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Effect of inter and intra row spacing on seed tuber yield and yield components of potato (*Solanum tuberosum* L.) at Ofla Woreda, Northern Ethiopia

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Farmers in southern zone of Tigray are using different spacing below or above the national recommendation depending on the purpose of planting either for seed tuber or consumption due to lack of recommended plant spacing. This study was therefore conducted with the objective of determining the best inter and intra-row spacing for optimum tuber seed yield and quality of potato seed tuber at Ofla Wereda, Northern Ethiopia. Four different intra-row (20, 25, 30 and 35 cm) and inter-row (65, 70, 75 and 80 cm) spacing were used in the experiment. The result reveals that inter and intra-row spacing significantly ($p<0.001$) affected seed tuber yield ha^{-1}, the maximum seed tuber yield (36.89 and 37.54 ton ha^{-1}) was recorded at 65 and 20 cm inter and intra-row spacing, respectively. From this study, it can be concluded that the narrow spacing (20 and 65 cm intra and inter-row spacing) produced higher seed tuber yield per hectare than other spacings. Thus, potato (Jalenie variety) growers in the study area can benefit if they use this narrow spacing (20 and 65 cm intra and inter-row spacing).

Key words: Potato, intra-row spacing, inter-row spacing, seed tuber yield.

INTRODUCTION

Potato (*Solanum tuberosum* L.) originated from the high Andes of South America and was first cultivated in the vicinity of Lake Titicaca near the present border of Peru and Bolivia (Horton, 1987). In terms of quantity produced and consumed worldwide, potato is the most important vegetable crop. It is one of the most important food crops in the world; it produces more energy and protein per unit area and unit of time than most other major food crops.

The potato crop was introduced to Ethiopia around 1858 by Schimper, a German botanist (Pankhurst, 1964). Among African countries, Ethiopia has possibly the greatest potential for potato production; 70% of its arable land mainly in highland areas above 1500 m is believed to be suitable for potato. Since the highlands are also home to almost 90% of Ethiopia's population, the potato could play a key role in ensuring national food security

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(FAO, 2008). However, the current area cropped with potato is about 0.16 million hectares and the national average yield is about 7.2 t/ha, which is very low as compared to the world's average production of 16.8 t/ha (Adane et al., 2010). The crop yield in Ethiopia is lower than that of most potato producing countries in Africa like South Africa and Egypt, which produce 34.0 and 24.8 t/ha, respectively (FAO, 2008).

Many diverse and complex biotic, abiotic and human factors have contributed to the existing low productivity of potato. Some of the production constraints which have contributed to the limited production or expansion of potato in Ethiopia include shortages of good quality seed tubers of improved cultivars, disease and pests, and lack of appropriate agronomic practices including optimum plant density, planting date, soil moisture, row planting, depth of planting, ridging and fertility status (Berga et al., 1994).

The optimization of plant density is one of the most important subjects of potato production management, because it affects seed cost, plant development, yield and quality of the crop (Bussan et al., 2007). The yield of seed potato can be maximized at higher plant population (closer spacing) or by regulating the number of stems per unit area and to certain extent by removing the haulm earlier during the maturity (O'Brien and Allen, 2009). Rahemi et al. (2005) reported that the effect of intra-row spacing on yield of potatoes was significant especially at 20 cm intra-row spacing, which showed 36.85% yield increment as compared to 30 cm intra-row spacing. Intra-row distance of 20 cm increased total tuber number and weight, and tuber weight per plant and the marginal return rate increased by 13% when intra-row distance decreased from 35 to 25 cm. EARO (2004) also determined that there is a little difference in yield between intra-row spacing of 25 and 30 cm for all varieties released so far in Ethiopia and the 30 cm intra-row and 75 cm inter-row spacing accepted as standard.

Farmers in the study area (Sothern zone of Tigray) are using different spacing below or above the national recommendation depending on the purpose of planting either for consumption or for seed tuber due to lack of recommended inter and intra-row spacing. Hence, it is important to maintain appropriate plant population per unit area to have high yield, marketable size and good quality of seed tuber. Even though different research is done in different parts of the country on potato plant density, the condition is not studied in Ofla Woreda, Southern Zone of Tigray. This study was therefore conducted to determine the best inter and intra-row spacing for optimum tuber seed yield and quality of potato seed tuber at Ofla Wereda, Northern Ethiopia.

MATERIALS AND METHODS

The experiment was conducted in 2011/2012 under irrigation condition in Southern Zone of Tigray, Ofla Woreda at Hashenge Kebele, on farmer's field. The experimental site is located at an elevation of 2500 m above sea level. Maximum and minimum temperature ranges from 22.57and 6.8°C, respectively. The mean annual rainfall of the area is 806.5 mm. The major soils include clay (28%), loam (57%) and sandy (15%) with a pH of 6.8 (BoARD, 2009).

The Woreda is classified into three agro-ecological zones, namely, highland, midland and lowland. The midland covers the largest part which accounts about 42% of the total 133, 296 ha while both the highland and lowland covers 29%. The average land holding in the Woreda is about 0.5 ha per household and estimated total population of 132,491 (BoARD, 2009).

Different local and improved potato varieties are being grown in the area. Among the improved variety, Jalenie is growing widely and has got acceptance by farmers due to its high yielding ability and acceptability by consumers.

The experiment was laid out in 4 x 4 factorial arrangements using a Randomized Complete block design (RCBD) with three replications and two factors, which consisted of four different intra-row spacing: 20, 25, 30 and 35 cm, and four different inter-row spacing: 65, 70, 75 and 80 cm. Each plot contain four rows with different plot size of (3.15 x 3.2, 3.15 x 3, 3.15 x 2.8, 3.15 x 2.6) and different number of plants per row which includes 15, 12, 10, 9 plants for 20, 25, 30 and 35 cm intra row spacing, respectively. A foot path of 0.5 and one meter was left between plots and blocks, respectively.

The collected data on different growth stage was analyzed by using SAS Computer software version 9.0 (SAS Institute Inc., 2008).

RESULTS AND DISCUSSION

Leaf area index

Intra-row spacing showed a very highly significant ($P<0.001$) effect on leaf area index. However, the effect of inter-row spacing and interaction showed no significant difference in leaf area index (Figure 1). The result revealed that significantly the highest leaf area index (3.21) was recorded at 20 cm intra-row spacing, and this could be due to high number of haulms per unit area. Whereas the lowest (2.32) leaf area index was recorded from 35 cm intra-row spacing and it is statistically difference from the other three (30, 25 and 20 cm) intra-row spacings.

This result is in agreement with the findings of Ronald (2005) and Tamiru (2005) who reported that the highest density increased leaf area index, possibly indicating potential partitioning of assimilates for vegetative growth.

Total tuber seed yield (t/ha)

The effect of inter-row and intra-row spacing showed a very highly significant ($P<0.001$) differences on total tuber yield ha^{-1} (Table 1). However, the interaction effect was non-significant ($P>0.05$). The highest yield (36.89 t/ha) was obtained from 65 cm inter-row spacing, whereas the lowest (31.87 t/ha) yield was recorded at 80 cm inter-row spacing.

Regarding the intra-row spacing, the higher total yield

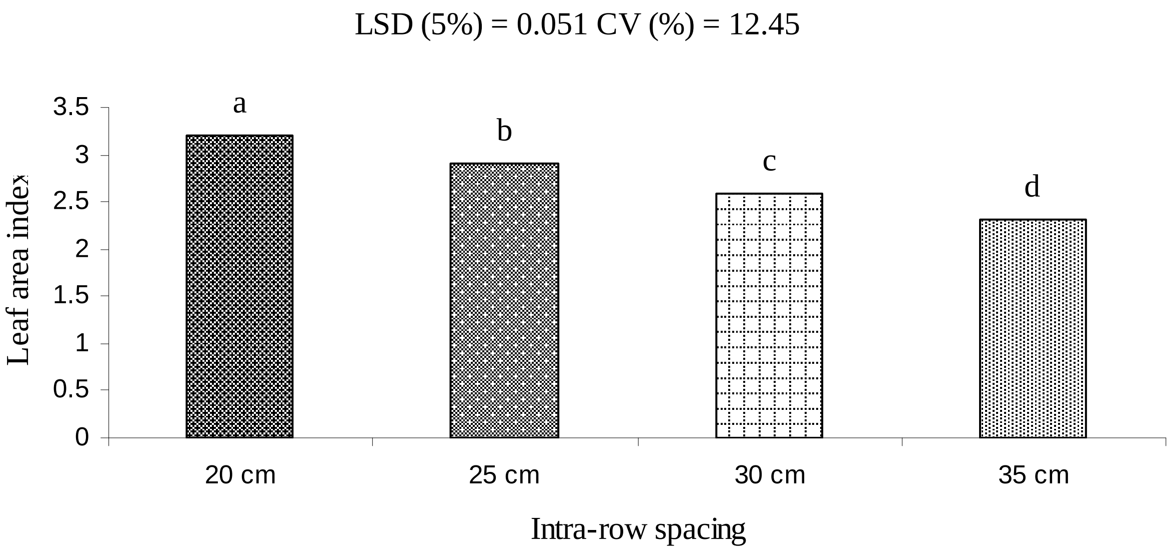

Figure 1. Means for the effect of intra-row spacing on leaf area index.

Table 1. Means for the effect of inter and intra-row spacing on total tuber yield and marketable tuber seed yield per hectare

Treatment	Total tuber seed yield (t/ ha)	Marketable seed tuber yield (t/ ha)
Intra-row spacings (cm)		
20	37.54[a]	35.89[a]
25	35.75[b]	34.49[b]
30	35.61[b]	34.66[b]
35	29.38[c]	28.65[c]
Inter-row spacings (cm)		
65	36.89[a]	35.09[a]
70	35.33[b]	33.86[b]
75	34.18[b]	33.32[b]
80	31.87[c]	31.42[c]
LSD (5%)	1.18	1.18
CV (%)	11.25	10.31

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

per hectare (37.54 t/ha) was obtained from 20 cm intra-row spacing. As intra-row spacing increased from 20 to 35 cm, total tuber yield decreased from 37.54 to 29.38 t/ha. Intra-row spacing of 35 cm showed lower total tuber yield (29.38 t/ha) and it was significantly different from the three levels. It was clearly evident from the results that the yield of seed tuber per hectare was increased with decreasing plant spacing.

The increased yield was attributed to more tubers produced at the higher plant population per hectare although average tuber size was decreased because of increased inter-plant competition at closely spaced plants leading to more unmarketable tuber yield. At closer spacing there is high number of plants per unit area which brings about an increased ground cover that enables more light interception, consequently influencing photosynthesis. It is therefore, very likely that substantial increases in rate of land coverage and thereby tuber yield could be achieved by dramatically increasing the stem density per unit area.

The present result agrees with the findings of Zabihi et al. (2011) who reported that plant density in potato affects some of the important plant traits such as total yield, tuber size distribution and tuber quality. Increase in plant

Table 2. Means for the effect of inter and intra-row spacing on total and marketable seed tuber number of tuber ha^{-1}.

Treatment	Total number of seed tuber per hectare	Number of marketable seed tuber per hectare
Intra-row spacing(cm)		
20	558174[a]	501651[a]
25	486858[b]	445568[b]
30	455014[bc]	423513[bc]
35	430311[c]	395106[c]
Inter-row spacing (cm)		
65	532865[a]	485144[a]
70	496599[a]	455026[a]
75	453307[b]	411315[b]
80	447586[b]	414352[b]
LSD (5%)	37587.6	37667.7
CV (%)	15.57	15.61

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

density led to decrease in mean tuber weight but number of tubers and yield per unit area were increased. In contrast, Berga et al. (1994) reported that wider row width by wider in-row distance (80 x 40 cm) gave the highest yield (34 t/ha) and the 60 x 20 treatment gave the lowest yield (22.2 t/ha).

Marketable seed tuber yield (t/ha)

The data concerning marketable yield as influenced by planting density is presented in Table 1. Inter and intra-row spacing showed a very highly significant ($P<0.001$) effect on marketable yield. Significantly maximum marketable yield (35.89 and 35.09 t/ha) was obtained at a 20 and 65 cm intra and inter-row spacing, respectively. While the lowest marketable yield (28.65 and 31.42 t/ha) was obtained at the wider spacing (35 cm intra and 80 cm inter-row spacing, respectively). However the interaction effect did not show significant difference on marketable yield per hectare.

The highest marketable yield recorded at closer spacing is attributed to more tubers produced at the higher plant population per hectare. The present result agreed with the findings of many authors (Stoffella and Bryan, 1988; Khalafalla, 2001) regarding plant density effect on marketability of the crop. Close spacing of 15-25 cm was reported to give better proportion of marketable yield than wider spacing of 35 cm.

Total number of tubers per hectare

The results of total number of tuber (ha^{-1}) as influenced by inter and intra-row spacing is presented in Table 2. Inter and intra-row spacing had very highly significantly ($P<0.001$) affected total number of tuber per ha. Significantly maximum total number of tuber per hectare (532,865) was recorded at 65 cm inter-row spacing. While the lowest number of tuber per hectare (447,586) was obtained at wider spacing (80 cm) inter-row spacing.

As far as the intra-row spacing is concerned, significantly maximum total number of tuber per hectare (558,174) was obtained from 20 cm spacing. Whereas the lowest total number of tuber per hectare (430,311) was obtained at 35 cm spacing. Total tuber number per hectare was increased with closer spacing. The highest number of tuber at closer spacing is due to high number of plants per unit area. Rahemi et al. (2005) reported that intra-row distance of 20 cm increased total tuber number and weight per unit area.

Marketable seed tuber number per hectare

Marketable tuber number (000's ha^{-1}) as influenced by inter-row and intra-row spacing is presented in Table 2. Inter and Intra-row spacing had very highly significant ($P<0.001$) effect on marketable tuber number per hectare. However, the interaction effect had no significant ($P>0.05$) effect on marketable tuber number per hectare. Maximum marketable tuber number (485,144 and 501,651) was obtained at 65 and 20 cm inter and intra-row spacing respectively, while the result recorded at 20 cm intra-row spacing was significantly different from the other intra-row spacings. The lowest number of marketable tuber per hectare (411,315 and 395,106) was obtained at 80 cm inter and 35 cm intra-row spacing, respectively. Among the inter-row spacings, statistically, the same results were obtained from 65 and 70 cm, which scored the highest marketable tuber number per hectare, 485,144 and 455,026, respectively.

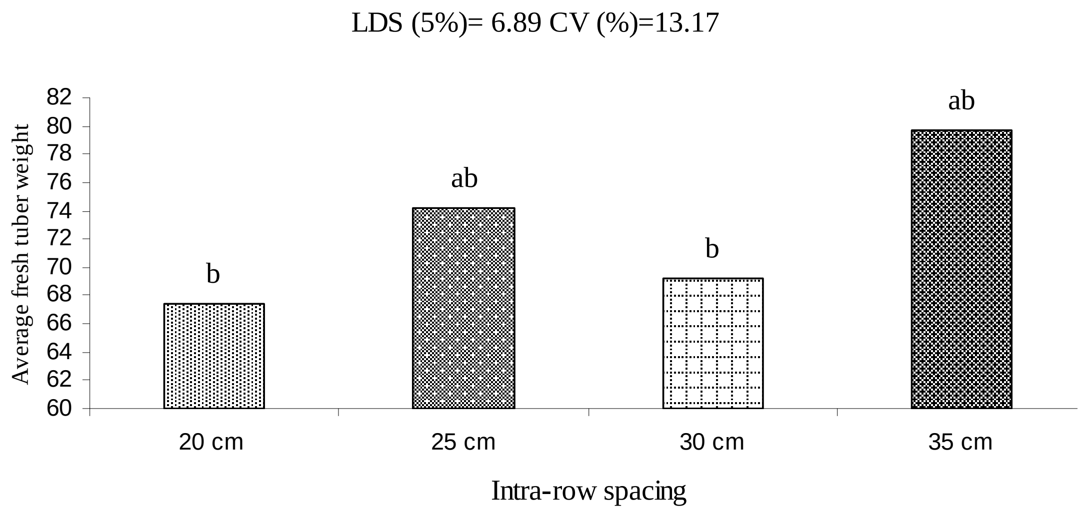

Figure 2. Means for the effect of intra-row spacing on average fresh tuber weight.

Related study was reported by Burton (1989); wider spacing may produce few tubers as it gave rise to few stems that could lead to high number and possibly misshapen tuber while, closer spacing improved quality and saleable yield.

Average fresh tuber weight (g)

Intra-row spacing showed highly significant (P<0.01) difference on average fresh tuber weight per plant (Figure 2). However, the main effects of inter-row spacing and its interaction with intra-row spacing had no significant (P>0.05) difference on average fresh tuber weight. The maximum mean tuber weight (79.68 g) was recorded at 35 cm intra-row spacing but not statistically different with 25 cm intra-row spacing. The smallest average fresh tuber weight (67.3 g) was recorded at 20 cm intra-row spacing. However, it was not significantly different from 25 and 30 cm intra-row spacing for the values of (74.24 and 69.16 g, respectively).

Increase in density probably increased competition between and within plants and hence, leads to decrease in availability of nutrients to each plant and consequently, resulted in decline of mean tuber weight. This result is in line with that of Ali (1997), who found higher average fruit weight at wider spacing as compared to closer spacing. Berga and Caesar (1990) also reported that stem number per plant and tuber number per plant are positively related, however, average tuber weight increased with wider spacing.

Tuber size category

Intra-row spacing had shown highly significant (P<0.01) effect on number of tubers graded less than 20 mm (Table 3). Maximum (9.96%) less than 20 mm number was recorded at intra-row spacing of 20 cm. However, it was not significantly different from 25 cm intra-row spacing. While, the lowest (6.629%) was at 35 cm. Intra-row spacing also showed a very highly significant (P<0.001) effect on weight of tubers graded less than 20 mm. Significantly maximum (0.74%) less than 20 mm weight was recorded at intra-row spacing of 20 cm. It was significantly different from the other intra-row spacings. However, the effect of inter-row spacing and interaction effect had no significant (P>0.05) difference for number and weight of tubers graded less than 20 mm.

Intra-row spacing also showed very highly significant (P<0.001) effect on tubers graded greater than 50 mm in terms of number and weight. Significantly maximum (23.74 number and 52.91 weight percent) greater than 50 mm graded tuber was recorded at 35 cm intra-row spacing. While, the lowest (18.50 number and 42.30 weight percent) was recorded at 20 cm intra-row spacing. Inter-row spacing showed highly significant (P<0.01) effect on tuber graded 30-40 mm weight.

The highest (17.14 percent) tubers graded 30-40 mm weight was recorded at 65 cm inter-row spacing. The results of this investigation clearly indicated that the level of intra-row spacing largely affected potato tuber size distribution. Thus, based on market and consumers' demand, it is possible to produce either seed potato or ware potato of required size through the selection of appropriate planting density (intra-row spacing).

The present result is in agreement with the findings of Wiersema (1987) who reported that at higher stem density, the tuber produced will remain smaller than at lower stem densities. Khajehpour (2006) also reported that increase in plant density decreases mean tuber size probably because of plant nutrient elements reduction, increase in interspecies competition and large number of tubers produced by high numbers of stems. Generally,

Table 3. Means for the effect of intra-row spacing on tuber size category.

Intra-row spacing (cm)	Weight of tubers graded less than 20 mm (%)	Number of tubers graded less than 20 mm (%)	Weight of tubers graded greater than 50 mm (%)	Number of tubers graded greater than 50 mm (%)
20	0.7335[a]	9.961[a]	42.30[c]	18.50[b]
25	0.7066[b]	8.121[ab]	44.21[c]	19.02[b]
30	0.6808[c]	7.485[b]	49.06[b]	22.00[a]
35	0.5005[d]	6.629[b]	52.91[a]	23.74[a]
LSD (5%)	0.005	1.904	3.401	2.419
CV (%)	14.10	25.2	12.12	17.55

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

the result of this study indicates that tuber size category is influenced mainly by intra-row spacing rather than inter-row spacing.

Summary and conclusion

The result of this study demonstrated that yield per unit area is influenced by the different level of inter and intra-row spacing. From this study, it can be concluded that the narrow spacing (20 and 65 cm intra and inter-row spacing) produced higher seed tuber yield and marketable yield per hectare than other spacings. Thus, potato (Jalenie variety) growers in the study area (southern zone of Tigray) can benefit if they use this narrow spacing (20 and 65 cm intra and inter-row spacing).

Conflict of Interests

The author(s) have not declared any conflict of interests.

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