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Journal of Advancements in Plant Science

RESEARCH ARTICLE

ISSN: 2639-1368

Effect of Inter and Intra Row Spacing on Tuber Yield and Yield Components of Potato (*Solanum tuberosum* L.) in Guji zone, Southern Ethiopia

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Citation: Arega A, Tekalign A, Solomon T, Tekile B (2018) Effect of Inter and Intra Row Spacing on Tuber Yield and Yield Components of Potato (*Solanum tuberosum* L.) in Guji zone, Southern Ethiopia. J Adv Plant Sci 1: 102

Article history: Received: 07 February 2018, **Accepted:** 25 April 2018, **Published:** 26 April 2018

Abstract

Potato (*Solanum tuberosum* L.) production plays an important role in improving household income and nutrition and thereby contributes to food security. Despite of this, the current productivity of the crop is below the potential. The major production problems of potato take into account that low tuber yield are unavailability and high cost of seed tubers, lack of well adapted cultivars, poor agronomic practices, diseases, insect pests, inadequate storage, transportation and marketing facilities. The experiment was conducted at Bore Agricultural Research center at Bore on station and Ana sora district on-farm during the period from April 2014 to September 2016 copping season with the aim to determine appropriate plant population per unit area to obtain high yield, quality tuber size and to evaluate the best economic return of inter and intra row spacing for potato production in area. The experiment was arranged in factorial RCBD with three replications. Treatments consisted of factorial combinations of four levels of inter row (70, 75, 80 and 85 cm) and four levels of intra row (20, 30, 40 and 50 cm) spacing. Data days to 50% emergence, 50% flowering and 90% maturity, plant height (cm), number of main stem, and average tuber number per hill, average tuber weight (gm) and marketable, unmarketable and total tuber yield (t ha-1) data were collected and analyzed by using SAS software computer. The ANOVA results revealed that both main and interaction effects of inter and intra row spacing not significantly ($P < 0.05$) influenced on days to 50% emergence, 50% flowering, and 90% maturity for both location and main stem number for bore location. However, the ANOVA results revealed that the main and interaction effect of inter and intra row spacing was significantly ($P < 0.05$) influenced plant height (cm), number of main stem, average tuber number per hill, average tuber weight, marketable and unmarketable tuber yield and total tuber yield due to the treatments. The maximum marketable tuber yield (42.57 t ha^{-1}) and (41.61 t ha^{-1}) for Bore and Ana sora site respectively obtained from 75 cm inter and 30 cm intra row spacing statistically at par with the control yield (20.55 and 19.91 t ha^{-1}) and treatment employed on maximum spacing (85*50 cm) which yielded 23.05 and 18.85 t ha^{-1} at Bore and Ana sora respectively. The marginal rates of returns, which determine the acceptability of any treatment, show that treatment that plants planted in a spacing of 75*30 cm yielded good results with 2087.61% marginal revenue. The results of the study suggested that Belete potato variety responded well to the combined application use of Inter and Intra row spacing. Therefore, potato growers in the study area can benefit if they use 75*30 cm inter and intra-row spacing.

Keywords: Belete potato variety; Guji zone; Partial budget analysis; Row spacing

Introduction

Potato (*Solanum tuberosum* L.) is the most important vegetable crop, constituting the fourth most important food crop in the world [1,2]. It is one of economically most important tuber crops in Ethiopia that play key roles as a source of food and cash income for smallholder farmers [3].

Ethiopia is endowed with suitable climatic and endemic conditions for potato production. Even though the country has suitable environmental condition the average national yield (13.768 ha^{-1}) productivity of potato during 2016/17 season (CSA, 2017) is very low as compared with world average of 17.16 t ha^{-1} (FAO, 2014) [4,5]. The potato crop was introduced to Ethiopia around 1858 by Schimper, a German botanist [6]. 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 (FAO, 2008) [7].

Potato crop is graded as a high potential food security and cash crop because of its ability to provide a high yield of high quality product per unit input with a shorter crop cycle (mostly < 120 days) compared to major cereal crops like maize [8-10]. The country has about 70% of the available agricultural land suitable for potato production [11]. The major production problems that account for such low yield are unavailability and high cost of seed tubers, lack of well adapted cultivars, poor agronomic practices, diseases, insect pests, inadequate storage, transportation and marketing facilities [12].

Even though, the country is endowed with suitable climatic and edaphic conditions the annual production of potato in Ethiopia is low (about 775,503 tons) and the national average yield is 7 tons/ha, which is very low compared to the world's average of 17 tons/ha [13]. To optimize Irish potato productivity, full package of information is required. Plant population needs to be optimized. The optimum use of spacing or plant population has dual advantage. There is also lack of location specific researches on Irish potato in particular and for other crops in general. In addition, the quality of the produce is also inferior due to pre-harvest and post-harvest biotic and abiotic factors. Therefore, in view of those gaps on potato production and productivity, the study was conducted to evaluate the influence of inter and intra row spacing on yield and yield component of the crop under Guji conditions. Some of the production constraints which have contributed to the limited production or expansion of potato in Ethiopia include shortage 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 soil fertility status [8].

The optimization of plant density is one of the most important subjects of potato production management, because it affect seed cost, plant development, yield and quality of the crop [14]. Farmers in the study in Guji zone are using different spacing below or above the national recommendation due to lack of recommended inter and intra row spacing.

However, currently in Guji zone the production as well as quality of tubers is low because of the existing climatic changes, agronomic practices and depletion of soil fertility expected as causes of low tuber yield of potato. Even though, in Guji zone there is yet much starving of new technology, including improved varieties and appropriate spacing. There is no research conducted concerning spacing alone or together inter and intra row spacing with variety on potato production. However, the supply of potato yield with the right seed quality remains far below the demands. Even though it is important to adjust/maintain appropriate plant population per unit area to have high yield, marketable tuber size, good quality seed tuber and appropriate agronomic practices. Therefore, this present study was conducted with the following objectives:

1. To determine appropriate plant population per unit area to obtain high yield, quality tuber size and
2. To evaluate the best economic return of inter and intra row spacing for potato production in area

Materials and Methods

Description of Experimental Sites

The experiment were conducted at Bore Agricultural Research center (BOARC), Bore on- station and Ana sora during Belg season during the year 2015 to 2016 cropping season under rain-fed conditions. Bore on station is located about 8 km North of the town in Songo Bericha *'Kebele'* just on the side of the main Addis Ababa road via Hawassa town. It is about 378 km far from capital Addis Ababa. Geographically, the experimental site is situated at latitude of 06°23'55"N and longitude of 38°35'5"E at an altitude of 2736 meters above sea level. The climatic condition of the area is a humid moisture condition, with a relatively longer growing season. The area receives annual rainfall ranging from1400 to 1800mm with a bimodal pattern that is extended from April to November. The mean annual minimum and maximum temperature is 10.1 °C and 20.0 °C, respectively. The type of the soil of the experimental site is red basaltic soil (Nitosols). The soil is clay loam in texture and strongly acidic with pH 4.53 to 5.13 while moderately acidic with pH 6.5 Yazachew and Kasahun respectively [15-17]. The traditional farming system of the area is characterized by cultivation of enset as a major crop, maize, potato, head cabbage, barley, wheat and faba bean. As far as fruit and non timber crops are concerned, apple and bamboo are the cash crops. Moreover, cattle are an integral part of the farming system.

Treatments and Experimental Design

The experiment was conducted using as test crop improved potato variety Belete. This variety was released by Holeta agricultural research center in 2009. The treatments consisted of four (70, 75, 80 and 85 cm) inter and four (20, 30, 40 and 50 cm) Intra row spacing. At different plot size ranging from (9.52m^2, 10.5m^2, 11.2m^2 and 11.9m^2).The experimental material potato variety Belete was used for the experiment as a test crop (Table 1). The experiment was laid out as a completely randomized block design (RCBD) in a factorial arrangement and replicated three times per treatment across two locations. Gross plot size was different based on spacing accommodating a minimum of 28 and Maximum of 68 harvestable plants with different rows and space length (Table 2).

Description	Agronomic Characteristics
Accession code	CIP-393371.58
Year of Release	2009
Altitude (meters above sea level)	1600-2800
Rainfall amount (mm)	750-1000
Days to maturity (days)	90-120

Description	Agronomic Characteristics
Yield farmers and research field (t/ha)	47.2 to 28-33.8
Late blight disease resistance	Resistance to late blight
Source: MoA, 2010	

Table 1: Description of Belete potato variety (CIP-393371.58)

Treatments	Number of tubers Per plot	Treatments	Number of tubers Per plot
Inter x Intra row spacing		Inter x Intra row spacing	
70cm*20cm	68 tubers	70 cm*40 cm	36 tubers
75cm*20cm	68 tubers	75cm*40 cm	36 tubers
80cm*20cm	68 tubers	80 cm*40 cm	36 tubers
85cm*20cm	68 tubers	85 cm*40 cm	36 tubers
70 cm*30 cm	48 tubers	70 cm*50 cm	28 tubers
75cm*30 cm	48 tubers	75 cm*50 cm	28 tubers
80 cm*30 cm	48 tubers	80 cm*50 cm	28 tubers
85cm*30cm	48 tubers	85 cm*50 cm	28 tubers

Table 2: Treatment combinations and number of plant population per plot

Data Collection and Management

Days to 50% emergence, 50% flowering and 90% maturity, plant height (cm), Number of main stem (branches), Average Tuber number per plant (hill), Average Tuber weight (gm), and marketable, unmarketable and total tuber yield (t ha^{-1}) were recorded accordingly.

Partial Budget Analysis

Cost benefit analysis was done to determine the relative economic returns on the applied treatments using the prevailing market prices. The yields were adjusted by 10% downwards due to management level variability between a researcher and a farmer (CIMMYT, 1988). Costs of farm services were taken at Bore and Ana sora market in the southern part of Ethiopia. The economic indicators used were: Gross benefit is the product of the adjusted yield (t ha^{-1}) and the sale prices (birr kg^{-1}) and calculated by multiplying the yield in t ha^{-1} by the market price and also net Benefit was calculated by subtracting the total cost of production from the gross benefit. Marginal analysis compares the net benefits with the total variable cost. The total variable cost was determined for each treatment and was compared with the net benefit. Here also dominant treatments were analyzed and arranged in terms of increasing variable costs. The corresponding net benefits were also indicated. A treatment is dominant when it has a higher cost but a lower net benefit than any preceding treatment. Finally, marginal rate of returns were calculated (MRR), where by percentage change in benefit over change in total variable cost in moving from a lower cost treatment to a higher one. All the treatments were arranged from the highest to the lowest in terms of profitability. This was achieved by dividing the total variable cost by the net benefit multiplied by 100.

$$\text{MRR } (\%) = \frac{\text{Marginal benefit}}{\text{Margina cost}} \times 100$$

Statistical Data analysis

Data were subjected to analysis of variance (ANOVA) using the General Linear Model of the SAS statistical package. All significant pairs of treatment means were compared using the DMRT at 5% level of significance.

Results and Discussion

Phenology of Irish Potato

Days to 50% emergency, flowering and maturity: The analysis of variance result showed that the phenological parameters days to 50% emergency, flowering and maturity was not significantly ($P < 0.05$) affected both by main and interaction effect of inter and intra row spacing at both locations and also number of main stem was not affected by both main and interaction effect of plant spacing at Bore (Table 3 and 4). This might be due to the fact that these traits are controlled by genetic factors rather than by plant spacing. In this study, only one variety (Belete) was used as an experimental material and the phenological parameters were not affected by the plant spacing.

Bore				
Treatment	Days to			
Inter row spacing (cm)	50% emergence	50% flowering	90% maturity	Main stem Number
70	24.33	46.20	87.37	6
75	23.75	46.33	89.20	5
80	23.58	46.62	90.37	5
85	23.75	46.29	89.62	6
SE	2.24	0.95	6.6	0.27
Significance level	Ns	Ns	Ns	Ns
Intra row spacing (cm)				
20	23.26	46.73	90.69	6
30	23.62	46.54	88.54	6
40	24.04	46.20	89.33	5
50	24.59	45.90	87.77	5
SE	0.847	0.99	0.46	0.43
Significance level	Ns	Ns	Ns	Ns
CV (%)	22.35	30.95	7.39	20.51

Means sharing by the same letter(s) within a row and column are not significantly different at 5% level Means sharing by the same letter(s) within a row and column are not significantly different at 5% level of significance, SE=Standard Error, CV=coefficient of variation

Table 3: Combined Main effect of inter and intra row spacing on days to 50% emergency, flowering, maturity and main stem number of Belete potato variety at Bore and Ana sora pooled data during 2014 to 2016

This result is in agreement with that of Vreugdenhil who stated that days required to flowering is highly dependent on gene factors and governed by many environmental factors, mainly temperature and light [19].

Ana sora			
Treatments	Days to		
Inter (cm)	50% emergence	50% flowering	90% maturity
			(days)
70	19.83	50.50	94.12
75	19.37	50.50	93.83
80	19.66	50.50	94.00
85	19.66	50.50	94.08
SE	0.91	1.00	0.99
Significance level	Ns	Ns	Ns
Intra (cm)			
20	18.96	50.50	93.76
30	19.16	50.50	93.66
40	20.04	50.50	93.70
50	20.50	50.50	95.00
SE	0.06	50.50	0.94
Significance level	Ns	Ns	Ns
CV (%)	11.53	36.40	8.98

Means sharing by the same letter(s) within a row and column are not significantly different at 5% level of significance, SE=Standard Error, CV=coefficient of variation

Table 4: Combined Main effect of inter and intra row spacing on days to 50% emergency, 50% flowering and 90% maturity of Belete potato variety at Ana sora pooled data during 2014 to 2016

Growth, Yield and Yield components of Potato

Plant height, main branch numbers, tuber number and tuber weight: The analysis of variance of plant height showed significant differences (P < 0.05) for the interaction effect of inter and intra row spacing. The highest plant height (89.86 cm) and lowest plant height (60.51 cm) was recorded by interaction effect of 85*50 cm and 70*20 cm plant spacing respectively on both locations (Table 5 and 6). The result of the experiment was in line with this study result, Zamil, *et al*. reported that the wider spacing enhances growth and height of the plant [20].

Inter (cm)	Intra (cm)				
	20	30	40	50	Mean
70	60.51^{c}	63.88^{c}	63.20^{c}	65.91^{c}	63.63
75	62.60^{c}	65.56^{c}	62.98^{c}	66.35^{c}	64.37
80	62.10^{c}	66.03^{c}	61.53^{c}	62.62^{c}	62.77
85	61.55^{c}	64.15^{c}	75.51^{b}	89.86^{a}	72.77
Mean	61.94	64.90	65.55	71.18	
SE=4.78 CV(%)=7.25					

Means sharing by the same letter(s) within a row and column are not significantly different at 5% level of significance, SE=Standard Error, CV=coefficient of variation.

Table 5: Interaction effect of inter and intra spacing on plant height of Belete potato variety at Bore during 2014 to 2016

Inter (cm)	Intra (cm)				
	20	30	40	50	Mean
70	60.51^{c}	63.88^{c}	63.20^{c}	65.91^{c}	63.63
75	62.60^{c}	65.56^{c}	62.98^{c}	66.35^{c}	64.37
80	62.10^{c}	66.03^{c}	61.53^{c}	62.62^{c}	62.77
85	61.55^{c}	64.15^{c}	75.51^{b}	89.86^{a}	72.77
Mean	61.94	64.90	65.55	71.18	
SE= 4.78 CV(%)=7.25					

Means followed by the same letter(s) within a row and column are not significantly different at 5% level of significance, SE=Standard Error, CV=coefficient of variation

Table 6: Interaction effect of inter and intra spacing on plant height (cm) of Belete potato variety at Ana sora during 2014 to 2016

The analysis of variance of main stem number showed significant differences (P < 0.05) for the interaction effect of inter and intra row spacing for Ana Sora location. The highest (5.66) main stem numbers at Ana sora location shows significantly different (P < 0.05) result by interaction effect of 75*30 cm plant spacing and the lowest (4.00) main stem number was obtained from interaction effect of plant spacing 80*40 cm (Table 7).

Inter (cm)	Intra (cm)				
	20	30	40	50	Mean
70	4.66^{ab}	3.83^{b}	4.16^{ab}	4.66^{ab}	4.32
75	5.00^{ab}	5.66^{a}	4.50^{ab}	4.83^{ab}	4.99
80	5.25^{ab}	4.50^{ab}	4.00^{ab}	4.50^{ab}	4.56
85	5.16^{ab}	5.16^{ab}	4.33^{ab}	4.16^{ab}	4.70
Mean	5.01	4.78	4.24	4.53	
SE=1.23 CV(%)=26.54					

Means sharing by the same letter(s) within a row and column are not significantly different at 5% level of significance, SE=Standard Error, CV=coefficient of variation

Table 7: Interaction effect of inter and intra spacing on main stem number of Belete potato variety at Ana sora during 2014 to 2016

In contrast with this study result, Beukema and Van der Zaag reported that the main stem number was not influenced by plant density [21]. But the analysis of variance of main stem number showed that there were no statistical differences (P < 0.05) for the interaction effect of inter and intra row spacing at Bore location. Number of main stem number per plant were not influenced by plant spacing as reported by Beukema and Van der zaag but stem number increased as a result of either by planting smaller tuber size [21,22]. It is a function of seed pieces type as their production was not affected by plant density.

Similarly, interaction effect of both inter and intra plant spacing shows significantly different ($P < 0.05$) result on average tuber numbers and tuber weight. In agreement with this study result, Zabihi *et al.* reported that plant spacing in potato influenced some of the important traits such as yield and yield components [23]. Plants grown at narrow plant spacing of 75 x 30 cm had the highest tuber number per plant (15.50) and (18.16) at Bore and Ana sora locations respectively. The lowest (7.50) number of tubers per hill was recorded from interaction effect of plant spacing 85*40 cm on both locations (Table 8 and 9). The production of total number of tubers per hill increased as plants grown at narrow plant spacing and decreased at wider plant spacing. This might be due to the higher number of plants produced at closer plant spacing than plants at wider spacing which led to the production of highest number of total tubers per hill.

Inter (cm)	Intra (cm)				
	20	30	40	50	Mean
70	15.50^{a}	9.33^{bc}	8.16^{bc}	8.83^{bc}	10.66
75	9.50^{bc}	10.16^{b}	9.33^{bc}	8.83^{bc}	9.25
80	8.25^{bc}	8.33^{bc}	8.00^{bc}	9.75^{bc}	8.45
85	9.66^{bc}	8.33^{bc}	7.50^{c}	8.66^{bc}	8.54
Mean	10.72	9.03	8.24	9.01	
SE=1.78 CV(%)=19.37					

Means sharing by the same letter(s) within a row and column are not significantly different at 5% level of significance, SE=Standard Error, CV=coefficient of variation

Table 8: Interaction effect of inter and intra spacing on average tuber number per plant of Belete potato variety at Bore during 2014 to 2016

Related study was reported by Burton, wider spacing may produce few tubers as it gave rise to few stems that could lead to high number and possibly misshapen tuber while narrow spacing improved quality and gave numerous tuber numbers [24].

Inter (cm)	Intra (cm)				
	20	30	40	50	Mean
70	18.16^{a}	10.50^{bc}	9.66^{bcd}	8.00^{cd}	11.58
75	8.16^{cd}	11.66^{b}	9.50^{bcd}	8.66^{cd}	9.50
80	9.37^{bcd}	8.50^{cd}	8.00^{cd}	8.25^{cd}	8.62
85	8.50^{cd}	9.00^{bcd}	7.50^{d}	9.50^{bcd}	8.62
Mean	11.04	9.16	8.66	9.35	
SE=2.11 CV(%)=22.09					

Means sharing by the same letter(s) within a row and column are not significantly different at 5% level of significance, SE=Standard Error, CV=coefficient of variation

Table 9: Interaction effect of inter and intra spacing on average tuber number per plant of Belete potato variety Belete at Ana sora during 2014 to 2016

The analysis of variance showed that the interaction effect of inter and intra row plant spacing had significantly ($P < 0.05$) influenced on tuber weight, unmarketable tuber yield, marketable tuber yield and total yield at both locations. Maximum average tuber weight (208.92 g and 211.83 g) was recorded for plants planted at wider plant spacing 85*50 cm and 85*40 cm at Bore and Ana sora Districts, respectively and the lowest average tuber weight (97.17 g and 131.67 g) was obtained at closer plant spacing 70*20 cm (Table 10 and 11). The production of tubers with maximum tuber weight recorded when tubers spaced wider might be due to the production of optimum number of stems with lesser competition for resource between plants as compared to closer plant spacing. Meaning increase in density probably causes the increase in competition between and within plants and hence, leads to decrease in availability of nutrients to each plant and consequently, results in decline of mean tuber weight.

Inter (cm)	Intra (cm)				
	20	30	40	50	Mean
70	97.17^{d}	120.92^{cd}	126.83^{cd}	124.50^{cd}	117.35
75	112.08^{cd}	139.33^{c}	133.42^{c}	169.73^{b}	166.64
80	116.25^{cd}	124.17^{cd}	131.32^{c}	128.50^{c}	124.03

Inter (cm)	Intra (cm)				
	20	30	40	50	Mean
85	108.83^{cd}	121.75^{cd}	175.83^{b}	208.92^{a}	125.83
Mean	108.58	135.66	151.6	139.03	
SE=22.17 CV(%)=16.61					

Means sharing by the same letter(s) within a row and column are not significantly different at 5% level of significance, SE=Standard Error, CV=coefficient of variation.

Table 10: Interaction effect of inter and intra spacing on average tuber weight (gm) of Belete potato variety at Bore during 2014 to 2016

Inter (cm)	Intra (cm)				
	20	30	40	50	Mean
70	131.67^{d}	144.00^{cd}	163.60^{bcd}	156.50^{bcd}	148.94
75	138.03^{cd}	162.58^{bcd}	142.33^{cd}	163.05^{bcd}	173.29
80	139.31^{cd}	147.92^{cd}	143.67^{cd}	156.25^{bcd}	145.37
85	166.33^{bc}	169.25^{bc}	211.83^{a}	180.25^{b}	160.12
Mean	143.83	160.35	170.42	154.53	
SE= 23.06 CV(%)=14.69					

Means sharing by the same letter(s) within a row and column are not significantly different at 5% level of significance, SE=Standard Error, CV=coefficient of variation

Table 11: Interaction effect of inter and intra spacing on average tuber weight (gm of Belete potato variety at Ana sora during 2014 to 2016

Unmarketable, marketable and total tuber yield of Potato: Plant spacing had significantly ($P < 0.05$) affect unmarketable tuber yield. The highest (13.85 t ha^{-1} and 15.19 t ha^{-1}) unmarketable tuber yield was obtained at closer plant spacing (70*20 cm) whereas the lowest (5.13 t ha^{-1} and 5.83 t ha^{-1}) unmarketable tuber yield was recorded at wider plant spacing of 85*50 cm and 80*50 cm at Bore and Ana sora district, respectively (Table 12 and 13). Generally, plants grown at closer spacing produced high unmarketable tuber yield than plants grown at wider plant spacing. When increased plant density also increased the yield of unmarketable tuber yield. This might be at closer plant spacing had high competition of plants for growth factors due to high plant number per unit area than wider plant spacing which led to produce high number of under size tubers which was high unmarketable tuber yield.

Inter (cm)	Intra (cm)				
	20	30	40	50	Mean
70	13.85^{a}	10.01^{b}	6.21^{cd}	6.95^{cd}	7.10
75	6.19^{cd}	7.85^{bcd}	8.52^{bc}	6.35^{cd}	6.38
80	6.87^{cd}	6.12^{cd}	7.36^{bcd}	7.40^{bcd}	6.89
85	5.63^{cd}	6.57^{cd}	6.70^{cd}	5.13^{d}	9.02
Mean	6.80	6.81	7.17	8.63	
SE=2.22 CV(%)=30.33					

Means sharing by the same letter(s) within a row and column are not significantly different at 5% level of significance, SE=Standard Error, CV=coefficient of variation

Table 12: Interaction effect of inter and intra spacing on unmarketable tuber yield (t ha^{-1}) of Belete potato variety at Bore during 2014 to 2016

Inter (cm)	Intra (cm)				
	20	30	40	50	Mean
70	15.19^{a}	9.78^{b}	7.91^{b}	8.92^{b}	8.37
75	8.92^{b}	8.25^{b}	7.26^{b}	9.54^{b}	8.49
80	8.32^{b}	8.27^{b}	6.25^{b}	5.83^{b}	7.37
85	6.24^{b}	6.56^{b}	6.71^{b}	6.88^{b}	8.67
Mean	8.31	7.49	5.35	9.87	
SE=2.98 CV(%)=36.20					

Means sharing by the same letter(s) within a row and column are not significantly different at 5% level of significance, SE=Standard Error, CV=coefficient of variation

Table 13: Interaction effect of inter and intra spacing on unmarketable tuber yield (t ha^{-1}) of Belete potato variety at Ana sora during 2014 to 2016

Interaction effect of plant spacing significantly (P < 0.05) influenced marketable tuber yield (Table 14 and 15). The highest marketable tuber yield (42.57 t ha^{-1} and 41.61 t ha^{-1}) was obtained in response to planting the tubers at the spacing of 75 x 30 cm whereas the lowest marketable tuber yield was recorded at the spacing of 70 x 20 cm inter and intra row spacing at Bore and Ana sora districts, respectively. A maximum marketable tuber yield was obtained at closest to medium plant spacing than wider plant spacing.

Inter (cm)	Intra (cm)				
	20	30	40	50	Mean
70	20.55^{d}	29.75^{bc}	24.45^{cd}	24.11^{cd}	24.72
75	22.90^{cd}	42.57^{a}	36.14^{ab}	26.48^{cd}	32.02
80	23.16^{cd}	22.48^{cd}	25.29^{cd}	20.22^{d}	23.03
85	21.25^{cd}	22.51^{cd}	21.32^{cd}	23.05^{cd}	22.03
Mean	21.96	29.32	26.80	23.46	
SE=6.17 CV(%)=24.24					

Means sharing by the same letter(s) within a row and column are not significantly different at 5% level of significance, SE=Standard Error, CV=coefficient of variation

Table 14: Interaction effect of inter and intra spacing on marketable tuber yield (t ha^{-1}) of Belete potato variety at Bore during 2014 to 2016

In agreement with this study result, Dwelle and Love (1993) who concluded that in closer intra row spacing bulking rate of individual tubers decrease and this resulted in smaller tubers and lower marketable tuber yield. But, our study showed that optimum plant spacing (75*30) had efficient use of soil nutrients and other resources which led to increasing the bulking rate to produce high, standard and marketable size tuber yield. This result finding is agreed with finding of Girma, *et al.* who reported that 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 in the centeral highlands of Ethiopia [25]. On the other hand, in contrary with finding of Zebenay, *et al.* reported that response to the spacing of 60 x 30 cm and 50 x 20 cm, respectively, while highest total and marketable tuber yields of potato [26]. Similarly, Birahanu, *et al*. found the spacing of 75 cm x 30 cm seem appropriate for high yield for ware potato [27].

Inter (cm)	Intra (cm)				
	20	30	40	50	Mean
70	19.91^{c}	32.69^{b}	23.89^{c}	20.84^{c}	24.33
75	24.38^{c}	41.61^{a}	34.94^{ab}	22.17^{c}	30.77
80	17.19^{c}	22.73^{c}	24.61^{c}	23.25^{c}	21.44
85	16.67^{c}	20.45^{c}	19.13^{c}	18.85^{c}	18.77
Mean	19.53	29.37	25.64	21.27	
SE= 5.76 CV(%)=24.19					

Means sharing by the same letter(s) within a row and column are not significantly different at 5 % level of significance, SE=Standard Error, CV = coefficient of variation

Table 15: Interaction effect of inter and intra spacing on marketable tuber yield (t ha^{-1}) of Belete potato variety at Ana sora during 2014 to 2016

In terms of the marketable yield, the results from number of researchers are also contrasting. Khalafalla found marketable yield to increase as the spacing was [28]. Lynch and Rowberry also found marketable yield to respond negatively to an increased plant density. Similar results were reported by Nelson he found that increased plant populations reduced average tuber weight but increased yields due to more tubers being harvested and also contrary with finding of Bikila, et al. who reported that using narrow spacing 65 cm x 20cm gave highest potato marketable tubers [29-31].

Inter and intra row spacing had significantly (P < 0.05) affected total tuber yield (Table 16 and 17). Maximum total tuber yield (50.42 t ha^{-1} and 49.86 t ha^{-1}) was obtained at plant spacing of 75 x 30 cm whereas the lowest (26.88 t ha^{-1} and 22.91 t ha^{-1}) was obtained at wider plant spacing of 85*20 cm both at Bore and Ana sora area, respectively. This is due to the compensation effect of closer intra row spaced plants per hectare than the wider intra row spacing which resulted in higher yield of tubers per plant. Burton also investigated the effect of intra row spacing on the yield of potato and finally concluded that in a wider intra row spacing yield per hectare was reduced due to the insufficient number of plants grown per hectare compared to plants grown at closer intra row spacing [32]. Similarly, Mahmood also confirmed that closer intra row spacing gave the highest yield per hectare than the wider intra row spacing [33]. Plants grown at plant spacing of 75 x 30 cm produced higher total tuber yield advantage than plants spaced at 85*20 cm by about 53.33% and 45.94%, for Bore and Ana sora districts respectively. This might be attributed to efficient use of available soil nutrients and other growth factors in plants grown at optimum plant spacing than closer and wider plant spacing. The increased yield might be due to the ground being covered with green leaves earlier (earlier in the season, light is intercepted and used for assimilation), fewer lateral branches are being formed and tuber growth starting earlier. In other words, increased plant population increased yield due to more tubers being harvested per unit area of land [21].

Inter (cm)	Intra (cm)				
	20	30	40	50	Mean
70	34.40^{bc}	36.46^{bc}	30.67^{cd}	31.07^{bcd}	33.15
75	29.09^{cd}	50.42^{a}	44.66^{b}	32.83^{bcd}	39.25
80	30.03^{cd}	28.60^{cd}	32.65^{bcd}	27.62^{cd}	29.72
85	26.88^{d}	29.09^{cd}	28.02^{cd}	28.18^{cd}	28.04
Mean	30.1	36.14	34	29.92	
SE= 6.85 CV(%)=20.94					

Means sharing by the same letter(s) within a row and column are not significantly different at 5% level of significance, SE=Standard Error, CV=coefficient of variation

Table 16: Interaction effect of inter and intra spacing on total tuber yield (t ha^{-1}) of Belete potato variety at Bore during 2014 to 2016

Inter (cm)	Intra (cm)				
	20	30	40	50	Mean
70	35.09^{bcd}	42.47^{ab}	31.80^{cde}	29.81^{de}	34.79
75	33.31^{cd}	49.86^{a}	42.20^{ab}	31.72^{cde}	39.27
80	25.51^{de}	31.01^{cde}	30.86^{cde}	29.09^{de}	29.11
85	22.91^{e}	27.01^{de}	25.84^{de}	25.73^{de}	25.37
Mean	29.20	37.58	32.67	29.08	
SE=7 CV(%)=21.82					

Means followed by the same letter(s) within a row and column are not significantly different at 5% level of significance, SE=Standard Error, CV=coefficient of variation

Table 17: Interaction effect of inter and intra spacing on total tuber yield (t ha^{-1}) of Belete potato variety at Ana sora during 2014 to 2016

Correlation Coefficient Analysis

Correlation coefficient values (r) computed to display the relationships between and within growth parameters and yield and yield components of potato are shown in Appendix Table 1. The correlation values explain the apparent association of the plant population (spacing) growth, yield and yield components with each other and clearly indicated the magnitude and direction of the association and relationships. Among the several parameters average tuber number and marketable tuber yield were negatively correlated with inter and intra row spacing of the plant. This means as the plant spacing between row and plant increases inversely decreased. In another case growth and yield parameters of plant height, main stem number and unmarketable tuber yield were highly positively correlated with plant population of the plant. Thus, the result implied that increased plant and row spacing in the plant maximize the indicated parameters. Similarly average tuber weight and total tuber yield of Irish potato responded positively to the plant population of the plant but not significantly. This implies that increase in inter and intra row spacing increases for the mentioned parameter, but not significantly correlated.

The correlation analysis between total tuber yield (t ha^{-1}) and yield and growth characters indicated that, total tuber yield was highly significantly positively correlated with mean plant height (r=0.411***), unmarketable yield (r=0.385***) and marketable yield (r=0.911***). Similarly main stem number (r=0.311) and average tuber weight (r=0.602) were positively correlated with total tuber yield, but not significantly. However average tuber number is negatively and poorly correlated with the total yield. This implies that improving any of these parameters may lead to the improvement in yield. Generally, the correlation coefficients indicated in (Appendix Table 1) clearly explained the pattern of inter relationship among the yield and yield attributes considered in the experiment.

Partial Budget Analysis

In this study, the costs of seed and cost for transporting the tuber varied while other costs were constant for each treatment. In order to recommend the present result for end users, it is necessary to estimate the minimum rate of return acceptable to farmers in the recommendation domain. The total tuber yield was adjusted downwards by 10% to represent the yield obtained by the farmers as compared to that of the research as suggested by CIMMYT (1988) and the net benefits were calculated by current tuber yield cost of 6 Birr kg^{-1} and the transportation cost for each 100 kg of tuber was estimated 10 Birr and the same level of management practices was used for all treatments.

Based on partial budget analysis, the net benefit accrued from the experiment ranged from narrow plant population is 167155 birr per hectare (Appendix Table 2) compared with wider spacing which is birr 146072 per hectare. This is an indication of the level of profitability of the plant population treatments on production of Irish potato. The marginal rates of returns, which determine the acceptability of any treatment, show that treatment that plants planted in a spacing of 75*30 cm yielded good results of 2087.61% marginal revenue. All in all the highest net benefit from this study was 260678 birr per hectare was obtained from treatment combination of 75 cm row spacing and 30 cm plant spacing with a marginal rate of return 2087.61% but the lowest net benefit 146072 birr was obtained from the treatment combination of 85 cm of row spacing and 50 cm plant spacing with a marginal rate of return of 156.65% in two growing seasons (Appendix Table 1). This means that for every 1.00 birr invested for 75 cm row spacing and 30 cm plant spacing input and transportation in the field, farmers can expect to recover the 1.00 birr and obtain an additional 20.87 birr. Therefore the most attractive plant spacing for the Irish potato production for producers with low cost of production and higher benefits in this case were 75 cm row spacing and 30 cm plant spacing combination. The marketable head yield was adjusted by 10% adjustment coefficient and the marginal rate of return (MRR) and net benefits are calculated by current tuber seed cost was 6.00 birr kg^{-1} and field price of tuber was 6.00 birr kg^{-1} and also transport cost of 10 birr kut^{-1}.

Summary and Conclusion

Appropriate plant spacing is an important agronomic practice for increasing yield of potato (*Solanum tuberosum* L.) for both ware and seed potato production. The most important objective of this study is to recognize optimal yields of potato tubers can be attained by appropriate plant spacing depending on purpose of tubers required for seed or ware potato production. Main effect of Inter and Intra row spacing had no significant effect on all phenological parameters and main stem numbers except for Bore location. However plant height, average tuber number per plant, average tuber weight, unmarketable tuber yield, marketable tuber yield and total tuber yield were highly significantly influenced by interaction effect of inter and intra plant spacing.

In general, this study indicates that yield and yield components of potato variety Belete can be improved/ manipulated with the use of planting density per unit area in the study area. The results have revealed that the current traditionally and blanket recommendation is insufficient for optimum tuber yield of the crop, but the current research recommended spacing of 75 cm between ridges and 30 cm between plants is obsolete and should be revised for enhancing the yield of the crop. The highest total and marketable tuber yield were obtained at medium plant spacing, whereas the lowest total and marketable tuber yield were obtained at wider plant spacing. In conclusion, the result of this study have revealed that plant spacing of 75 x 30 cm and 75 x 40 cm resulted in the production of higher marketable tuber yields than the other spacing.

Based on partial budget analysis the highest net benefit of 260678 birr per hectare was obtained from treatment combinations of 75 cm and 30 cm with a marginal rate of return 2087%. Therefore the most attractive inter and intra spacing for the producers with low cost of production and higher benefits were treatment combination of plant spacing of 75 cm with 30 cm. Therefore it can be concluded that different inter, intra row spacing and their interaction have remarkable effect on growth and development of potato. Generally as conclusion, potato growers at Bore and surrounding area need to plant an potato by inter and intra row spacing of 75*30 cm in order to maximize the yield of potato on the study area.

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