17 0.52 2.32

Means within a column followed by the same letter are not significantly different at 5% level of significance; ns = non significant; ** = significant at 1%; *** = significant at 0.1% probability levels.

Tuber size was not significantly influenced by the interaction effect of N and variety. Similarly, the main effect of N was not significant on small-sized tuber though it was significant on medium-sized tuber and highly significant on large-sized tuber. Highly significant influence of the main effect of variety on tuber sizes was also observed. Based on the result, as N application increased from 0 to 165 kg ha⁻¹ medium-sized tuber showed about 45 to 50% increase but large-sized tuber significantly decreased from 40 to 33% as compared to the control (Table 4). According to Assefa (2005), increased application of N increased the yield of medium-sized and large-sized tubers; however, the increase in N application was not significant with respect to small-sized tuber category. The author elucidated that the increase was significant at all levels of N application in the medium-sized and large-sized tuber yields, which indicates the positive effect of N in dry matter partitioning to tubers. The increase in the medium-sized tuber at the expense of larger-sized tuber is an accepted value since medium-sized tuber is more preferred. On small-sized tuber, the highest value was obtained for Jarso (about 22%) while the lowest was obtained for Bubu (about 9%), but on large-sized tuber, the lowest for Jarso (about 24%) and the highest for Bubu (about 45%) which was statistically similar to Batte; on medium-sized tuber, the highest value was obtained for Jarso (54.05%) and Zemen (51.9%) while the lowest was obtained for Batte (about 45.2%) though statistically not different from Bubu and Daddafa as shown in Table 4.

Mean tuber weight was not significantly influenced by the effect of N and its interaction with variety but there was highly significant influence of the main effect of variety. Contrary to this study, Harris (1978), Giardini (1992) and Morena et al. (1994) reported that yield increment due to mineral nutrition was attributed to its effect on average tuber weight; Peter and Hruska (1988) also reported that the increased size and duration of the haulm stemming from improved supply of nutrients favored the tuber weight; similarly, Patricia and Bansal (1999) reported the increase in average tuber weight of tubers with the supply of fertilizer nutrients could be due to more luxuriant growth, more foliage and leaf area and higher
supply of photosynthates which helped in producing bigger tubers, hence resulting in higher yields. In addition, Balenger et al. (2002), Barakat et al. (1991), and Gaber and Sarg (1998) reported that potato average tuber weight increased with N increasing. Similar result also found by Kołodziejczyk M. (2014) that is each application of N rate within the range to 180 kg N ha\(^{-1}\) caused a noticeable increase in an average tuber weight.

The result revealed that the highest and the lowest, respectively, mean tuber weights were observed for Bubu (about 55%) and Jarso (about 40%) relatively (Table 4). The result revealed that a positive and highly significant association was observed between marketable tuber number and marketable tuber yield, marketable tuber number and total tuber yield, mean tuber weight and marketable tuber yield, and mean tuber weight and total tuber yield. In line with this, the finding of Maris (1969) revealed that tuber number and average tuber weight are important components determining tuber yield. The finding of Berga and Caesar (1990) also agrees with this statement in that tuber number is more important than average tuber weight in determining tuber yield.

Harvest index was highly significantly influenced by the main effect of N. Similarly, the main effect of variety was highly significant on the above parameter. However, the interaction effect of the two factors was not significant. According to Wien (1997), the consequent prolonged shoot growth and the increased duration of a canopy for light interception usually produces a much higher final of tubers than in plots that receive no N fertilizer; this is in spite of the fact that the unfertilized plants have a much higher harvest index. This idea is contradicted with the result of the present study in which an increase of harvest index with an increase of N application from 0 to 165 kg ha\(^{-1}\) was observed (Table 4). This may indicate that the optimal yield was not obtained due to factors such as environmental condition (e.g. frost), disease (potato late blight), etc. otherwise the harvest index would have been decreased. It was indicated in a study by Beukema and Van der Zaag (1990) that in temperate zone harvest indices of 0.75-0.85 are quite common but in warmer climates, the harvest index tend to be lower and often a wider variation is also observed between cultivars or growing conditions. In the present study, the highest value was recorded on Zemen (0.78) while the lowest was obtained by Batte (0.702). However, Zemen was statistically not different from Bubu; similarly, Batte was not statistically different from Daddafa and Jarso. In general, improved varieties (Bubu and Zemen) obtained better values as compared to the local varieties namely, Batte, Daddafa and Jarso (Table 4).
Table 4. The main effects of N and variety on tuber size distribution (%) in weight, mean tuber weight (g) and harvest index.

<table>
<thead>
<tr>
<th>Nitrogen (kg ha(^{-1}))</th>
<th>Tuber size distribution (Small-sized)</th>
<th>mean tuber weight (g)</th>
<th>harvest index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>45.59(^b)</td>
<td>40.72(^a)</td>
<td>49.89</td>
</tr>
<tr>
<td>55</td>
<td>51.48(^a)</td>
<td>32.47(^b)</td>
<td>46.17</td>
</tr>
<tr>
<td>110</td>
<td>48.50(^{ab})</td>
<td>36.20(^{ab})</td>
<td>47.78</td>
</tr>
<tr>
<td>165</td>
<td>50.27(^a)</td>
<td>33.67(^b)</td>
<td>45.26</td>
</tr>
</tbody>
</table>

Significance Level
LSD (5%) 3.59  4.743  --  0.02371

Means within a column followed by the same letter are not significantly different at 5% level of significance; ns = non significant; * = significant at 5%; ** = significant at 1%; *** = significant at 0.1% probability levels.

3.3 Effects of N and Variety on Quality Parameters

Tuber dry matter was highly significantly affected by the main effect of N. Similarly, the main effect of variety on tuber dry matter as well as on specific gravity was highly significant. However, the main effect of N on specific gravity was not significant which is in agreement to the reports of Roberts and Cheng (1988) as well as Joern and Vitosh (1995). Likewise, the interaction effect of N and Variety was not significant on both the attributes of quality parameters.

The result showed that increasing N application from 0 to 55 kg ha\(^{-1}\) decreased tuber dry matter by about 5%. However, beyond this level of N supply, tuber dry matter yield was unaffected. The highest value of tuber dry matter was obtained for Bubu (about 28.5%) while the lowest was obtained for Jarso (about 19.7%). According to the finding of Beukema and Van der Zaag (1979), dry matter content is influenced by a large number of factors; most importantly, cultivar, maturity, growth pattern as influenced by N fertilizer application, and climate and soil. Related to the present result, different scholars (Westermann et al., 1994b; Kanzikwera et al., 2001) reported a significant reduction in percent dry matter content due to increase in N application; this could be attributed to the fact that high rates of N stimulate more top growth than tuber growth thereby delaying tuber formation and maturity; thus, tubers tend to be harvested immature with low dry matter percentages. Similar results were found in a study by Assefa (2005) and Anabausi et al. (1997). On the other hand, Balenger et al. (2002), Barakat et al. (1991), and Gaber and Sarg (1998) reported that potato tuber dry matter % increased with N increasing.

Although statistically not different from Bubu, the highest value for specific gravity (about 1.08) was obtained for Zemen; the lowest result was obtained for Jarso (about 1.054) though not statistically different from Daddafa as shown in Table 5. In general, improved varieties (Zemen and Bubu) had higher values of specific gravity than the local ones (Batte, Daddafa and Jarso). Specific gravity was positively and strongly correlated (0.44*** ) to tuber dry matter, which is in agreement with the report of (Blumenthal et al., 2008) stating that since specific gravity has a near-linear relation with dry matter and starch content in tubers, it is
the common way for measuring these quality characters. Similarly, there is a very high correlation between the specific gravity of the tuber and the starch content and also the percentage of dry matter or total solids (Tony, 2010).

Nitrogen content of the leaf tissue was highly significantly influenced by the effect of N. It also observed that the effect of variety was significant. Nevertheless, there was no significant effect regarding the interaction of the two factors. As shown on the result, increasing N application from 0 to 165 kg ha\(^{-1}\) increased the availability of N concentration in leaf tissue from about 4.64 to 5.14%. Results of the present study agreed with that of Anabausi et al. (1997), Maier et al. (1994) and Rykbo et al. (1993) who reported increase in leaf N concentrations in response to increasing the rates of N application. The highest and the lowest values of N content in their tissue were recorded by Batte, local variety (about 5.16%) and Zemen, improved variety (about 4.71%), respectively (Table 5).

It was reported on nutrient sufficiency and toxicity thresholds for potato (early bloom: 3.5-4.5, toxic > 6.5; late: 3.0-4.0), petiole (early bloom: >1.5 (nitrate-N)), and tuber (maturity: 1.2-1.8) tissues for N (%) content in this crop (Carl et al., 2004). In accord to this, the result of the present study revealed that N content of the varieties in their leaf tissue, ranging from 4.7 to 5.1 %, were sufficient.

Table 5. The main effects of N and variety on tuber dry matter (%), specific gravity (g/cm3), and leaf tissue analysis (total N in %).

<table>
<thead>
<tr>
<th>Treatment Nitrogen( kg ha(^{-1}))</th>
<th>tuber dry matter</th>
<th>specific gravity</th>
<th>leaf tissue analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>25.20(^{a})</td>
<td>1.0632</td>
<td>4.64(^{a})</td>
</tr>
<tr>
<td>55</td>
<td>23.96(^{b})</td>
<td>1.0639</td>
<td>5.08(^{a})</td>
</tr>
<tr>
<td>110</td>
<td>23.47(^{b})</td>
<td>1.0706</td>
<td>4.98(^{a})</td>
</tr>
<tr>
<td>165</td>
<td>23.87(^{b})</td>
<td>1.0696</td>
<td>5.14(^{a})</td>
</tr>
</tbody>
</table>

Significance Level
LSD (5%)  0.71

Variety
<table>
<thead>
<tr>
<th>Batte</th>
<th>23.40(^{c})</th>
<th>1.0652(^{b})</th>
<th>5.16(^{a})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bubu</td>
<td>28.52(^{a})</td>
<td>1.0768(^{a})</td>
<td>4.84(^{bc})</td>
</tr>
<tr>
<td>Daddafa</td>
<td>23.12(^{c})</td>
<td>1.0598(^{bc})</td>
<td>5.03(^{ab})</td>
</tr>
<tr>
<td>Jarso</td>
<td>19.86(^{d})</td>
<td>1.0543(^{c})</td>
<td>5.05(^{ab})</td>
</tr>
<tr>
<td>Zemen</td>
<td>25.74(^{b})</td>
<td>1.0782(^{a})</td>
<td>4.71(^{c})</td>
</tr>
</tbody>
</table>

Significance Level
LSD (5%)  0.79

CV (%)  4.0  0.11  0.29

Means within a column followed by the same letter are not significantly different at 5% level of significance; ns = non significant; * = significant at 5%; ** = significant at 1%; *** = significant at 0.1% probability levels.

4. CONCLUSIONS

The results showed that increasing the rate of N fertilizer from 0 to 55 kg N ha\(^{-1}\) increased most of the measured parameters. However, beyond the supply of 55 kg N ha\(^{-1}\), there was no change in most of the parameters. Within these N rates, the improved variety Bubu and local variety Daddafa showed promising performance during the experiment. However, the yields obtained from these varieties were much less than the expected potential productivity common on research fields. In addition, the response of all varieties to the increased rates of N application was not also found to be robust. An environmental stress that occurred just before maturity, namely, frost, may account for the underperformance and less response of the improved varieties in particular to the increased rates of N. In addition, the local varieties suffered most
from attack by late blight disease during growth in the wet season. Therefore, to reach a conclusive recommendation on the response of N fertilizer and tuber productivity of the varieties, further multi-location studies should be conducted under both irrigated and rain-fed conditions.

5. CONFLICT OF INTEREST
The authors have not declared any conflict of interests.

6. ACKNOWLEDGMENTS
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