Performance of Potato(*Solanum tuberosum* L.) Cultivars and Spacing at Different in Central Highlands of Ethiopia

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ABSTRACT

The experiment was aimed at determining the effect of plant spacing and cultivars on yield and yield components of potato (Solanum tuberosum L.). The treatments consisted of three potato cultivars (Gudane, Jalane and Bone) and six levels of plant spacing (75 cm x 30 cm, 60 cm x 35 cm, 65 cm x 30 cm, 65 cm x 25 cm, 55 cm x 30 cm, and 55 cm x 25 cm). The experiment was laid out as a randomized complete block design in a factorial arrangement and replicated three times. Analysis of the results revealed that the main effects of spacing and cultivars significantly affected days to physiological maturity, leaf area index, marketable tuber number, total tuber numbers, total yields, and tuber size distribution. However, cultivar and plant spacing did not interact to influence any of the parameters studied. All three varieties significantly differed in the duration required to reach physiological maturity, with Jalane requiring the longest duration but Gudane requiring the shortest duration to reach physiological maturity. Gudane produced the tallest plants whereas the local variety Bone produced the shortest plants. Plant height increased significantly in response to increasing or widening plant spacing. All three varieties significantly differed in the number of stems they produced. Leaf area index significantly increased with increase in plant spacing and decreased significantly when plant spacing was narrowed. Gudane produced the heaviest tubers compared to both Jalane and Bone. Gudane also produced significantly higher total as well as marketable tuber yields than the two other cultivars. Increasing or widening plant spacing significantly reduced total as well as unmarketable tuber yields whereas decreasing or narrowing it significantly increased this yield parameter. On the other hand, increasing plant spacing significantly increased marketable tuber yields. Gudane and Bone cultivars had higher specific gravity than Jalane cultivar. Marketable tuber yield had a positive and significant linear correlation with plant spacing. In conclusion, the three potato cultivars produced the highest tuber yields (ton ha^{-1}) as well as medium-sized tuber numbers in response to planting at the spacing of 75 cm between rows and 30 cm between plants. Furthermore, Gudane was superior in tuber yield as well as tuber dry matter content compared to the other two cultivars.

Keywords*: Cultivars, Plant Spacing, Potato*

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the most important food crops in many countries of the world. In volume of production, it is the fourth most important crop in the world after wheat, maize, and rice with annual production of 314.1 million tons cultivated on about 18.1 million hectares of land (Adane *et al*., 2010).

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 (Adane *et al*., 2010). It is a major part of the diet of half a billion consumers in the developing countries (Mondal, 2004). Potato is an important food and cash crop in eastern and central Africa, playing a major role in national food security and nutrition, poverty alleviation and income generation, and provides employment in the production, processing and marketing sub-sectors (Lung'aho *et al*., 2007).

Potato is the second most important tuber crop grown in the country next to 'Enset' (*Ensete ventricosum* L.) in terms of area coverage (Girma, 2001). The potential attainable average yields of the crop on research and farmers' fields are 45 and 25 tons/ha, respectively, while the national average production is limited to about 10 tons/ha (MoARD, 2005; CSA, 2007). Potato has now become an important food and cash crop in Ethiopia, especially in the high and mid altitude areas. It also has promising prospect in improving the quality of the basic diet in both rural and urban areas of the country (Berga *et al*., 1994).

The major ones are lack of well adapted and high-yielding cultivars, unavailability and high cost of seed tubers, inappropriate agronomic practices, and lack of marketing and suitable post-harvest management facilities, pests and disease (Gildemacher *et al*., 2009). The most common recommended spacing for ware potato production in Ethiopia is 75 cm between rows and 30 cm between plants. On the other hand, the spacing for seed potato production should be usually smaller, about 60 cm between rows and 30 cm between plants (Lung'aho *et al*., 2007). However, the same spacing is commonly used for both ware and seed potato production of different potato varieties despite their distinct growth morphology in many areas of the country. However, plant spacing should depend on type of variety, fertility status of soil, plant architecture or growth habit etc. Therefore, using the same spacing for all varieties may not lead to optimum tuber yields. (Lung'aho *et al*., 2007).

However, in Welmera and Ada'a Barga district, which is located in the Central Ethiopia, the frequent use of unspecified narrow or wide spacing to produce ware and seed tuber potato is common (Personal communication).In the study area the common practice followed for potato production was with a spacing of 65 cm x 25 cm which may have contributed to the low yield or quality of the crop in the area. Therefore, the possibility of securing high yields of potato in the area depends much upon a proper consideration of optimum number of plants per unit area. In the study area, information on potato plant spacing for cultivars for optimum tuber yield and other agronomic practices is limited. Hence, determining optimum planting spacing for specific cultivars is very important to come up with relevant recommendations that can optimize potato tuber yield. Thus, the objective of the study was to investigate the effect of different plant spacing on tuber yield and yield components of potato cultivars.

MATERIALS AND METHODS

Description of the Study Area

The field experiment was conducted on farmer's fields in 2014 with the irrigation in west shewa, in the central highlands of Ethiopia. Potato is widely grown in this area. The district is situated at the distance of 48km West of Addis Ababa with altitudes ranging between 1750 - 2400 metres above sea level. The total cultivated land is estimated to be 34,503 ha out of which 33,778.8 ha is rain-fed while 724.2 ha are irrigated. The site has irrigation water from Mogor River, which is by now being further developed through the collaboration of Agricultural Sector Support Project (ASSP) and the Oromia Government to upgrade its irrigation capacity, and is hoped to have the irrigation capacity of about 450 ha of land at the end of the project 2016.

The study area receives about 1100 mm mean annual rainfall. The rainy season extends from May to October and the maximum rain is received in the months of June to August. The mean annual temperature is about 17.5 ^{0}C, with the mean maximum and minimum temperatures of 25^{0}C and 10^{0}C, respectively. The soil of the area is characteristically Nitosol, which is reddish brown in colour and clay loam in texture and its pH ranges between 4.2 to 5.8.

Experimental Materials and Design

The experiment was conducted using two improved potato varieties (Gudane and Jalane) and one local variety (Bone), which are commonly cultivated in the district. Gudane and Jalane were released by Holeta Agricultural research centre in 2006 and 2002, respectively. The local variety is a farmers' cultivar that has been used for production in the study area for a long period of time and stored for three months in diffused light store (DLS) along with the two varieties until sprouting for planting. The treatments consisted of three potato cultivars (Gudane, Jalane, and Bone) and six plant spacing (75 cm x 30 cm; 60 cm x 35 cm; 65 cm x 30 cm; 65 cm x 25cm; 55 cm x 30 cm; 55cm x 25 cm) between plants and rows, respectively. The experiment was laid out as a randomized complete block design (RCBD) in a factorial arrangement and replicated three times. The gross plot size was 3.6 m x 4 m (14.4m^2) accommodating a minimum of 30 harvestable plants with different rows and space lengths. The net plot size was determined with area and plant density leaving the two outermost rows and sides of each row. There were18 treatment combinations (Table 1) and the treatments were assigned to each plot randomly. Land preparation was done at the end of September 2014 in accordance with a standard practice locally used. The experimental plot was cultivated by an oxen-drawn implement to the depth of 25-30 cm. The land was levelled and ridges were made manually. Sprouted medium sized seed tubers (with a sprout length of 1.5 to 2.5 cm) were planted on 15 November 2014 according to the specified treatments. Cultivation, weeding, chemical spray and harvesting were done at the appropriate time according to the research recommendations.

Harvesting was done at physiological maturity when the leaves of the potato plants senesced. Ten days before harvesting, the haulms of the potato plants were mowed using a sickle to toughen the periderm and pre-empt predisposal of tubers to skinning and bruising during harvesting.

Data Collection

Data on growth, yield and yield components were recorded as described below:

Days to flowering: was recorded as number of days from emergence to the time when 50 percent of the plant population in each plot produced flowers.

Plant height (cm): was measured by taking five randomly reselected plants per plot as the distance in cm from the soil surface to the top most growth point of aboveground at full maturity.

Leaf number per plant: was counted from five plants (hills) taken at random in each plot before the start of tuber formation.

Table 1: Treatment combinations, number of plants per plot and plant population ha^{-1}.

Treatment	Cultivar	Spacing (inter and intra row)	No. of plants per plot	No. of plants per m^2	Plant population per hectare
1	Gudane	75cmx30cm	60	4.44	44444
2	Gudane	60cmx35cm	60	4.76	44444
3	Gudane	65cmx30cm	72	5.13	51282
4	Gudane	65cmx25cm	84	6.15	61538.5
5	Gudane	55cmx30cm	84	6.06	61538.5
6	Gudane	55cmx25cm	98	7.27	72727.3
7	Jalane	75cmx30cm	60	4.44	44444
8	Jalane	60cmx35cm	60	4.76	44444
9	Jalane	65cmx30cm	72	5.13	51282
10	Jalane	65cmx25cm	84	6.15	61538.5
11	Jalane	55cmx30cm	84	6.06	61538.5
12	Jalane	55cmx25cm	98	7.27	72727.3
13	Bone	75cmx30cm	60	4.44	44444
14	Bone	60cmx35cm	60	4.76	44444
15	Bone	65cmx30cm	72	5.13	51282
16	Bone	65cmx25cm	84	6.15	61538.5
17	Bone	55cmx30cm	84	6.06	61538.5
18	Bone	55cmx25cm	98	7.27	72727.3

Leaf area index: To determine leaf area, five plants (hills) from each plot were randomly taken at 50 percent flowering. Then, three leaf samples were measured using leaf meters. By multiplying the average leaf area with the respective leaf number of the plant, total leaf area was calculated. Leaf area index was calculated by dividing total leaf area to the respective land area occupied by plants.

Stem number: Five plants per unit area were counted at 50% flowering.

Days to maturity: Number of days from emergence to maturity was recorded when 95% percent of the plants of different treatments were ready for harvest as indicated by the senescence of the haulms.

Tuber size distribution: At harvest, tubers were collected from 5plants randomly selected from each plot, and they were categorized into: very small (< 25 g); small (25-39g); medium (40-75 g); and large (>75 g). The proportion of the number of tubers in the different tuber size categories were converted to percentages (Sharma and Arora, 1987).

Marketable tuber yield (tons/ha): included marketable and healthy tubers with size categories greater than 25 g.

Unmarketable tuber yield (tons/ha): unmarketable tubers included unhealthy tubers as well as healthy tuber weighing less than 25g.

Total tuber yield (tons/ha): total tuber yield was recorded as the sum of all marketable and unmarketable tubers.

Specific gravity of tubers (gcm^{-3}): To determine the specific gravity, tubers of all size categories weighing about two kilogram were randomly taken from each plot, washed with water. The sample was then first weighed in air and then re-weighed suspended in water. Specific gravity was then determined using the following formula (Kleinkopf *et al*, 1987).

$$Specific\ gravity = \frac{Weight\ in\ air}{Weight\ in\ air - weight\ in\ water}$$

Tuber dry matter content (%): Five fresh tubers were randomly selected from each plot and weighed at harvest. The tubers were then sliced and dried in an oven at 65^0C for about 72hrs until a constant weight was obtained. The dry weight was recorded and the dry matter percent calculated according to Williams (1968).

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

Statistical Analysis

Analysis of variance (ANOVA) was done for Randomized Complete Block Design in a factorial arrangement using the Generalized Linear Model of the SAS procedure of version 9.1 (SAS, 2007). All significant pairs of treatment means were compared using the Least Significant Difference Test (LSD) at 5% level of significance. Linear correlation analysis was done to know the association of traits.

RESULTS AND DISCUSSION

Growth Parameters of Potato

Days to flowering

Cultivars showed significant effect ($P < 0.01$) on days to 50% flowering. However, plant spacing as well as the interactions were non significant. The improved Jalane variety required the longest duration whereas the improved Gudane variety required the shortest duration to reach this stage of growth. Comparatively, the local variety Bone required an intermediate duration to reach 50% flowering. Thus, compared to Gudane variety, Jalane required an additional duration of about 12% to reach 50% flowering whereas Bone required an additional duration of about 4% to reach the same stage of growth (Table 2)

The differences observed in 50% flowering among the three varieties may be attributed to genetic differences. This result is in agreement with that of Vreugdenhil (2007) who stated that days required to flowering is highly dependent on gene factors and governed by many environmental factors, mainly temperature and light. The number of days required to flowering is one of the important parameter for potato farmers due to the fact that it enables the grower to forecast its harvesting scheme as well as the marketing plan (Khalafalla, 2001).

Days to physiological maturity

Cultivars showed significant effect ($P < 0.01$) on days to physiological maturity. However, plant spacing as well as the interactions were non significant. All three varieties significantly differed in the duration required to reach physiological maturity (Table 2). Jalane required the longest period to reach physiological maturity than both Bone and Gudane. Thus, in terms of the length of time required to reach physiological maturity, Jalane > Bone > Gudane. Accordingly, the days required to reach physiological maturity by the Jalane was prolonged by about 8% compared to the duration in days required by the Gudane to reach physiological maturity. Similarly, the days required by Jalane to reach physiological maturity was prolonged by about 4% compared to the days required by Bone to reach the same stage of growth. On the other hand, Bone variety required about 4% longer duration than Gudane to reach physiological maturity.

The results of this study are in accord with those of Tekalign (2005) who reported that potato grown depends on cultivars and environmental factors. EARO (2004) also stated that days to maturity of potato varieties varied from 90 to 120 days and the variation is accounted for by variety, growing environment and cultural practices. The number of days to reach maturity is the important parameter for potato producers in that, it enables the growers to develop a suitable production calendar, as well as the marketing plan (Khalafalla, 2001).

3.1.3. Plant height

Cultivars as well as plant spacing showed significant effect ($P < 0.01$) on plant height. However, the interaction was non significant. The data in Table 2 shows that Gudane had the tallest plants whereas the local variety Bone had the shortest plants. Jalane had plants that were intermediate between the heights of plants produced by Gudane and Bone. Thus, plants produced by Gudane were significantly taller than plants produced by Jalane and Bone by about 11 and 19%, in the order mentioned here. On the other hand, plants produced by Jalane were taller than those produced by Bone by about 4% (Table 2). The significant differences in plant height due to the varieties may be attributed to genetic differences. This suggestion is in accord with that of Singh and Singh (1973) that plant height is a quantitative trait controlled by many genes. Plant height increased significantly in response to increasing or widening plant spacing. Thus, increasing plant spacing from 55 cm x 25 cm to 75 cm x 30 resulted in significant increases in plant height by about 5%. The increased plant height in response to increasing plant spacing may be attributed to the fact that relatively more spacing may lead to less competition among plants for growth factors such as nutrients, moisture, and light leading to enhanced vegetative growth and increased plant height. This shows that plant height is influenced by environmental factors. This suggestion is corroborated by that of Singh and Singh (1973) who reported that environmental factors like nutrient status of the soil, available moisture and intercepted radiation significantly influence plant heights. This result is in accord with the findings of Endale and Gebremedhin (2001) who reported significant effect of spacing on plant height of potato with different plant spacing. In the current study, positive and highly significant correlation value was obtained between plant height and total tuber number(r = 0.68***), which indicated the existence of strong linear association between this two parameters.

Stem number

Cultivars showed significant effect (P < 0.01) on stem number per hill. However, plant spacing as well as the interactions were non significant. Varieties significantly differed in the number of stems they produced and the improved varieties of potato had generally significantly higher stem number than the local variety. Gudane variety had stem number that exceeded the stem number of the Bone variety by about 40% and that of the Jalane variety by about 13%. Similarly, Jalane had stem number that exceeded the stem number of Bone by about 23%.

The difference in stem number between the varieties may be attributed to the inherent variations in the number of buds per tubers. This result is in agreement with the findings of Allen (1978) who reported increased numbers of stems as a result of either planting large-sized tubers or large numbers of tubers per unit area. Plant spacing did not affect stem number. This result may be attributed to the fact that stem number is basically determined by the number of eyes present on the tubers and the physiological age of the tuber during the storage period rather than by manipulating agronomic practices as suggested by Lung'aho *et al.* (2007). However, other finding indicated that, decreasing plant spacing or increasing seed rate resulted in more number of stems per meter square (Allen and Wurr, 1978), which may be attributed to less stiff competition for growth factors that may lead to growth and development of more stems. Entz and La Croix (1984) noted that the main stem numbers per plant were influenced by seed mass while auxiliary branches increased with decreased plant space competition. Therefore, variation in the number of stems per plant may be associated with variation in their seed size and performance. The individual stems of a plant are largely dependent up on their parent tuber size and other factors such as the physiological age of the seed tuber because tuber age markedly affects stem growth and development (Allen and Wurr, 1978).

Table 2: The effects of cultivar and plant spacing on some potato growth parameters

Treatment	DF	PH	SN	DPM	LNP^{-1}	LAI
Cultivars						
Gudane	71.5^{c}	53.46^{a}	27.1^{a}	108.5^{c}	615.6^{a}	4.4^{a}
Jalane	80.17^{a}	47.77^{b}	23.9^{b}	117.72a	421.0^{c}	4.5^{a}
Bone	74.56^{b}	44.87^{c}	19.3^{c}	112.89^{b}	451.9^{b}	3.1^{b}
LSD (0.05)	2.04	1.329	0.62	1.169	13.59	0.49
Plant Spacing						
75cm x 30cm	76.00	50.04^{a}	24.2	113.11	501.9	5.1^{a}
60cm x 35cm	75.44	49.67^{ab}	23.1	113.0	503.9	4.23^{b}
65cm x 30cm	74.22	49.13^{abc}	23.5	112.0	491.8	4.2^{b}
65cm x 25cm	76.56	47.93^{bc}	23.8	113.22	481.7	3.8^{bc}
55cm x 30cm	75.78	47.87^{bc}	23.04	113.89	497.9	3.4^{c}
55cm x 25cm	74.44	47.53^{c}	23.1	112.56	499.7	3.2^{c}
LSD (0.05)	NS	1.88	NS	NS	NS	0.69
CV (%)	3.99	4.03	3.91	1.53	4.04	18.17

Means followed by the same letter within a column are not significantly different at 5 % level of significance LSD= Least significant differences; CV= coefficient of variation; PH=plant height; DF=days to 50% flowering; DPM= days to 50% Physiological maturity; SN=main stem number; LNP^{-1} = Leaf number per plant; LAI=Leaf area index.

Leaf number per plant

Cultivars showed significant effect ($P < 0.01$) on leaf number per plant. However, plant spacing as well as the interactions were non significant. All cultivars significantly differed in leaf number. In terms of leaf number produced per plant, Gudane > Bone > Jalane. Accordingly, Gudane produced 46 and 36% more leaf number than Jalane and Bone, respectively. On the other hand, Bone produced 7% more leaf number than Jalane. The results of the present study revealed that the cultivar with the highest leaf number produced the highest total tuber yields. This may be attributed to increased leaf area index with the increase in the number of leaves per plant. This suggestion is corroborated by that of Winkler (1971), who reported that leaf numbers of potato influences light interception and season on potato growth and yield. The rate of gross photosynthesis is almost proportional to leaf number per plants. The leaf number per plant was highly significantly and positively associated with total tuber yield (r =0.70***) and total tuber number (r =0.67***). Higher leaf numbers per plant are essential for higher biomass and increased tuber yield and number in potato production. This indicates that an increase in leaf numbers per plant results in high yield of potato tubers.

Leaf area Index

Cultivars as well as plant spacing showed significant effect ($P < 0.01$) on leaf area index. However, the interaction effects of both factors were non-significant on this parameter. Gudane and Jalane had leaf area indices that were in statistical parity. However, the local cultivar Bone had a significantly lower leaf area index than the other two cultivars (Table 2). Gudane and Jalane had about 42 and 45% more leaf area indices than Bone, in the order mentioned here. According to Eremeev (2007), different potato cultivars have different LAI values and maximum LAI was attained by all cultivars 75 days after planting. This might be attributed to the presence of greater number of leaves at closer spacing compared to the plants placed at wider spacing as well as the growth habit of different varieties. The result of the present investigation is in contradict to the findings of Burstall and Harris (1983) who reported the number of leaves at closer spacing is higher due to the presence of more number of plants at closer spacing than the sparsely populated plants. Leaf area index significantly increased with increase in plant spacing and decreased significantly when plant spacing was narrowed (Table 2). Thus, the highest leaf area index was recorded for plants grown at the spacing of 75 cm between rows and 30 cm between plants, closely followed by plants grown at the spacing of 60 cm x 35 cm, 65 cm x 30 cm, and 65 cm x 25 cm between rows and plants, respectively. On the other hand, the lowest leaf area indices were recorded for plants grown at the spacing of 65 cm x 25 cm, 55 cm x 30 cm, and 55 cm x 25 cm between rows and plants, respectively. Thus, the leaf area index recorded for plants grown at the spacing of 75 cm between rows and 30 cm between plants exceeded the leaf area index of plants grown at the spacing of 55 cm between rows and 25 cm between plants by about 59%.

In general, the leaf area indices of the plants belonging to potato varieties; Gudane and Jalane, as well as the plant spacing (75 cm x 30 cm, 60 cm x 35 cm, 65 cm x 30 cm) that produced higher tuber yields ranged between 4 to 5. This suggestion is consistent with the proposition of Vreugdenhil (2007) who stated that the rate of gross photosynthesis is almost proportional to LAI. In a closed canopy, however, leaf area extension is of minor importance compared to a young crop with sparse canopy coverage, because more light is intercepted at high LAI and further increase in LAI has only a marginal effect on photosynthesis due to mutual shading (Wurr 1992).

differences in total tuber yields among different potato cultivars.

Major Yield Components of Potato

Total Tuber Yield, Marketable Tuber Yield, and Unmarketable Tuber Yield

Total tuber yield

Cultivars as well as plant spacing showed significant effect ($P < 0.01$) on total tuber yield. However, the interaction was non significant. Gudane produced significantly higher total tuber yield than the two other cultivars. The total tuber yields of Jalane and Bone were in statistical parity (Table 3). The total tuber yield of Gudane exceeded that of Jalane and Bone by about 13%. This indicates that Gudane is superior to both Jalane and Bone in terms of tuber productivity. The differences in total tuber productivity between the Gudane cultivar on one hand and the Jalane and Bone cultivars on the other hand may be attributed to genetic differences. This suggestion is in accord with that of Mahamood (2005) who reported significant

Increasing or widening plant spacing significantly reduced total tuber yield whereas decreasing or narrowing it significantly increased total tuber yield (Table 3). Thus, the total tuber yield obtained from plants cultivated at the spacing of 55 cm between rows and 25 cm between plants was about 14% higher than the total tuber yield obtained from plants grown at the spacing of 75 cm between rows and 30 cm between plants. This shows that wider spacing results in under utilization of growth factors such as moisture, nutrients, and light resulting in the production reduced total tuber yields. This suggestion is consistent with that of Sharpe and Dent (1968) who reported that narrower plant spacing resulted in significantly higher total tuber yield than wider plant spacing. The increased yield at closer plant spacing may be due to the higher canopy coverage of the ground with green leaves earlier (earlier in the season, light is intercepted and used for assimilation), as well as the formation of fewer lateral and the possible early start of tuber growth and bulking. For production of small-sized tubers, higher plant densities are needed than for the production of large tubers. In other words, increased plant population density increased yield due to more tubers being harvested per unit area of land as reported by Beukema and Vander Zaag (1990). However, decreases in total yields as a result of wider spacing may be compensated for in part by an increase in large-size tubers and decrease in small tuber yields. This is apparently a result of reduced inter plant competition which may result in an increase in the total number of tubers per plant and average tuber size with wider seed piece spacing (Rex *et al,* 1987).

The observed simple linear correlation analysis indicated that total tuber yield was positively and highly significantly correlated with total tuber number (r = 0.24***) and significantly correlated with unmarketable tuber number (r = 0.44**) and marketable tuber number (r = 0.43**). However, total tuber yield was highly significantly and negatively correlated with days to maturity (r = -0.5***). This implies that factors that result in shortening maturity may also result in increased total tuber yield. The results of the current study are corroborated by the findings of various authors. For example, Entz and La Croix (1984) found reduction in total tuber yield in response to increased in-row spacing. Wurr (1974b) reported narrow plant spacing resulted in higher total tuber yields than wider spacing. Similarly, Nelson (1967) found that higher population density resulted in slightly higher total tuber yields and greater number of small-sized tubers.

Table 3: The effect of the cultivar and plant spacing on total, marketable, and unmarketable tuber yield (ton ha^{-1}) of potato.

Main effect	Total tuber yield(ton ha^{-1})	Marketable tuber Yield(ton ha^{-1})	Unmarketable tuber yield(ton ha^{-1})
Cultivars			
Gudane	33.20[a]	25.14[a]	8.10[a]
Jalane	29.26[b]	20.66[c]	8.60[a]
Bone	29.43[b]	22.63[b]	6.79[b]
LSD (0.05)	0.737	1.189	0.55
Plant Spacing			
75cm x 30cm	28.51[e]	25.66[a]	2.86[f]
60cm x 35cm	29.13[de]	24.37[ab]	4.76[e]
65cm x 30cm	30.14[cd]	23.56[bc]	6.46[d]
65cm x 25cm	31.01[bc]	22.17[cd]	8.51[c]
55cm x 30cm	31.51[b]	21.00[de]	10.1[b]
55cm x 25cm	32.56[a]	20.12[e]	12.3[a]
LSD (0.05)	1.042	1.682	0.77
CV (%)	3.57	7.69	10.78

Means followed by the same letter within a column are not significantly different at 5 % level of significance. LSD = Least significant differences; CV = coefficient variation.

Marketable tuber yield

Cultivars as well as plant spacing showed significant effect ($P < 0.01$) on marketable total tuber yield. However, the interaction was non significant. Similar to the total tuber yield, cultivar Gudane produced significantly higher marketable tuber yield than both Bone and Jalane cultivars. However, unlike total tuber yields, the marketable tuber yields of Bone and Jalane cultivars were in statistical parity (Table 3). Thus, the marketable tuber yield of Gudane was significantly higher than that of Bone and Jalane by about 11 and 22%, in the order mentioned here. The significant difference in the production of marketable tuber yield between Gudane on one hand and Bone and Jalane, on the other hand, may be attributed to genetic variations. This result is in agreement with that of Endale *et al*. (2001) who reported that different potato varieties differed in the amounts of marketable tubers yields produced. In contrast to the decreasing effect on total tuber yield, however, widening plant spacing significantly increased marketable tuber yield. Thus, plants grown at the wider plant spacing produced significantly higher marketable tuber yields than plants grown at the narrower spacing (Table 3). Thus, for example, the marketable tuber yields of plants cultivated at the spacing of 75 cm between rows and 30 cm between plants exceeded the marketable tuber yields of plants grown at the spacing of 55 cm between rows and 25 cm between plants by additional percentage of about 28%. The production of higher marketable tuber yield in response to planting the seed tubers at wider or increased spacing may be attributed low competition between plants for growth factors such as moisture, nutrients, and light and the optimal utilization of the growth factors for photosynthesis and assimilation of carbohydrates to tubers. This finding is in agreement with that of Wurr (1992) who reported that narrower spacing led to the production of many small-sized tubers that were not marketable.

Unmarketable tuber yield

Cultivars as well as plant spacing showed significant effect ($P < 0.01$) on unmarketable tuber yield of potato. However, the interaction was non significant. Gudane and Jalane cultivars produced significantly higher unmarketable tuber yield than Bone cultivar (Table 3). Thus, the two cultivars produced 19 and 27% more unmarketable tuber yields than the Bone cultivar, in the order mentioned cultivar. On the other hand, increasing plant spacing significantly decreased the amount of unmarketable tuber yields produced. Thus, plants grown at the spacing of 75 cm and 30 cm, 60 cm x 35 cm, 65 cm x 30 cm, 65 cm x 25 cm, and 55 cm x 30 cm between rows and plants, respectively, produced unmarketable tuber yields that were lesser than the unmarketable tuber yields produced by plants grown at the spacing of 55 cm between rows and 25 cm between plants by about 77, 61, 47, 31, and 18%, in the order mentioned here. Planting potato closely leads to the production of relatively higher proportion of unmarketable tubers such as small and misshaped tubers than planting the crop at a wider spacing. This may be attributed to the stiff competition for growth factors that may ensue between plants and growing tubers during bulking. This suggestion is corroborated by the results of Beukema and Vander zaag (1990) who reported that plant spacing had a marked effect on unmarketable tuberyield and the highest unmarketable tuber yield was recorded from closely-spaced potato plants due to higher inter-plant competition and the associated production of smaller-sized tubers.

Tuber Size Distribution

Yield of very small-sized tuber (< 25 g)

Gudane and Jalane cultivars produced significantly higher small-sized tubers than Bone cultivar (Table 4). Thus, the two cultivars produced 19 and 27% higher yields of very small-sized tubers than the Bone cultivar, respectively. These variations may be observed due to the inherent characteristics of the cultivars used. On the other hand, decreasing plant spacing significantly increased the yield of very small-sized tubers. Thus, plants grown at the spacing of 75 cm x 30 cm, 60 cm x 35 cm, 65 cm x 30 cm, 65 cm x 25 cm, 55 cm x 30 cm between rows and plants, respectively, produced yields of very small-sized tubers that were lesser than the yields of very small-sized tubers produced by plants grown at the spacing of 55 cm between rows and 25 cm between plants by about 77, 61, 48, 31, and 18%, in the order mentioned here. Planting potato closely leads to the production of relatively higher proportion of very small-sized tubers than planting the crop at a wider spacing. This finding is in agreement with that of Mass (1993) who reported that closer planting spacing restricted tuber sizing and resulted in an excessive proportion of very small-sized tubers which is attributed to increased competition between plants.

Table 4: The effects of cultivar and plant spacing on tuber number in tuber categories per m^2 of potato.

Main effect	Very small tuber Number	Small tuber number	Medium tuber number	Large tuber number
Cultivars				
Gudane	9.6^{b}	9.4	27.6^{a}	23.8^{a}
Jalane	10.7^{a}	9.9	23.4^{b}	18.1^{b}
Bone	10.3^{ab}	9.5	21.6^{b}	16.5^{c}
LSD (0.05)	0.78	NS	2.04	1.08
Plant Spacing				
75cm x 30cm	3.18^{f}	6.3^{f}	28.8^{a}	23.2^{a}
60cm x 35cm	5.97^{e}	7.6^{e}	26.76^{ab}	21.9^{a}
65cm x 30cm	9.09^{d}	8.7^{d}	24.58^{bc}	20.2^{b}
65cm x 25cm	11.5^{c}	10.0^{c}	23.5^{c}	18.7^{bc}
55cm x 30cm	14.04^{b}	11.5^{b}	21.8^{cd}	17.5^{c}
55cm x 25cm	17.4^{a}	13.2^{a}	19.83^{d}	15.1^{d}
LSD (0.05)	1.11	1.003	2.89	1.52
CV (%)	11.34	10.95	12.45	8.17

Means followed by the same letter with in a column are not significantly different at 5% level CV = coefficient variation; LSD = Least significant differences.

Generally, with increasing plant density, the number of tubers produced was increased. Thus, increase in number of tubers may result in increase in tuber weight per unit area. However, increase in plant density increases the competition between and within the plants and hence, leads to decrease in availability of nutrients for each plant and, consequently, results in decline of mean tuber weight (Rex *et al,* 1987).

Yield of small-sized tubers (25 - 39 g)

Cultivars as well as plant spacing showed significant effect ($P < 0.01$) on yield of small -sized tubers. However, the interaction was non-significant. Gudane produced significantly higher yields of small-sized tubers than Jalane and Bone cultivars. Thus, the two cultivars produced 14.5 and 8.7% less yields of this tuber category than the Gudane cultivar, in the order mentioned here. Similarly, decreasing plant spacing significantly increased the yield of small-sized tubers Thus, plants grown at the spacing of 75 cm x 30 cm, 60 cm x 35 cm, 65 cm x 30 cm, 65 cm x 25 cm, 55 cm x 30 cm between rows and plants, respectively, produced small tuber size that were lesser than the small tuber size produced by plants grown at the spacing of 55 cm between rows and 25 cm between plants by about 50, 60, 48, 18, and 10%, in the order mentioned here. The highest yield of small tuber at closer plant spacing might be due to stiff competition and production of higher proportion of small-sized tubers. Similarly, Nelson (1967) and Wurr (1974) also noted that higher population resulted in slightly higher total yields and a greater number of small tubers.

Yield of medium-sized tubers (40-75 g)

Cultivars as well as plant spacing showed significant effect ($P < 0.01$) on yield of medium-sized tubers. However, the interaction was non significant. Gudane and Bone cultivars produced significantly higher yield of medium-sized tubers than Jalane cultivar. Thus, the two cultivars produced 17 and 10% more medium sized tubers than the Jalane cultivar, respectively. On the other hand, increasing planting density significantly decreased the yield of medium-sized tubers produced. Thus, plants grown at the spacing of 60 cm x 35 cm, 65 cm x 30 cm, 65 cm x 25 cm, 55 cm x 30 cm and 55 cm x 25 cm between rows and plants, respectively, produced lesser than the medium tuber size than those produced by plants grown at the spacing of 75 cm between rows and 30 cm between plants by about 41 32, 25, 18, and 9%, in the order mentioned here. This result may be attributed to the fact that planting potatoes at a wider spacing leads to the production of relatively higher proportion of medium-sized tubers than planting the crop at a narrow spacing.

Yield of large-sized tubers (>75 g)

Cultivars as well as plant spacing showed significant effect ($P < 0.01$) on yield of large-sized tubers. However, the interaction was non significant. Gudane and Bone cultivars produced significantly higher large tuber-size than Jalane cultivar (Table 5). Thus, the two cultivars produced 21 and 3% more large tuber size than the Jalane cultivar, in the order mentioned cultivar.

Table 5: The effects of cultivar and plant spacing on some yields of very small, small, medium, and large-sized tubers of potato (ton ha^{-1})

Main effect	Very small-sized tubers	Small-sized tubers	Medium-sized tubers	Large-sized tubers
Cultivars				
Gudane	8.12^{a}	6.9^{a}	10.6^{a}	7.5^{a}
Jalane	8.60^{a}	5.9^{b}	9.1^{b}	6.2^{b}
Bone	6.80^{b}	6.3^{b}	10.0^{a}	6.4^{b}
LSD (0.05)	0.55	0.49	0.86	0.5
Plant Spacing				
75cm x 30cm	2.86^{f}	4.21^{e}	12.52^{a}	9.02^{a}
60cm x 35cm	4.76^{e}	5.04^{d}	11.46^{ab}	7.95^{b}
65cm x 30cm	6.46^{d}	6.04^{c}	10.26^{bc}	7.32^{b}
65cm x 25cm	8.51^{c}	6.92^{b}	9.37^{cd}	6.19^{c}
55cm x 30cm	10.13^{b}	7.60^{b}	8.49^{de}	5.41^{d}
55cm x 25cm	12.34^{a}	8.43^{a}	7.41^{f}	4.37^{e}
LSD (0.05)	0.77	0.69	1.21	0.71
CV (%)	10.78	11.27	12.72	11.07

Means followed by the same letter within a column are not significantly different at 5 % level of significance. LSD= Least significant differences; CV=coefficient of variation.

Yield increased at wider plant spacing (large tuber size). Thus, plants grown at the spacing of 60 cm x 35 cm, 65 cm x 30 cm, 65 cm x 25 cm, 55 cm x 30 cm and 55 cm x 25 cm between rows and plants, respectively, produced yield of large-sized tubers e that were lesser than the yield of large-sized tubers produced by plants grown at the spacing of 75 cm between rows and 30 cm between plants by about 52, 40, 31, 19, and 12%, in the order mentioned here. Consistent with the results of this study, Mass (1993) reported that wider spacing led to the production of higher yield of large-sized tubers, but resulted in reduction of the yield of small-sized and very small-sized unmarketable tubers. In the present study, positive and highly significant correlation value was observed between large tuber yield and marketable (r =0.69***) as well as medium tuber number (r =0.79***). The reason that yields of large-sized tubers increased significantly in response to planting at a wider spacing with a corresponding decrease in the yield of small-sized tubers may be due to reduced inter-plant competition at lower plant density (Mass, 1993).

Some Potato Tuber Quality Parameters

Tuber specific gravity

Cultivars as well as plant spacing showed significant effect ($P < 0.01$) on tuber specific gravity. However, the interaction was non significant. Gudane and Bone cultivars had higher specific gravity value than Jalane cultivar. Thus, the two cultivars had about 4 and 1% more value specific gravity than the Jalane cultivar, respectively (Table 9). However, plants grown at the wider spacing of 75 cm x 30 cm had 1.063 and plants grown at closer plant spacing of 55 cm x 30 cm had the lowest value of specific gravity (1.033). Positive and highly significantly correlation (r= 0.49***) was observed between specific gravity and tuber dry matter percentage. This implies that specific gravity is one of the most important traits in potato crop that may provide a faster and easier measure of dry matter content (Tai *et al.*, 1985). This is consistent with the suggestion of Tekalign (2005) that the positive correlation between specific gravity and tuber dry matter content signifies that specific gravity is a true indicator of the amount of dry matter of tubers.

Dry matter

Cultivars as well as plant spacing showed significant effect ($P < 0.01$) on dry matter. However, the interaction was non-significant.Gudane had significantly higher tuber dry matter percentage than both Bone and Jalane. However, Jalane had the lowest tuber dry matter yield (Table 6). Thus, the tuber dry matter yield of Gudane was significantly higher than that of Jalane and Bone by about 11 and 2%, respectively. On the other hand, the tuber dry matter yield of Bone significantly exceeded that of Jalane by about 8%. This result is consistent with that of Soltanpour (1969) who reported that tuber dry matter yields vary significantly with variety.

Table 6: The effects of cultivar and plant spacing on some potato tuber quality Parameters

Main effect	Specific gravity	Tuber dry matter (%)
Cultivars		
Gudane	1.072[a]	24.4[a]
Jalane	1.034[c]	22.1[c]
Bone	1.041[b]	23.9[b]
LSD (0.05)	0.009	0.39
Plant Spacing		
75cm x 30cm	1.063[a]	23.56[a]
60cm x 35cm	1.056[ab]	23.44[ab]
65cm x 30cm	1.05[bc]	23.0[b]
65cm x 25cm	1.041[cd]	23.64[a]
55cm x 30cm	1.033[d]	23.44[ab]
55cm x 25cm	1.045[bcd]	23.66[a]
LSD (0.05)	0.013	0.5
CV (%)	1.29	2.47

Means followed by the same letter within a column are not significantly different at 5% level of significance. LSD= Least significant differences; CV=coefficient variation

CONCLUSIONS

The experiments were carried out at Welmera and Ada'a Barga in the central highland of Western Ethiopia. The varieties Gudane, Jalane and Bone were evaluated at six levels of plant spacing (75 cm x 30 cm, 60 cm x 35 cm, 65 cm x 30 cm, 65 cm x 25 cm, 55 cm x 30 cm and 55 cm x 25 cm) in a Randomized Complete Block Design in 3 x 6 factorial arrangements with three replications. The main effect of spacing and cultivars affected days to 50% flowering, days to physiological maturity, plant height, leaf area index, marketable tuber yield, unmarketable tuber yield and total tuber yield.

Similarly, yield of different tuber size categories, tuber dry matter content, and specific gravity were significantly influenced by the main effects of both cultivar and plant spacing. However, cultivar and plant spacing did not interact to influence any of the parameters studied. The improved Jalane variety required the longest duration (118 days) whereas the improved Gudane variety required the shortest duration (109 days) to reach this stage of growth. Comparatively, the local variety Bone required an intermediate duration (113 days) to reach physiological maturity.

Gudane had the tallest plants whereas the local variety Bone had the shortest plants while Jalane had plants that were intermediate between the heights of plants produced by Gudane and Bone. Similarly, increasing plant spacing from 55 cm x 25 cm to 75 cm x 30 resulted in significant increases in plant height. All three varieties significantly differed in the number of stems they produced. Thus, the improved varieties of potato had generally significantly higher stem number than the local variety. Gudane and Jalane had significantly higher leaf are indices that were in statistical parity. However, the local cultivar Bone had a significantly lower leaf area index than the other two cultivars.

Leaf area index significantly increased with increase in plant spacing. Thus, the highest leaf area index was recorded for plants grown at the widest spacing of 75 cm between rows and 30 cm between plants. On the other hand, the lowest leaf area indices were recorded for plants grown at the spacing of 65 cm x 25 cm, 55 cm x 30 cm, and 55 cm x 25 cm between rows and plants, respectively. Gudane produced significantly higher total tuber yield than the two other cultivars. Similar to the total tuber yield, cultivar Gudane produced significantly higher marketable tuber yield than both Bone and Jalane cultivars.

Increasing plant spacing significantly decreased the amount of unmarketable tuber yields produced. Thus, plants grown at the wider spacing produced lower unmarketable tuber yields. Thus, planting potato closely leads to the production of relatively higher proportion of unmarketable tubers as well as higher total tuber yields. On the other hand, decreasing plant spacing significantly increased the yield of very small-sized tubers but decreased yield of medium and large-sized tubers. Gudane and Bone cultivars had higher specific gravity value than Jalane cultivar. Plants grown at the wider spacing of 75 cm x 30 cm had the Gudane had significantly higher tuber dry matter percentage than both Bone and Jalane. Jalane had the lowest tuber dry matter yield. The results of this study strongly imply that spacing and cultivar could be manipulated for higher yields of potatoes depending on the purpose of production i.e., whether for ware or seed potato. The results of the study also indicated that too much narrowing of plant spacing in potato production may lead to the production of large quantities of small-sized tubers that are too small to be marketed for both ware and seed purposes.

In conclusion, the results of this experiment revealed that cultivating any of the three cultivars at the spacing of 75 cm between rows and 30 cm between plants resulted in the highest marketable tuber yield for both ware and seed potato. Therefore, smallholder farmers in the study area, who often use the spacing of about 65 cm between rows and 30 cm between plants for the production of both ware and seed potatoes, should be advised to revise

highest value of specific gravity (1.063) and plants grown at closer plant spacing of 55 cm x 30 cm had the lowest value of specific gravity (1.033).

their practice. Furthermore, comparatively, cultivar Gudane was the best in terms of tuber as well as tuber dry matter yields. Therefore, farmers should be encouraged to cultivate primarily this variety at the spacing of 75 cm between rows and 30 between plants for ware or seed potato production. However, it is premature to make a final recommendation since the experiment was conducted at one location for only one season using three cultivars. Hence, studies involving more cultivars should be conducted at several locations over seasons to arrive at a conclusive recommendation.

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