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Effects of inter and intra rows spacing on the growth and yield of potato grown under irrigation system, at Shinta nursery site, Amhara region, Ethiopia

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Abstract

Potato is the most important tuber crop in Ethiopia. However, its productivity is restricted by inapt intra- and inter-row spacing. This study aimed to assess the effects of intra- and inter-row spacing on potato growth and yield. The experiment utilized three intra-row spacings (20, 30, and 40 cm) and three inter-row spacings (60, 70, and 80 cm) within a randomized complete block design (RCBD). Irrigation was applied throughout the entire experiment. The result revealed that intra- and inter-row spacing significantly impacted different features of the crop. A bigger inter-row spacing (80 cm) was comparatively better for growth parameters, but a closer intra-row spacing (20 cm) was better for yield components. A higher total yield (34 t ha^{-1}) was obtained with 20 cm × 80 cm spacing. Overall, potato cultivators are advised to employ a 20 cm × 80 cm spacing under irrigation, and further research should be conducted on the effects of spacing.

Key words: Tuber, potato, plant height, yield

Introduction

The potato (*Solanum tuberosum* L.) is an important food and cash crop being used as an income source globally (Kundu *et al.*, 2024). Globally, potato is the fifth most cultivated food crop, next to sugar cane, wheat, rice, and maize (FAO, 2023) with an annual production of 176.1 million tons. In Africa, it is also used as a food source (Devaux *et al.*, 2021).

According to CSA (2020), the average yield/ha of potato ranged from 79.89 q/ha to 141.76 q/ha within the last ten years in the Meher season in Ethiopia. The country has significant potential to enhance the productivity of potatoes, particularly in the northwestern regions, where current yields remain below 10 t/ha (Amare *et al.*, 2022). The Amhara region is the major potato-growing area in the country, accounting for about 40% of the potato farmers (Deressa *et al.*, 2017). Gondar is amongst the major potato production zones in north northwestern part of Ethiopia.

Various factors limit potato productivity in Ethiopia including inadequate production technologies, pests, diseases and poor seed distribution system (Gebru *et al.*, 2017) and spacing impact is another factor (Limeneh *et al.*, 2021). The different phenological, growth and yield parameters can all be greatly impacted by proper plant spacing. Research has shown that optimal spacing can improve tuber quality, boost yield, and raise farmers' economic returns (Dagar *et al.*, 2023). The optimal plant density is important for achieving maximum products in crops (Derebe and Kola, 2024). In Ethiopia, predominantly in the Amhara region, where irrigation is progressively utilized to increase potato production, there is a dearth of research recommending farmers on the ideal inter- and intra-row spacing. Some studies were conducted on the efficiency and profitability of potato and red pepper in Ethiopia's Bale and North Gondar zones (Dube *et al.*, 2018; Abate *et al.*, 2019).The study fills the gaps in relation to the spacing that optimize yield and promotes sustainable potato production in the area. Thus, this study focused on how the growth and yield of local potato cultivars are affected by intra- and inter-row spacing, as well as recommending the optimal spacing.

Materials and methods

Study area: This study was conducted at Shinta Nursery Site, University of Gondar, Gondar, Ethiopia. Gondar city, in Amhara Region, lies north of Lake Tana along the Angereb River, southwest of the Simien Mountains, about 727 km from Addis Ababa. It is positioned at 12°29'0"N to 12°40'0"N latitude and 37°19'0"E to 37°45'0"E longitude, at 2, 133m elevation.t

Study cultivar: High-quality seeds of the DAGIM potato cultivar were procured from the Gondar Agricultural Research Center. This cultivar was chosen due to its adaptability to the study area. Fertilizer was applied during sowing and urea was administered in two stages: at sowing and during the flowering phase.

Treatments and experimental design: The field experiment was done in irrigation system that included a factorial combination of three levels of inter-row spacing (60, 70, and 80 cm) and three levels of intra-row spacing (20, 30, and 40 cm). This resulted in nine treatment combinations: 60 cm x 20, 60 x 30, 60 x 40, 70 x 20, 70 x 30, 70 x 40, and 80 x 20, 80 x 30, 80 x 40 (Table 2). The experimental setup included a randomized complete block design (RCBD) with three replications. Plot sizes ranged from 7 rows for 60 cm to 6 rows for 70 cm and 5 rows for 80 cm, depending on the inter-row spacing. Each plot measured 12.6 m² (4.2 m × 3 m). The inter-row spacing varied, as did the net plot area.

Table 1. Details of experimental units

Experimental units	Inter-row spacing (cm)	Intra-row spacing (cm)	Number of rows	Number of plants per row	Total plants for one replication per plot	Harvested row	Plants grow in net plot area per plot per replication	Net plot area (data collected (m^2)
1	60	20	7	15	105	5	75	9
2	70	20	6	15	90	4	60	8.4
3	80	20	5	15	75	3	45	7.56
4	60	30	7	10	70	5	50	9
5	70	30	6	10	60	4	40	8.4
6	80	30	5	10	50	3	30	7.56
7	60	40	7	7	49	5	35	9
8	70	40	6	7	42	4	28	8.4
9	80	40	5	7	35	3	21	7.56

Experimental procedures: The experimental field was prepared using traditional ox-drawn ploughing and harrowing. Additionally, large clods were broken down to get a fine tilth to make it suitable for growth. Canals for drainage and irrigation were constructed to help water flow easily. The plots were made ready to fix the potato. Then, potato tuber fragments with two eyes were planted into the soil in the plots on February 15, 2023. Finally, the growing tubers were irrigated every two days during the first four weeks and were extended to seven days until 15 days before harvest. Good management practices such as weeding, watering, and other suggested agricultural practices were implemented for all experimental units. When neck fall was observed in 70% of the plants, collection was initiated. The potato tubers were windrowed on the ground and cured for four days after harvesting.

Data collection: Growth and yield data were collected from five randomly selected, pre-tagged plants in each plot. However, flowering date and days to maturity were recorded on a plot basis. The following parameters were measured accordingly.

Phenological data: Both the first flowering date and days to maturity were recorded. Days to 50% flowering was recorded as the actual number of days from the date of planting to when 50% of the plant populations in each plot were bloomed and produced flowers. Days to 50% physiological maturity was recorded when the haulms (vines) of 70% of the plant population per plot showed signs of senescence and turned yellowish.

Growth data

The growth data, including plant height, number of branches, number of leaves, and canopy diameter, were measured in the study.

Plant height: Plant height was also measured in centimetres from the soil surface to the tip of the matured leaf in the plant at maturity for the randomly selected five plants per plot.

Number of branches: The number of branches per plant was counted at maturity. When counting the number of branches, only stems that had directly grown from the mother plant, which acted as an independent plant above the soil, were considered main stems.

Number of leaves per plant: The number of leaves per plant was determined by counting all leaves from five previously tagged plants in each plot before the start of tuber formation at 50% flowering stage. Then, the average was taken as the number of leaves.

Canopy diameter: The canopy structure was measured using a graduated measuring ruler from North to South and from East to West.

Yield data

Potato yield components such as number of tubers per plant, average tuber weight, marketable yields and unmarketable yields were taken during harvesting time.

Number of tubers per plant: The number of tubers per plant was calculated by taking five plants and the average was taken**.**

Average tuber weight: Average tuber weight (g) was determined by taking ten tubers per plot by leaving the two border rows and was weighted by using a sensitive balance (ACS price-Computing Scale balance IF 1976) after harvesting. Then, the total fresh tuber yield was divided to their respective total tubers in order to get the average tuber weight.

Marketable yield: Marketable tuber yield (t ha^{-1}) was determined by weighing defect-free tubers over 50g from each plot, converting the weight to tons per hectare. Harvesting was done after the plants had yellowed and withered.

Unmarketable yield: Unmarketable yield of potato was taken by identifying under sized and deformed potato tubers.

Total tuber yield: Total tuber yield of potato was recorded as the sum of both marketable and unmarketable tuber yields from the net plot area. The total tuber yield (kg/plot) was weighed and converted to tons per hectare t ha^{-1}.

Statistical analysis: The experimental data were subjected to analysis of variance (one way-ANOVA) by using SPSS version 26. Means were compared using the Least Significant Difference (LSD) test at (P< 0.05) level of significance. The Pearson correlation coefficient was used to show the relationships of different parameters.

Results and discussion

Effect of intra and inter-row spacing on phenological parameters: The results revealed that intra and inter-row spacing affected the various parameters under study (P< 0.05). The mean days to 50% flowering of potatoes were shown to be significantly impacted by the interaction effects of intra- and inter-row spacing. The spacing 40 × 60 cm showed the longest flowering (50 days), while the earliest (46.3 days) took place at the 30 × 70 cm spacing. This confirmed the previous reports (Chala *et al.*, 2020). Faster flowering may result from higher resource competition caused by closer row spacing (Derebe and Kola, 2024). On the other hand, a study conducted on the Belete potato variety in Ethiopia found that inter- and intra-row spacing had no effects on days of 50% flowering (Arega *et al.*, 2018).

The present study also had significant interaction effects of intra- and inter-row spacing on days of 50% maturity (P< 0.05). The shortest to 50% maturity (105.7 days) was recorded at a closer spacing of 20×70 cm (Table 2). Gebremariam and Baraki (2020) also found that increased inter-plant competition at narrower spacing shortens days of 50% maturity. On the other hand, faster days of 50% maturity in sunflower and chickpeas in wider intra- and inter-row spacing were reported by Chala *et al.* (2020). According to Arega *et al.* (2018), genetic factors are more important in accelerating or shortening the flowering time than spacing.

Table 2. The combined mean comparison of phenological parameters under spacing conditions

Experimental units	Days to 50% flowering	Days to 50% maturity
20×60cm	47[a]	107.3[bc]
20×70cm	46.7[a]	105.7[c]
20×80cm	48[a]	113[ab]
30×60cm	49.3[a]	113[ab]
30×70cm	46.3[a]	110.3[abc]
30×80cm	49.3[a]	110[abc]
40×60cm	50[a]	112[ab]
40×70cm	49.7[ab]	112.6[ab]
40×80cm	47.7[ab]	112.6[ab]
Mean	48.2	110.7
LSD	9.18	5.96
CV	11.1	3.15

SD= standard deviation, CV= coefficient of variation. The data represent the mean of the three replicates in the experiment. Means followed by the different letters in a column are significantly different at P<0.05 level according to the LSD.

Effect of intra and inter-row spacing on growth parameters: There was a significant interaction (P < 0.05) effect of intra- and inter-row spacing on the plant height (Table 3). The finding revealed that the highest plant height (94.94 cm) was observed at the wider intra- and inter-rows spacing of 40×80 cm, while the shortest plant height (83.61 cm) was recorded at the closer spacing of 20×70 cm. This finding aligns with the previous reports of Zamil *et al.* (2010). However, the findings contradict the previous reports on soybeans, mung bean and chickpea plants (Chala *et al.*, 2020; Siraje *et al.*, 2020; Tadesse and Bekele, 2021) that state the longest plant height was obtained at closer spacing than wider spacing. This may result from less light interception per plant, causing longer internodes (Alam *et al.*, 2011).

Regarding the number of branches, there was no significant combined (at P< 0.05 level) effect of intra- and inter-row spacing (Table 3). The highest (3.86) number of branches per plant was obtained at 40 x 80 cm plant spacing, whereas the lowest (2.33) was obtained at 20 x 60 cm. This agrees with the previous reports of Chala *et al.* (2020). The wider intra- and inter-row spacing increases the number of branches (Chala *et al.*, 2020). This is related to the idea that more food and light may boost axillary bud formation and branching (Tuarira and Moses, 2014).

The combined intra- and inter-row spacing showed significant (P < 0.05) effects on the number of leaves per plant (Table 3). The highest number of leaves (207.6) was observed at the wider spacing of 40 × 80 cm, while the lowest number (120.66) occurred at the closer intra- and inter-rows spacing of 20 × 60 cm. This confirmed the previous results of Zemichael *et al.* (2017) on lettuce and contradicted the reports of Dabessa *et al.* (2024). The reduced number of leaves in closer row spacing can be attributed to diminished leaf initiation and decreased activity of the shoot meristems. Similarly, there was a significant interaction effect of intra- and inter-row spacing on the stem thickness of potato plants (P < 0.05). The largest stem thickness (10.34 mm) was recorded at the wider (40 × 80 cm) intra- and inter-row spacing, whereas the smallest (8.53 mm) stem thickness was recorded at closer (20 × 60 cm) spacing (Table 3). Kandil *et al.* (2016) also found that wider spacing increases the stem thickness in maize crops. On the other hand, closer spacing can reduce stem thickness due to competition (Mekonnen, 2017).

The canopy coverage was also impacted significantly by the interaction effect of intra- and inter-row spacing (P< 0.05). The highest canopy coverage (77.96 cm) was obtained at the intra- and inter-rows spacing (30 × 70 cm), whereas the smaller canopy coverage (59.9 cm) was recorded at intra- and inter-rows spacing (40 × 70cm) (Table 3). A study on Bishola tomato in Ethiopia found that 40 × 100 cm spacing reduced canopy coverage. Wider spacing increases the canopy growth of potato crops due to minimum competition for resources (Dabessa *et al.*, 2024). However, this is contradicted by the previous reports of Derebe and Kola (2024).

Table 3. Combined mean comparison of growth parameters under different spacing conditions

Experimental units (cm)	Plant height (cm)	Number of branches	Number of leaves (per plant)	Stem thickness (mm)	Canopy coverage (cm)
20x60	85.16[a]	2.33[a]	120.66[b]	8.53[b]	65.26[bcd]
20x70	83.61[a]	2.6[a]	122.46[b]	9.25[ab]	63.5[cd]
20x80	94[a]	2.66[a]	154.93[b]	9.63[ab]	65.83[bcd]
30x60	87.39[a]	3.33[a]	168.46[ab]	8.57[b]	70.16[abcd]
30x70	85.55[a]	3.46[a]	137.73[b]	9.05[ab]	77.96[a]
30x80	89.05[a]	3.26[a]	160.26[ab]	8.65[b]	75.56[ab]
40x60	91.5[a]	3.06[a]	157.73[b]	9.80[ab]	63.06[d]
40x70	87.5[a]	3.6[a]	128.2[b]	8.92[ab]	59.9[d]
40x80	94.94[a]	3.86[a]	207.6[a]	10.34[a]	63.96[cd]
Mean	88.74	3.02	150.88	9.19	67.24
LSD	12.03	1.29	49.47	1.51	10.61
CV	7.95	24.8	19.06	9.57	9.17

The data represent the mean of the three replicates in the experiment. Means followed by the different letters in a column are significantly different at P< 0.05 level according to the LSD.

Effect of intra and inter-rows spacing on yield parameters: The interaction of intra- and inter-rows spacing showed a significant (P< 0.05) effect on the yield (Table 4). The highest tuber count (15) was observed at a spacing of 30×80 cm, while the lowest (11.13) occurred at 20×80 cm, indicating that the potato variety responds differently to spacing alterations. For instance, the Kufri Neelkanth variety did best in its tubers with a 60 cm x 20 cm spacing, highlighting the significance of adjusting spacing to specific varieties (Dagar *et al.*, 2023). High altitude and salinity also require specific spacing to minimize stress and boost yield. Wider spacing reduced green tubers in the Moscow region (Kundu *et al.*, 2024). The average tuber weight was also affected significantly by the combination of intra- and inter-row spacing (P< 0.05). The highest average tuber weight (112.6g) was recorded at wider intra and closer inters rows spacing (40 × 60 cm), whereas the smallest (96.6g) average tuber weight was recorded at closer spacing of 20 × 60 cm (Table 4). This agrees with the previous findings (Zerga *et al.*, 2017; Regasa *et al.*, 2022). This might be related to increased resource competition (Blauer and Mattinson, 2024). In Ethiopia, the study conducted by Regasa *et al.* (2022) also found that wider spacing produced greater tuber weight in plants. The closer spacing most likely made plants more competitive and causes a reduction in the average tuber weight (Harnet *et al.*, 2014). The result of ANOVA also revealed that intra- and inter-row spacing affected the marketable yield significantly (P < 0.05). The highest yield (32.4 t ha^{-1}) was recorded at closer spacing (20 x 80 cm) and the lowest marketable yield (23.06 t ha^{-1}) at wider spacing (40 x 70 cm). This was confirmed by previous reports (Abriham and Kefale, 2020).

The unmarketable yields were also significantly impacted ($P< 0.05$) by intra-and inter-row spacing (Table 4). The 30×70 cm spacing produced the highest yield (2.09 tha^{-1}), but 40 × 80 cm spacing produced the lowest yield (1.05 t ha^{-1}). The total yield was also reduced significantly by intra- and inter-row spacing. At 20 × 80 cm spacing, the highest yield (34 tha^{-1}) was seen, whereas at 40 × 70 cm, the lowest yield (20.4 t ha^{-1}) was reported. Closer plant spacing typically results in higher total yields due to the greater plant density. For instance, a study conducted in the Columbia Basin revealed that closer spacing reduced yields (Blauer and Mattinson, 2024). On the other hand, studies in Bangladesh and Ethiopia suggest that specific spacings can maximize yield. In the coastal saline zones of Bangladesh, a spacing of 25 cm x 15 cm with the BARI Alu 41 variety yielded 20.30 t/ha using zero tillage techniques (Kundu *et al.*, 2024). Similarly, a study conducted in Ethiopia found that the Belete variety produced the maximum marketable and total tuber yields in a spacing 60 x 20 cm (Limeneh *et al.*, 2021).

Table 4. Combined mean comparison of yield parameters under different spacing conditions

Experimental units (cm)	Number of tubers	Average tuber weight (gm)	Marketable yield (t ha^{-1})	Unmarketable yield (t ha^{-1})	Total yield (t ha^{-1})
20x60	12.66^{a}	96.6^{a}	30.8^{a}	1.94^{a}	32.74^{ab}
20x70	13^{a}	108.3^{a}	29.2^{ab}	1.64^{ab}	30.81^{ab}
20x80	11.13^{a}	108.6^{a}	32.4^{a}	1.62^{ab}	34^{a}
30x60	11.4^{a}	104.83^{a}	24.6^{abc}	1.33^{ab}	25.94^{abc}
30x70	13.6^{a}	113^{a}	25^{abc}	2.09^{a}	27.08^{abc}
30x80	15^{a}	78.5^{b}	26.7^{abc}	2.003^{a}	28.7^{abc}
40x60	13.86^{a}	112.6^{a}	24.4^{abc}	1.65^{ab}	26.04^{abc}
40x70	14.3^{a}	106^{a}	23.06^{bc}	1.43^{ab}	24.5^{bc}
40x80	13.9^{a}	105.8^{a}	28.6^{ab}	1.25^{ab}	29.89^{ab}
Mean	13.2	103.8	27.19	1.66	28.85
LSD	3.97	25.54	8.5	0.84	8.94

The data represent the mean of the three replicates. Means followed by the different letters in a column are significantly different at $P< 0.05$ level according to the LSD.

Correlation study between growth and yield parameters of potato: the Pearson correlation coefficient showed there was both positive and negative correlation between growth and yield parameters. Positively correlated parameters indicated that there was a close association between them (Table 5). Days of 50% flowering have a significant positive correlation with days of 50% physiological maturity (r = 0.61**). This suggests that genotypes or treatments that initiate flowering earlier also tend to reach physiological maturity sooner, indicating a shorter overall vegetative cycle. Number of stem (branches) was positively correlated with plant height (r = 0.08). The increased number of stems per plant leads to increased plant height due to light availability and its effect on increased length and number of nodes.

Table 5. Pearson's correlation studies on growth and yield parameters of potato

	DF	DM	PH	NB	NL	CD	ST	NT	ATW	MY	UMY
DF	1										
DM	0.61**	1									
PH	0.37*	0.55**	1								
NB	0.44*	0.37*	0.08	1							
NL	-0.04	0.37*	0.49**	0.15	1						
CD	0.05	-0.05	-0.04	0.38*	0.23	1					
ST	-0.07	0.20	0.31	-0.26	0.35	-0.25	1				
NT	-0.54**	-0.36*	-0.25	0.04	0.22	0.22	0.16	1			
ATW	0.02	0.27	-0.06	0.13	0.01	-0.19	0.35	-0.07	1		
MY	-0.34	-0.42*	0.05	-0.25	-0.05	0.05	-0.15	-0.02	-0.18	1	
UMY	-0.56**	-0.48**	-0.15	-0.31	-0.28	0.14	-0.25	0.17	-0.36	0.46**	1
TY	-0.37*	-0.45*	0.04	-0.26	-0.06	0.06	-0.16	0.001	-0.21	0.99**	0.53**

** Correlation was significant at 0.01 and * correlation was significant at 0.05 level. Where, DF= Days of 50% flowering, DM= Days of 50% maturity, PH= Plant height, NB= Number of branches, NL= Number of leaves, CD= Canopy diameter, ST= Stem thickness, NT= Number of tubers, ATW= Average tuber weight, MY= Marketable yield, UMY= Unmarketable yield, TY= Total yield

In conclusion, the study revealed that plant spacing substantially impacted the phenology, growth, and yield of the DAGIM cultivar. Particularly, most traits, including plant height, number of branches, number of leaves, and stem thickness, grew well in an intra and inter-row spacing of 40 cm x 80 cm. On the other hand, the studied cultivar showed better total and unmarketable yields when the spacing was closer (20 cm x 60 cm). The study found that wider spacing improves growth parameters and closer spacing increases yield traits, even though some of the harvested tubers might not meet market standards. Therefore, maintaining the proper spacing is crucial to maximizing the growth and yield of the cultivars.

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