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Growth and yield of potato (*Solanum tuberosum* L.) cultivars as influenced by plant spacing at Haramaya and Hirna, Eastern Ethiopia

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A field experiment was conducted at Haramaya and Hirna during the main cropping season of 2013 to determine the appropriate plant spacing for potato cultivars in relation to growth and yield. The treatments consisted of five seed tuber spacing (75 cm × 30 cm, 60 cm × 30 cm, 60 cm × 25 cm, 50 cm × 25 cm and 45 cm × 20 cm) and four potato varieties (Bubu, Badhassa, Zemen and Chiro). A randomised complete block design was used with three replications. The analyzed data results showed that the main effects of spacing and variety and the interaction effect significantly affected growth and yield parameters of the crop. The maximum marketable tuber yield at Haramaya (24.7 t ha^{-1}) and Hirna (27.99 t ha^{-1}) was recorded in response to seed tuber spacing of 60 cm × 30 cm whereas the maximum total tuber yield at Haramaya (34.29 t ha^{-1}) and Hirna (42.07 t ha^{-1}) was obtained from seed tuber spacing of 45 cm × 20 cm. Cultivar Bubu produced the maximum marketable tuber yields at Haramaya (29.91 t ha^{-1}) and Hirna (30.01 t ha^{-1}) and the same variety also produced the maximum total tuber yields at both locations.

Key words: Cultivar, growth, marketable yield, non-marketable yield, plant spacing, *Solanum tuberosum* L., total tuber yield.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is a crop of major economic importance worldwide. Potato (*Solanum tuberosum* L.) is a crop native to the central Andean area of South America, but it is now cultivated and consumed in most parts of the world, with an average consumption in 2011 of 96 g/capita/day. On a global scale, potato is the third most important food crop in the world after rice and wheat in terms of human consumption (FAO, 2014). The relatively high carbohydrate and low fat content of potato makes it an excellent energy source for human consumption (Dean, 1994).

The potato crop was introduced to Ethiopia around 1858 by Schimper, a German botanist (Pankhurst, 1964). The country has about 70% of the available agricultural

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land suitable for potato production (Gebremedhin et al., 2008). However, the potato sub-sector in Ethiopia is relatively undeveloped and is faced with low productivity of less than 10 t/ha (Roger, 2014).

The optimizing of plant density is one of the most important agronomic practices of potato production, because it affects seed cost, plant development, yield and quality of the crop (Bussan et al., 2007). As plant density increases, there is a marked decrease in plant size and yield per plant. This effect is due to increased inter-plant competition for water, light and nutrients (Masarirambi et al*.,* 2012). Plant density in potato affects some important plant traits such as total yield, tuber size distribution and tuber quality (Samuel et al., 2004). The blanket recommended plant spacing for all potato varieties in Ethiopia is 75 cm by 30 cm between rows and plants, respectively (MoA, 2014) but there are still many farmers who grow potatoes frequently in the area giving less regard to optimal plant population density for production of ware and seed potatoes. Moreover, tubers are often planted by smallholder farmers at narrower and erratic spacing resulting in non-optimum plant population densities that may result in low and erratic yields. The possibility of securing high yields depends on the optimum number of plants per unit area (Endale and Gebremedhin, 2001). Plant spacing should depend on type of variety, fertility status of soil, plant architecture or growth habit etc. (Girma and and Niguisse, 2015). Potato varieties also differ on growth habit and other attributes. Therefore, using the same spacing for all varieties may not lead to optimum tuber yields (Lung'aho et al., 2007).

Farmers in eastern Ethiopia use much closer spacing without making any distinction between the purposes of ware potato production and seed potato production. Therefore, potato seed tuber spacing in eastern Ethiopia does not account for varietal differences as well as whether the potato production is meant for ware or seed tubers. Therefore, the current study was conducted with the objective of determining the optimum plant population density for potato varieties in relation to growth and yield.

MATERIALS AND METHODS

Description of experimental sites

The study was conducted under rain-fed conditions during the 2013 main cropping season at Haramaya and Hirna districts, in eastern and western Hararghe zones of the Oromia Regional State in Ethiopia, respectively.

Weather condition of the experimental sites

During the crop growing season, Haramaya exhibited 1171.2 mm annual rainfall and the mean maximum and the mean minimum temperatures were 24.51 and 10.20°C, respectively. However, Hirna showed 1093.5 mm annual rainfall and mean maximum and mean minimum temperatures was 26.88 and 11.91°C, respectively (Figure 1).

Description of experimental materials

The experiment was conducted with four improved potato varieties (Bubu, Badhasa, Zemen and Chiro) which are widely cultivated in eastern Ethiopia (Table 1). Well sprouted medium seed tubers sized materials were prepared for planting.

Treatments and experimental design

The experiment consisted of four improved potato varieties (Bubu, Badhasa, Zemen and Chiro) and five seed tuber spacing between rows (ridges) and between plants (75 cm × 30 cm, 60 cm × 30 cm, 60 cm × 25 cm, 50 cm × 25 cm and 45 cm x 20 cm). The treatments were laid out as a randomized complete block design (RCBD) in a factorial arrangement and replicated three times per treatment. Gross plot size was 3.6 m × 4.0 m (14.4 m^2). The spacing between adjacent plots was 1.0 m and the spacing between adjacent blocks was 1.5 m.

Management of the experiment

The experimental fields were cultivated to a depth of 25-30 cm and then levelled after which ridges were made by hand. Well-sprouted medium sized seed tubers were planted according to the specified treatments. Cultivation, weeding and harvesting were done at the appropriate time. Untifengicidal chemical (Mancozeb 80% WP) was applied on 15 days interval at the rate of 1.5 kg ha^{-1} diluted at the rate of 40 g per 20 L to control late blight disease.

Phosphorus fertilizer was applied at the rate of 92 kg P_2O_5 ha^{-1} by banding the granules of DAP (diammonium phosphate) (18% N, 46% P_2O_5) at the depth of 10 cm below and around the seed tuber at planting. The blanket N recommendation is 111 kg N ha^{-1} (Anonymous, 2004). Thus, Urea (46% N) was applied only at the rate of 75 kg N ha^{-1} two times, that is, 1/2 at mid-stage (at about 45 days after planting), and 1/2 at the start of flowering.

Harvesting was done at physiological maturity when the leaves of the potato plants senesced. Two weeks before harvesting, the haulms of the potato plants were mowed using a sickle to toughen the periderm and avoid bruising during harvesting; harvesting was done by hand using hoes.

Data collection and measurements

Phenological and growth parameters

Days to maturity: was recorded when 50% of the plants in each plot became ready for harvest as indicated by the senescence of the haulms. The days were counted from emergence to maturity of the crop.

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

Leaf area index: of the plants were estimated from individual leaf length using the following formula developed by Firman and Allen (1989).

$$\text{Log 10 (leaf area in cm}^2) = 2.06 \times \log10 \text{ (leaf length in cm)} - 0.458$$

Yield components

Average tuber number per hill: was recorded as the actual number of tubers to be collected from a matured plant at harvest.

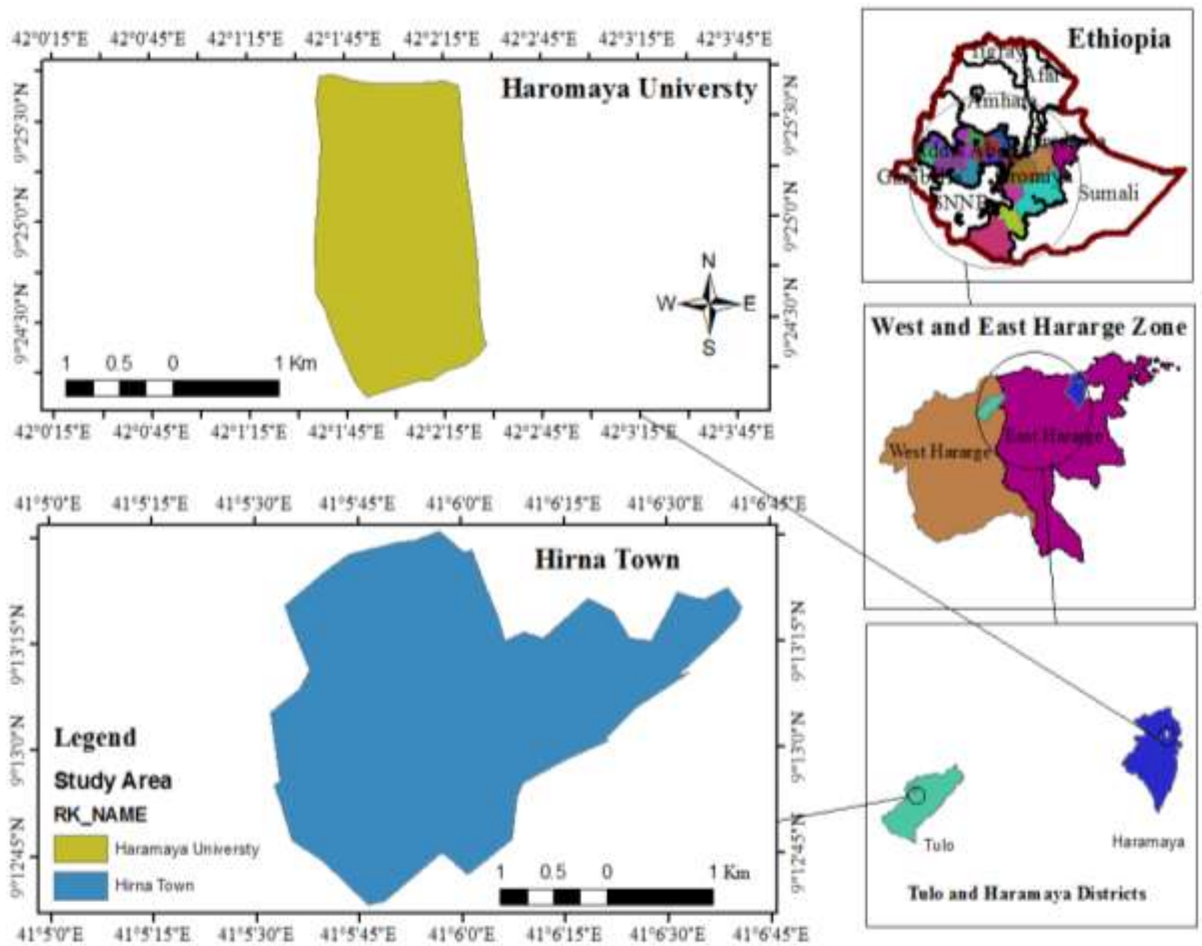

Figure 1. Geographical location of the study sites.

Table 1. Description of the potato varieties used for the experiment.

S/N	Variety	Year of release	Growth habit	Plant height (cm)	Area of adaptation	
					Altitude (metres above sea level)	Rainfall (mm)
2	Badhasa	2001	Erect	50-55	1700-2000	700-800
3	Zemen	2001	Erect	55-60	1700-2000	700-800
4	Chiro	1998	Semi-erect	60	1600-2000	700-800

Source: MoARD (2012).

Average tuber mass per hill (g/tuber): was obtained by dividing total weight of tubers per plant by the number of tubers.

Number of marketable and unmarketable tubers: was counted based on their size category, that is, tubers greater than or equal to 25 g, free from diseases, insect pests and other forms of damage considered marketable and tubers having less than 25 g, and with diseases, insect pests, and other forms of damage considered as unmarketable tubers.

Yield parameters

Marketable yield: All the marketable tubers which were free from diseases, insect pests and other damages as well as those greater than or equal to 25 g in weight were recorded and calculated per ha.

Non-marketable tuber yield: Unmarketable tubers included diseased, deformed tubers as well as tubers weighing less than 25 g were recorded and calculated per ha.

Total tuber yield: was recorded as the sum of marketable and unmarketable tuber yields.

Data analysis

The data were subjected to analysis of variance (ANOVA) using the

Table 2. Days to 50% maturity of potato varieties as influenced by the interaction effect of variety and seed tuber spacing at Haramaya and Hirna during the 2013 cropping season.

Variety (A)	Days to 50% maturity		
	Spacing (B)	**Haramaya**	**Hirna**
Bubu	75 cm × 30 cm	98.33^{ab}	94.67^{a}
	60 cm × 30 cm	95.00^{a-f}	93.67^{ab}
	60 cm × 25 cm	92.33^{c-h}	91.33^{abc}
	50 cm × 25cm	98.67^{a}	90.67^{bcd}
	45 cm × 20 cm	87.33^{h}	89.33^{cde}
Badhasa	75 cm × 30 cm	96.33^{a-d}	89.33^{cde}
	60 cm × 30 cm	97.00^{abc}	89.33^{cde}
	60 cm × 25 cm	93.00^{b-g}	88.67^{cde}
	50 cm × 25 cm	91.00^{d-h}	88.00^{cde}
	45 cm × 20 cm	90.67^{e-h}	86.33^{e}
Zemen	75 cm × 30 cm	94.33^{a-g}	90.00^{cd}
	60 cm × 30 cm	91.67^{c-h}	88.33^{cde}
	60 cm × 25 cm	94.33^{a-g}	90.00^{cd}
	50 cm × 25 cm	93.33^{a-g}	89.67^{cde}
	45 cm × 20 cm	92.33^{c-h}	87.33^{de}
Chiro	75 cm × 30 cm	95.67^{a-e}	88.33^{cde}
	60 cm × 30 cm	93.00^{b-g}	90.33^{bcd}
	60 cm × 25cm	91.33^{d-h}	89.67^{cde}
	50 cm × 25 cm	89.33^{gh}	89.67^{cde}
	45 cm × 20 cm	89.67^{fgh}	87.67^{de}
LSD (AXB) (0.05)		2.885	1.932
F-test		**	*
CV%		1.9	1.3

Means followed by the same letter within a column for the interaction effect of variety and plant spacing are not significantly different at 5% level of significance. ** = significant at 1% probability level. * = significant at 5% probability level. LSD = Least significant difference; CV = Coefficient of variation.

General Linear Model of the SAS statistical package (SAS, 2007) version 9.1. All significant pairs of treatment means were compared using Tulkey Test at 5% level of significance. T-test was conducted to determine differences between the two locations in the performance of the potato varieties to plant spacing. F-test for homogeneity of variances showed significant differences for the parameters, thus separate analysis was done for the locations except for unmarketable tuber number.

RESULTS AND DISCUSSION

Phenological and growth parameters

Days to 50% maturity

The interaction effect of variety and plant spacing significantly affected days to 50% maturity at both Haramaya ($P < 0.01$) and Hirna ($P < 0.05$) (Table 2).

At Haramaya the maximum days to 50% maturity was recorded at the interaction of variety bubu with 50 cm x 25cm spacing. At Hirna the maximum number of days for 50% maturity was recorded at the interaction of variety Bubu with 75 cm × 30 cm spacing. At both locations, decreasing plant spacing hastened the time required to reach 50% maturity by the plants although the data are inconsistent. Thus, the maximum number of days for 50% maturity was required mostly by plants grown at the wider spacing of 75 cm × 30 cm and 60 cm × 30 cm whereas the minimum number was required by plants grown at the narrower spacing of 50 cm × 25 cm and 45 cm × 20 cm. Plants grown at the spacing of 60 cm × 25 cm somewhat fell in the intermediate range in terms of the time required to reach 50% maturity at both locations (Table 2). This trend of hastened maturity in response to narrowing seed tuber spacing and prolonged maturity in response to widening it is attributable to competition for growth

Table 3. Plant height and leaf area index of potato as influenced by the main effects of variety and seed tuber spacing at Haramaya and Hirna during the 2013 main cropping season.

Variety	Plant height (cm)		Leaf area index	
	Haramaya	Hirna	Haramaya	Hirna
Bubu	62.09^{a}	68.83^{a}	2.868^{a}	3.178^{a}
Badhasa	40.91^{c}	52.67^{c}	2.162^{b}	2.953^{a}
Zemen	50.82^{b}	62.83^{ab}	1.798^{b}	2.613^{ab}
Chiro	48.40^{b}	59.20^{bc}	1.773^{b}	2.167^{b}
LSD (0.05)	4.185	5.458	0.4084	0.4694
Spacing				
75 cm × 30 cm	55.18^{a}	68.32^{a}	1.303^{b}	1.776^{c}
60 cm × 30 cm	54.02^{ab}	65.33^{a}	1.668^{b}	2.222^{c}
60 cm × 25 cm	49.04^{abc}	60.17^{ab}	2.344^{a}	2.487^{bc}
50 cm × 25 cm	47.98^{bc}	55.60^{b}	2.476^{a}	3.065^{b}
45 cm × 20 cm	46.53^{c}	54.98^{b}	2.961^{a}	4.087^{a}
LSD (0.05)	4.679	6.102	0.4566	0.5248
F-test	**	**	**	**
CV%	11.2	12.1	25.7	23.3

Means followed by the same letter within a column for the main effects of variety and plant spacing are not significantly different at 5% level of significance. ** = significant at 1% probability level. LSD = Least significant difference; CV (%) = Coefficient of variation.

factors, which becomes stiffer in the former case but lesser in the latter case. The results of this study are consistent with the reports of Beukema and Vander Zaag (1990) who stated that a high planting density stimulates early tuber growth and maturity in potatoes.

Plant height

Plant height responded significantly (P < 0.01) to the main effects of variety and plant spacing at both locations (Table 4). However, variety and spacing did not interact to influence plant height at both locations (Table 8).

Variety Bubu showed the tallest plant length (62.09 and 68.83 cm) and Badhasa gave the smallest length (40.91 and 52.67 cm) at both locations, respectively (Table 4). The difference in plant height due to variety may be attributed to genetic differences. This suggestion is consistent with that of Elfnesh et al. (2011) who found varietal difference across locations in plant height of the varieties Badhasa, Zemen and Chala at Haramaya, Kulubi and Langey in the eastern highlands of Ethiopia.

Increasing seed tuber spacing significantly increased plant height. Thus, at both locations plant heights remained high at the spacing of 75 cm × 30 cm, 60 cm × 30 cm, and 60 cm × 25 cm. However, decreasing seed tuber spacing further to 50 cm × 25 cm and 45 cm × 20 cm significantly reduced plant height. There was no significant difference between 50 cm × 25 cm and 45 cm x 20 cm for plant height at both locations (Table 4). At Haramaya and Hirna, the maximum plant height (55.18 and 68.32 cm, respectively) was recorded at relatively widest spacing 75 cm × 30 cm whereas the minimum (46.53 and 54.98 cm, respectively) was recorded at the narrowest spacing 45 cm × 20 cm. The increased plant height at wider spacing might be due to availability of more growth resources under wider spacing for better plant growth per hill than the closer spacing.

Leaf area index

At both Haramaya and Hirna, the main effects of variety and plant spacing significantly (P < 0.01) influenced leaf area index of potato (Table 3). However, a non-significant difference was observed due to the interaction effect of variety and plant spacing on this parameter at both locations. However, the interaction of variety and spacing did not influence leaf area index at both location (Table 8).

The cultivars significantly differed in leaf area index. At Haramaya, the leaf area index of Bubu (2.87) significantly exceeded that of all other cultivars while that of Badhasa, Zemen and Chiro cultivars were in statistical parity with each other. However, at Hirna, the leaf area index of Bubu (3.18) significantly exceeded the leaf area index of only Chiro (2.17), being in statistical parity with the leaf area indices of the other two varieties (Table 3).

Reducing seed tuber spacing (increasing population density) significantly increased the leaf area index of the crop. At Hirna, the narrowest plant seed tuber spacing of 45 cm × 20 cm resulted in the highest leaf area index

Table 4. Average tuber number and average tuber mass of potato as influenced by the main effects of variety and seed tuber spacing at Haramaya and Hirna (2013 main cropping season).

Parameter	Average tuber number (hill)		Average tuber mass (g)	
Variety	**Haramaya**	**Hirna**	**Haramaya**	**Hirna**
Bubu	11.61[ab]	12.43[ab]	53.56[a]	61.26[a]
Badhasa	13.01[a]	13.59[a]	37.35[b]	40.83[c]
Zemen	10.23[b]	12.16[ab]	42.63[b]	47.86[bc]
Chiro	10.81[b]	11.42[b]	49.70[a]	51.31[b]
LSD (0.05)	1.331	1.511	4.686	5.487
F-test	**	*	**	**
Spacing				
75 cm x 30 cm	9.53[b]	10.65[b]	53.99[a]	60.43[a]
60 cm x 30 cm	11.56[ab]	11.17[b]	51.13[a]	57.64[a]
60 cm x 25 cm	10.95[ab]	12.37[ab]	50.14[a]	56.00[a]
50 cm x 25 cm	12.15[a]	13.62[a]	37.79[b]	39.21[b]
45 cm x 20 cm	12.90[a]	14.20[a]	36.00[b]	38.28[b]
LSD (0.05)	1.488	1.689	5.239	6.135
F-test	**	**	**	**
CV%	15.8	16.5	13.8	14.8

Means followed by the same letter within a column for the main effects of variety and plant spacing are not significantly different at 5% level of significance. ** = significant at 1% probability level. * = significant at 5% probability level. LSD = Least significant difference; CV (%) = Coefficient of variation.

(4.087) whereas the wider seed tuber spacing of 75 cm × 30 cm and 60 cm x 30 cm resulted in the lowest leaf area index (1.776 and 2.222, respectively). The spacing of 60cm × 25 cm and 50 cm × 25 cm resulted in intermediate leaf area index values (2.487 and 3.065, respectively). However, at Haramaya, plant seed tuber spacing of 45 cm x 20 cm, 50 cm × 25 cm and 60 cm × 25 cm resulted in the highest leaf area index (2.961, 2.476 and 2.344, respectively) whereas the wider seed tuber spacing of 75 cm × 30 cm and 60 cm × 30 cm resulted in the lowest leaf area index (1.303 and 1.668, respectively) (Table 3). The optimum leaf area index for high yield of potato ranges between 3.0 and 6.0 (Marschner, 1991). Accordingly, in terms of varietal response, it was only the Bubu variety that attained a leaf area index value falling in the optimum range. However, a leaf area index value falling in this range was not attained until narrowing the seed tuber spacing to 45 cm x 20 cm at Haramaya, and 50 cm × 25 cm and 45 cm × 20 cm at Hirna (Table 3). This indicates that the narrower spacing resulted in better canopy coverage for more photo-assimilation to take place through light interception, and may result in better tuber yields of the cultivars.

Yield components

Average tuber number per hill

At both locations, the main effects of variety and spacing significantly ($P < 0.01$) affected average tuber numbers per hill. The mean average tuber number per hill of the two locations revealed that the main effects of both spacing and variety significantly ($P < 0.01$) influenced average tuber number per hill. However, the interaction effect of spacing and variety did not affect this parameter at both locations (Table 8).

At both locations Badhasa produced maximum number of tubers per hill closely followed by Bubu while the lowest number of tubers per hill was produced for Chiro. At Haramaya, a non-significant difference was observed between Zemen and Chiro varieties. At Hirna, Bubu, Badhasa and Zemen varieties were in statistical parity.

Average tuber number per hill responded differently to plant spacing at both locations. Narrowing seed tuber spacing led to the production of significantly higher numbers of tubers per hill. At Haramaya, the highest number of tubers per hill was obtained at the narrowest spacing of 50 cm × 25 cm (12 tubers) and 45 cm × 20 cm (13 tubers) whereas the lowest was obtained at the spacing of 75 cm × 30 cm (9.5 tubers). However, significant differences in average tuber number per hill at Haramaya were observed between plants grown at the spacing of 75 cm × 30 cm one hand and those grown at the spacing of 50 cm × 25 cm and 45 cm × 20 cm on the other hand, with production of significantly higher number of tubers produced at the later spacing. Similarly, at Hirna, the highest number of tubers per hill was produced at the spacing of 50 cm × 25 cm (13.6 tubers) and 45 cm × 20 cm (14 tubers) whereas the lowest were produced at

Table 5. Marketable, unmarketable and total tuber number per m^2 of potato as influenced by the main effects of variety and seed tuber spacing at Haramaya and Hirna during the 2013 main cropping season.

Parameter	Marketable tuber number (m^2)		Unmarketable tuber number (m^2)		Mean	Total tuber number (m^2)	
Variety	**Haramaya**	**Hirna**	**Haramaya**	**Hirna**		**Haramaya**	**Hirna**
Bubu	51.12^a	56.98^a	25.40^d	27.27^d	26.34^d	76.53^a	84.26^a
Badhasa	39.27^b	46.43^b	38.07^b	36.79^b	37.43^b	77.34^a	83.22^a
Zemen	21.45^d	33.58^c	42.56^a	39.31^a	40.93^a	64.00^b	72.89^b
Chiro	30.99^c	32.56^c	31.00^c	30.46^c	30.73^c	61.99^b	63.02^c
LSD (0.05)	2.142	2.46	1.347	1.395	0.983	2.782	2.756
Spacing							
75 cm × 30 cm	44.99^b	48.83^b	9.15^e	6.67^e	7.91^e	54.14^d	55.50^d
60 cm × 30 cm	52.73^a	52.07^b	12.25^d	10.22^d	11.23^d	64.99^c	62.28^c
60 cm × 25 cm	47.90^b	57.73^a	22.50^c	24.67^c	23.59^c	70.4^b	82.40^b
50 cm × 25 cm	18.36^c	31.84^c	53.74^b	53.05^b	53.40^b	72.10^b	84.88^b
45 cm × 20 cm	14.56^d	21.48^d	73.63^a	72.68^a	73.16^a	88.19^a	94.16^a
LSD (0.05)	1.916	2.751	1.505	1.56	1.099	3.11	3.082
F-test	**	**	**	**	**	**	**
CV%	7.3	7.9	5.3	5.6	3.9	5.4	4.9

Means followed by the same letter within a column for the main effects of variety and plant spacing are not significantly different at 5% level of significance. ** = significant at 1% probability level. *= significant at 5% probability level. NS = non-significant. LSD = Least significant difference; CV (%) = Coefficient of variation.

the spacing of 75 cm × 30 cm (10.65 tubers) and 60 cm × 30 cm (11.17 tubers). The tuber numbers produced in response to spacing the plant at 60 cm × 25 cm was in the intermediate range (12.4 tubers).

The increase in the tuber number produced per hill in response to narrowing the seed tuber spacing is due to a stiffer competition among tubers for growth factors, which restricts expansion in size and increases tuber number. Beukema and Vander Zaag (1990) suggested that high plant densities should be used to produce relatively large number of seed size tubers. Similarly, Allen and Wurr (1992) also found that the total number of tubers increased with seed size and reduction of spacing.

Average tuber weight

The main effects of variety and plant spacing significantly ($P < 0.01$) affected average tuber mass of potato at both locations (Table 4). However, variety and spacing did not interact to influence this parameter at both locations (Table 8). At Haramaya, Bubu and Chiro had significantly heavier tubers (53.56 g and 49.7 g, respectively) than the other two varieties. However, at Hirna, Bubu had significantly heavier tubers (61.26 g) than all other three varieties (Table 4).

Increasing seed tuber spacing significantly increased average tuber weight at both locations. Thus, the heaviest tubers were produced at the wider spacing of 75 cm × 30 cm, 60 cm × 30 cm and 60 cm × 25 cm whereas the lightest tubers were produced at the narrower spacing of 45 cm × 20 cm and 50 cm × 25 cm (Table 4). The increase in average tuber weight in response to widening plant spacing may be attributed to less stiffer competition among tubers for growth factors. This suggestion is in agreement also with that of Rex et al. (1987) who postulated that a reduction in the average size of tubers because of increased inter-plant competition with closer spacing.

Marketable tuber number

The main effects of variety and plant spacing significantly ($P < 0.01$) influenced marketable tuber number at both Haramaya and Hirna (Table 5). However, the interaction effect of variety and spacing did not influence this parameter at both locations (Table 8).

Cultivar Bubu produced a significantly higher numbers of marketable tubers at both Haramaya (51.12) and Hirna (56.98). However, Zemen produced the lowest numbers of marketable tubers (21.45) at Haramaya while Zemen and Chiro produced the lowest number of marketable tubers (33.58 and 32.56, respectively) at Hirna (Table 5). For the main effect of spacing, at Haramaya, significantly highest numbers of marketable tubers was recorded at the spacing of 60 cm × 30 cm (52.73 tubers) whereas at Hirna, significantly highest numbers of marketable tubers (57.73) was recorded at the spacing of 60 cm × 25 cm. The highest numbers of marketable tubers was resulted from the spacing of 60 cm × 30 cm (52.73) at Haramaya, and 60 cm × 20 cm (57.73) at Hirna (Table 5). This might be due to reduced competition among tubers for resources and space at wider seed tuber spacing for better tuber enlargement lead to the production of more number of marketable tubers. Corroborating the findings of this study, Frezgi (2007) reported the higher marketable tuber number at wider seed tuber spacing.

Unmarketable tuber number

The main effects of variety and plant spacing significantly ($P < 0.01$) influenced the numbers of unmarketable tubers at Haramaya and Hirna (Table 5). However, variety and spacing did not interact to influence this parameter at both locations (Table 8).

At both locations, Zemen had significantly highest numbers of unmarketable tubers than the other varieties while Bubu had the lowest number of unmarketable tubers. At Haramaya, Zemen had 37.3 and 67.6% more unmarketable tuber numbers than Chiro and Bubu, respectively. However, at Hirna, Zemen exceeded Chiro and Bubu for unmarketable tuber number by about 29.1 and 44.2%, respectively. For the other main effect of spacing, 45 cm × 20 cm spacing resulted in a significantly higher number of unmarketable tubers over the other spacing while the spacing of 75 cm × 30 cm led to the production of the lowest number of unmarketable tubers (Table 5). At Haramaya, the narrowest spacing of 45 cm × 20 cm led to the production of 37, 227.24, 501.1 and 705% more numbers of unmarketable tubers over the spacing of 50 cm × 25 cm, 60 cm × 25 cm, 60 cm × 30 cm, and 75 cm × 30 cm, respectively. However, at Hirna, the narrowest spacing of 45 cm × 20 cm exceeded the spacing of 50 cm × 25 cm, 60 cm × 25 cm, 60 cm × 30 cm, and 75 cm × 30 cm spacing by about 37, 194.6, 611.2 and 989.7% more unmarketable tuber numbers, respectively.

Unmarketable tuber numbers increased with decreased plant spacing. This could be attributed to stiffer competitions for growth factors which might have led to the production of under-sized tubers, which are unmarketable. Consistent with the results of this study, Frezgi (2007) also indicated that closer see tuber spacing resulted in a significantly higher yield of small-sized tubers as the consequence of higher competition between plants. Similarly, Tesfa (2012) reported that the narrower spacing of 50 cm × 25 cm and 60 cm × 25 cm resulted in the production of large numbers of under-sized unmarketable tubers compared to the wider spacing of 80 cm × 30 cm and 75 cm × 30 cm.

Total tuber number

At both locations, the main effects of variety and plant spacing had significantly ($P < 0.01$) influenced total tuber numbers (Table 5). However, variety and spacing did not interact to influence this parameter at both locations (Table 8).

At both locations, Bubu and Badhasa produced the highest total tuber numbers. Zemen and Chiro had produced the lowest total tuber numbers (64 and 61.99) at Haramaya whereas Chiro produced the lowest total tuber number (63.02) at Hirna (Table 5). Decreasing spacing significantly increased total tuber number per unit area. Thus, the narrowest spacing of 45 cm × 20 cm resulted in a significantly higher total tuber number than the wider spacing of 75 cm × 30 cm, which produced the lowest total tuber number at both locations. The trend was similar between all the spacing at both locations. Decreasing spacing from 75 cm × 30 cm to 45 cm × 20 cm significantly increased total tuber number per unit area by about 62.89% at Haramaya. Similarly, reducing seed spacing from 75 cm × 30 cm to 45 cm × 20 cm significantly increased total tuber number per unit area by about 69.66% at Hirna.

In general, decreasing the seed tuber spacing led to a significant increase in the number of total tubers produced. This could be attributed to the production of lager numbers of tubers per unit area at the narrower spacing than at wider spacing, owing to stiffer competition among tubers for resources, which would limit their expansion in size. The results of this study are in agreement with the findings of other authors (Beukema and Van der Zaag, 1990), who reported that high planting densities should be used to produce relatively large numbers of seed-sized tubers.

The highest numbers of marketable tubers per unit area of land were obtained from the spacing of 60 cm x 30 cm (52.4 tubers) and 60 cm × 25 cm (52.81 tubers), indicating that the two seed tuber spacing produced the largest number of tubers fit to be used as seed.

Marketable, total, and unmarketable tuber yields

The main effects of variety and plant spacing significantly ($P < 0.01$) affected marketable and total tuber yields at both locations (Table 6). Variety and spacing interacted significantly ($P < 0.01$) to influence unmarketable tuber yield at both locations (Table 7). However, the interaction effect of variety and plant spacing did not affect marketable and total tuber yields at both locations (Table 8). At both locations, Bubu produced the maximum marketable and total tuber yields whereas Zemen produced the minimum. However, Bubu did not differ significantly from Badhasa and Chiro for total tuber yield at Hirna. Higher marketable tuber yields were obtained at Haramaya in response to planting the seed tubers at the spacing of 60 cm × 30 cm (24.7 ton ha^{-1}), 60 cm × 25 cm (22.68 ton ha^{-1}) and 75 cm × 30 cm (24.03 ton ha^{-1}) (Table 6). At Hirna, higher marketable tuber yields were obtained at all spacing except for 45 cm × 20cm (18.53 ton ha^{-1}). However, the spacing of 45 cm × 20 cm, 50 cm

Table 6. Marketable and total tuber yields of potato as influenced by the main effects of variety and seed tuber spacing at Haramaya and Hirna during the 2013 main cropping season.

Parameter	Marketable tuber yield (ton/ha)		Total tuber yield (ton/ha)	
Variety	**Haramaya**	**Hirna**	**Haramaya**	**Hirna**
Bubu	29.91[a]	30.01[a]	37.84[a]	42.96[a]
Badhasa	23.27[b]	21.86[bc]	32.82[b]	37.71[a]
Zemen	16.20[c]	18.34[c]	24.33[d]	31.61[b]
Chiro	18.14[c]	24.90[ab]	27.83[c]	37.49[ab]
LSD (0.05)	1.796	4.626	2.176	4.583
Spacing				
75 cm x 30 cm	24.03[a]	26.29[a]	25.00[b]	29.95[c]
60 cm x 30 cm	24.70[a]	27.99[a]	28.38[b]	33.50[bc]
60 cm x 25 cm	22.68[ab]	24.52[ab]	32.11[a]	40.20[ab]
50 cm x 25 cm	20.11[bc]	21.56[ab]	33.75[a]	41.48[a]
45 cm x 20 cm	17.88[c]	18.53[b]	34.29[a]	42.07[a]
LSD (0.05)	2.008	5.172	2.433	5.124
F-test	**	**	**	**
CV%	11.1	26.3	9.6	16.6

Means followed by the same letter within a column for the main effects of variety and plant spacing are not significantly different at 5% level of significance. ** = significant at 1% probability level. LSD = Least significant difference; CV % = Coefficient of variation.

Table 7. Unmarketable tuber yield (ton/ha) of potato as influenced by interaction effect of variety and seed tuber spacing at Haramaya and Hirna during the 2013 main cropping season.

Parameter		Unmarketable tuber yield (ton/ha)	
Variety	**Spacing**	**Haramaya**	**Hirna**
	75 cm × 30 cm	0.500[hi]	3.49[h]
	60 cm × 30 cm	3.143[ghi]	4.62[gh]
Bubu	60 cm × 25 cm	9.504[f]	14.54[f]
	50 cm × 25 cm	12.086[def]	18.41[de]
	45 cm × 20 cm	14.412[bcd]	23.66[b]
	75 cm × 30 cm	2.502[ghi]	4.35[gh]
	60 cm × 30 cm	4.681[g]	6.87[g]
Badhasa	60 cm × 25 cm	9.940[ef]	18.19[de]
	50 cm × 25 cm	13.516[cd]	22.79[bc]
	45 cm × 20 cm	17.137[ab]	27.04[a]
	75 cm × 30 cm	0.031[i]	3.35[h]
	60 cm × 30 cm	3.695[gh]	5.95[gh]
Zemen	60 cm × 25 cm	9.152[f]	14.73[f]
	50 cm × 25 cm	13.130[cde]	19.80[cd]
	45 cm × 20 cm	14.674[bcd]	22.48[bc]
	75 cm × 30 cm	0.849[hi]	3.43[h]
	60 cm × 30 cm	3.217[ghi]	4.57[gh]
Chiro	60 cm × 25 cm	9.120[f]	15.28[ef]
	50 cm × 25 cm	15.851[bc]	18.69[d]
	45 cm × 20 cm	19.397[a]	21.01[bcd]

Table 7. Contd.

LSD (0.05)	1.844	1.775
F-test	**	*
CV%	12.6	7.9

Means followed by the same letter within a column for the interaction effect of variety and plant spacing are not significantly different at 5% level of significance. ** = significant at 1% probability level. * = significant at 5% probability level. LSD = Least significant difference; CV% = Coefficient of variation.

Table 8. Mean squares from analysis of variance (ANOVA) for potato parameters at Haramaya and Hirna.

Location	Variables	Replication	Variety (V)	Spacing (S)	V x S	Error
	Degrees of freedom	**2**	**3**	**4**	**12**	**38**
Haramaya	Maturity days (50%)	23.117	17**	60.558**	18.792**	3.046
	Plant height	30.34	1153.76**	175.62**	19.26^{ns}	32.05
	Leaf area index	0.1368	3.9045**	5.2544**	0.388^{ns}	0.3053
	Tuber number/hill	33.467	17.384**	8.57**	4.651^{ns}	3.448
	Tuber mass (g/tuber)	278.77	783.98**	823.47**	63.07^{ns}	40.18
	Marketable tuber number	36.661	2380.138**	3818.775**	9.94^{ns}	6.72
	Total tuber number	62.88	983.39**	1836.67**	8.12^{ns}	14.16
	Marketable tuber yield	3.648	563.762**	97.006**	10.866^{ns}	5.904
	Unmarketable tuber yield	1.115	12.763**	507.564**	4.17**	1.245
	Total tuber yield	7.658	521.553**	186.133**	8.426^{ns}	8.664
Hirna	Maturity days (50%)	0.717	37.75**	16.442**	3.486*	1.366
	Plant height	188.52	686.06**	415.03**	26.67^{ns}	54.52
	Leaf area index	1.5887	2.9059**	9.5465**	0.439^{ns}	0.4033
	Tuber number/hill	5.642	12.214*	27.915**	5.613^{ns}	4.179
	Tuber weight (g/tuber)	57.38	1084.04**	1369.32**	52.21^{ns}	55.1
	Marketable tuber number	3.91	2017.24**	2756.6**	11.97^{ns}	11.08
	Total tuber number	22.45	1491.66**	3173.98**	13.15^{ns}	13.9
	Marketable tuber yield	66.22	366.5**	171.43**	34.03^{ns}	39.17
	Unmarketable tuber yield	0.135	32.947**	923.018**	2.975*	1.153
	Total tuber yield	65.21	322.76**	351.31**	35.94ns	38.44

× 25 cm and 60 cm × 25 cm produced high total tuber yield at both locations (Table 6). The increased yield at higher densities may be due to ground coverage with green leaves earlier in the season for photosynthesis to take place efficiently. In this case, maximum light is intercepted and used for photo assimilation; fewer lateral branches are formed and tuber growth starts earlier. Consistent with these results, increased plant population increased yield due to more tubers being harvested per unit area of land (Beukema and Vander Zaag, 1990). This result shows that narrower spacing may be required for high yield of potato tuber than the commonly used spacing practiced by the research system of the country now, which is 75 cm x 30 cm. The result of this study agrees with the findings of various authors such as Wurr (1974b) who reported narrow plant spacing led to the production of a higher total tuber yield than wider spacing. Similarly, Nelson (1967) found that a higher plant population density resulted in slightly higher total yields and a greater number of small tubers.

At both locations, the varieties responded differently to spacing treatments for unmarketable tuber yields. Thus, all the varieties produced the highest unmarketable tuber yield at narrow spacing. At Haramaya, the highest unmarketable tuber yield was obtained from Chiro (19.39 ton ha^{-1}) and Badhasa (17.14 ton ha^{-1}) at the narrowest spacing of 45 cm × 20 cm. The next highest yields were obtained from Bubu (14.41 ton ha^{-1}) and Zemen (14.67 ton ha^{-1}) at narrow spacing of 45 cm × 20 cm. The least unmarketable yield was obtained from all varieties at wider spacing of 75 cm x 30 cm (Table 7). Similarly, at Hirna, a significantly highest unmarketable yield (27.04

ton ha^{-1}) was obtained from Badhasa at the narrowest spacing of 45 cm × 20 cm. The least unmarketable yields were obtained for Bubu, Zemen and Chiro at the wider spacing of 75 cm × 30 cm and 60 cm × 30 cm (Table 7). This could be due to stiffer competition at closer spacing for nutrients, moisture and light which promotes the production of more numbers of undersize tubers, which are unmarketable. Frezgi (2007) reported that closest spacing resulted in significantly higher yield of small tubers as the consequence of higher competition between plants. Similarly, Tesfa (2012) also reported that high unmarketable tuber yield was observed at high planting density while a wider spacing of 80 cm × 30 cm and 75 cm × 30 cm resulted in a lower unmarketable tuber yield.

Conclusion

The results of this study have revealed that the spacing of 75 cm × 30 cm, 60 cm × 30 cm, and 60 cm × 25 cm produce higher marketable tuber yields than the other spacing, and are appropriate for ware potato production. However, the intermediate seed tuber spacing of 60 cm × 30 cm and 60 cm × 25 cm seem appropriate for seed tuber production. Denser spacing of 45 cm × 20 cm, 50 cm × 25 cm and 60 cm × 25 cm produced the highest total tuber yields and consequently higher total starch per hectare. Bubu was superior to other cultivars for all agronomic parameters including tuber yield.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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