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Research Article

Effect of Inter-Row and Intra-Row Plant Spacing on Phonological and Growth Parameters of Potato (*Solanum Tuberosum* L.) in Western Ethiopia Horo District

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Abstract

Plant distances (The distance between and inside rows of plants) is an important agronomic management tool for potatoes as it determines growth, yield, yield components, and quality of the crop in nature this crop is a high nutrient feeder which may lead to whether to increase or decreases the tuber yields. In certain places, however, the information is limited. So, to shed light on this issue, experiments were carried out to ascertain the ideal plant spacing between and within rows for gudane varieties of potatoes as well as how this affects growth, yield, yield components, and quality. A field experiment was conducted at the Horro district in western Ethiopia during the 2022/2023 cropping season. The experiment consists of four levels of inter-planting spacing (65cm, 70cm, 75cm, and 80cm) and three levels of intra-plant spacing (25cm, 30cm, and 35cm) that were laid out in a randomized complete block design in factorial arrangements with three replications. The result indicated that both the main and interaction effects of inter and intra-plant spacing were highly significantly ($p < 0.001$) influenced days to 50% flowering, 90% maturity date, plant height, number of stems per hill, and leaf area index (LAI). The study's findings indicate that greater plant distances (80cm × 35cm) was more advantageous for both phonological and growth parameters of potato crops.

Keywords

Growth Parameters, Phonological Parameters, Plant Spacing, Potato

1. Introduction

Potato is one of the world's most important vegetable cash crops grown in highland areas [10]. Nowadays, the major species of potato crop grown worldwide is *Solanum tuberosum*. It is the majority of tropical humid areas crops that grown in the dry season through irrigation and the rainy season. Therefore, in terms of human consumption and income generation, it ranked fourth, behind a few cereal crops (rice, wheat, and maize), where a total of 376 million tonnes of potato crops were produced in the world only in 2021 [6]. It plays a great role in improving the food security of smallholder farmers due to it is a major source of inexpensive energy and produces more food per unit of time than major crops [2, 8, 12].

Especially, in 2017, it was anticipated that 388,191,000 tons of potatoes were produced annually on 1930,2600 hectares of land worldwide [9]. However, according to FAOSTAT (2020), Ethiopia's output has climbed from 349,000 tons in 1993 to

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around 743,153 tons in 2018/2019. However, according to the [13], in 2017 the average yield of potatoes in Africa was 6 to 12 tons ha^{-1} (as opposed to 35 to 45 tons ha^{-1} in Europe and North America). Again, in Ethiopia, the yield is 7.97 tons ha^{-1} [4, 5], which is significantly less than the crop's potential [13].

Generally, Ethiopia has considerable potential for potato production and productivity since around 70% of arable land is suitable for its production, productivity, and cultivation, mainly in highland areas [2, 9]. Even though, the country is endowed with suitable climatic and edaphic conditions the annual production of potatoes in Ethiopia is low. This is mainly, due to different problems, among these factors, inappropriate agronomic practices, including improper uses of plant spacing both inter and intra-row plant spacing, are the major constraints of potato production in Ethiopia [3]. However, because there is a greater chance to control the plant population in order to target the marketable tuber size, appropriate application of agronomic measures, such as both the distance between row and within plant spacing, is crucial. [20].

Likewise, in the Horro district, there is a land that is more favorable and good ecology that is not less productive than the central highlands of Ethiopia, which produce high yields. Conversely, most Horro district farmers who grow the crop use inappropriate plant spacing without row planting, as some rural smallholder farmers react to this idea, but some of them use the recommended national level of space (75 cm X 30 cm) for all varieties, ware, and seed production purposes. Plant distances, however, ought to be determined by the variety, soil quality, growth patterns, etc. In addition, different varieties of potatoes have different growth patterns and other qualitative characteristics. Therefore, the best tuber development, yield, and quality features might not result from employing the same spaces for all types.

Therefore, to alleviate these gaps in potato production and productivity, this study was conducted to investigate the effect of inter and intra-row plant spacing on the phonological and growth parameters of potatoes in the Western Ethiopia Horro district.

2. Materials and Methods

2.1. Description of the Study Area

The field experiment was conducted at Wallaga University, Shambu campus research site, Shambu district of Horro Guduru Wallaga Zone in the 2022/2023 cropping season. The district is located 330 Km away from Finfinnee. Geographically, the experimental site is situated at 9°34' 0" north latitude and 37°6' 0" east longitude, with an average elevation of 2600 m.a.s.l. The site generally receives an average annual rainfall of 1700–2000 mm, and the main rainy season is from June to October, with an average minimum and maximum temperature of 10 and 24°C, respectively. The soil type of study area is Nitisols and the pH of the soil is 4.8 [18, 23].

2.2. Description of the Experimental Materials

The experiment was conducted using an improved potato variety called 'Gudane', which was released by the Holeta Agricultural Research Centre (HARC) in 2006 [17]. This variety was selected based on the farmer's preference because of its wider adaptation, good taste quality, moderate size, and moderate resistance to late blight in the highlands of the study area compared to other varieties as a test crop [23]. Agronomic and morphological characteristics of the variety are shown below in Table 1.

Table 1. *Description of the experimental material (Gudane).*

Description	Agronomic Characteristics
Crop name	Potato
Crop variety	Gudane
Year of Release	2006
Altitude (meters above sea level)	1600 - 2800
Rainfall amount (mm)	750 - 1000
Days to maturity (days)	90 - 120
Yield farmers field (t ha-1)	21
Yield research field (t ha-1)	29
Late blight disease resistance	Moderately Resistance to Late Blight
Breeding center	HARC

Source: MoARD (2009).

2.3. Experimental Design

The experimental setup consists of four levels of inter-row plant spacing (65, 70, 75, and 80 cm) and three levels of intra-row plant spacing (25, 30, and 35 cm) combined in a factorial arrangement and laid out in randomized complete block design and replicated three times. Thus, there were 4×3=12 treatment combinations, which accounted for a total of 36 experimental plots. Each treatment was assigned to experimental plots within each block randomly. The adjustment spacing between plots was 0.5m and the spacing between adjustment blocks was 1m. The area of the plot was 7.8 m^2 for 65 cm, 8.4 m^2 for 70 cm, 9 m^2 for 75 cm, and 9.6 m^2 for 80 cm, with different numbers of tubers per row, which include 12, 10, and 8 tuber plants for 25, 30, and 35 cm intra-row spacing, respectively.

The total area of the experiment was obtained from the largest plot size, which contained 3.2 x 3 m, which was 481.6 m^2 for the experimental site, accommodating a minimum of 32 and a maximum of 48 harvestable plants with different intra- and inter-row spacing. The data was extracted from the inner two rows. Yet the two outermost rows were regarded as guards.

2.4. Experimental Procedures and Field Management

Experimental fields were cultivated by oxen three times, following the standard practice locally used. The land was leveled, and the ridges were made manually. Tubers with a medium size (39–75 g) and well-developed sprouts of variety were also planted at 15 cm depth. All treatments were fertilized at a recommended rate of 236 kg NPS ha^{-1} and 194 kg Urea ha^{-1}. The entire rate of NPS and the half rate of Urea fertilizer were applied at the time of planting, while the remaining half of the Urea was applied during the second earthling-up (41 days after planting) as side dressing. Earthling-up was done two times before flowering. Cultivation, ridging, weeding, earthing up, and harvesting were carried out at the appropriate time as per the research recommendation required for potato production [14, 15].

Table 2. The experimental layout or details of the treatment combination.

Treatments	Inter-row and Intra spacing (cm)	Number of tubers per plot planted
T1	65× 25	48
T2	65× 30	40
T3	65× 35	32
T4	70× 25	48
T5	70× 30	40
T6	70× 35	32
T7	75× 25	48
T8	75× 30 (recommended)	40
T9	75× 35	32
T10	80× 25	48
T11	80× 30	40
T12	80× 35	32

2.5. Data Collected

Five plants were randomly selected and tagged from the central two rows for all treatments before flowering to record quantitative data measurements such as crop phonology and growth parameters and the details of collected data were described below.

2.5.1. Phonological Parameters

Number of days to 50% of plant emergence: The number of days elapsed between the dates of planting and the date of 50% emergence on a net plot is expressed as the average number of days to emergence.

Number of days to 50% plant flowering: was determined by counting the number of days elapsed from days to planting to the time when 50% of the plants in each plot started to flower through visual observation, and the mean count of days was used for further analysis.

Number of days to 90% maturity: was determined by counting the number of days elapsed from days to planting to the days when more than 90% of the plants in a plot attained physiological maturity, i.e., when 90% of the haulm of the plants dried and the plants showed senescence of haulms.

2.5.2. Growth Parameters

Number of main stems per hill: collected from five randomly selected hills was counted 45 days after planting, and the mean values were computed and used for further analysis. Only stems arising from the mother tuber were considered main stems.

Plant height: The plant heights of five randomly selected plants from the net plot area at physiological maturity were measured from the ground level to the tip of the main stem at full flowering using rulers, and the mean values were used for further analysis.

Leaf area: recorded from five randomly selected plants in each plot, and the areas of the sample leaves were taken from the middle, as the width and length portions of the plant were measured using a meter. Leaf area is calculated as W x L x 0.674, where 0.674 is the correction factor [7].

$$\text{Leaf area} = W \times L \times 0.674 \quad (1)$$

Where LA = leaf area, W = width, and L = length of leaf.

2.6. Data Analysis

All collected data were checked for normality and subject to analysis of variance (ANOVA) using the GenStat 15^{th} edition computer software. The detection of differences among treatment means for significance was performed using LSD (Least Significant Tests at a 5% probability level).

3. Results and Discussion

3.1. Effects of Inter and Intra-row Plant Distances on Phonological Parameters of Potato

The main effects of the inter-row and intra-row plant spacing, as well as their interaction, were found to be highly significant (P< 0.001) effects on all phonological and growth parameters, including the number of days to 50% plant flowering, number of days to 90% plant physiological maturity, leaf area, plant height whereas the number of days to 50% plant emergence, and number of main stems per plant are non-significance, that discussed as follows:

3.1.1. Number of Days to 50% Plant Flowering

The main effects of inter-row and intra-plant spacing as well as their interaction were highly significantly ($P<0.001$) influenced the number of days to 50% flowering of potatoes, (Table 3). The earliest number of days to 50% flowering (59 days) of potato was obtained from the closest plant spacing (65*25 cm). While the highest number of days to 50% flowering (69 days) of potatoes was obtained from the widest plant spacing (80*35 cm), which extended days until 50% of the flowers bloom by ten (10) days, almost about two weeks (Table 3). The results of this study are in agreement with the findings of [1, 21], who reported that the days until 50% plant flowering were prolonged for plants grown with wider plant spacing. This may be due to the prolonged time to flowering due to the widest plant spacing having sufficient nutrients available and could be attributed to the enhancement of vegetative growth and the storage of sufficient reserved food materials for the differentiation of buds into flower buds.

In contrast, closer plant spacing stresses the plants and eventually causes them to flower sooner rather than grow vegetatively for a longer period of time. This might be because plants compete more fiercely for resources with comparable maturity levels.

Table 3. Phonological and growth parameters of potatoes as influenced by the interaction of inter-row and intra-plant spacing.

Treatments		Phonological and growth parameters of potato			
Inter-row (cm)	Intra-row (cm)	PF	PM	LA	PH
65	25	59.00^{g}	95.00^{h}	27.51^{h}	54.87^{f}
65	30	60.67^{fg}	96.67^{g}	29.20^{g}	56.87^{ef}
65	35	61.00^{ef}	97.00^{fg}	29.58^{fg}	58.33^{ef}
70	25	61.00^{ef}	97.00^{fg}	30.39^{efg}	60.53^{e}
70	30	62.00^{def}	98.00^{efg}	30.96^{ef}	65.40^{d}
70	35	62.67^{de}	98.67^{de}	31.22^{ef}	68.53^{cd}
75	25	62.33^{def}	98.33^{def}	31.59^{de}	69.03^{cd}
75	30	63.67^{cd}	99.67^{d}	31.98^{cde}	70.00^{c}
75	35	65.33^{bc}	101.33^{c}	33.14^{cd}	70.60^{c}
80	25	61.33^{ef}	98.33^{def}	33.53^{c}	68.00^{cd}
80	30	67.00^{b}	103.00^{b}	36.16^{b}	75.53^{b}
80	35	69.00^{a}	105.00^{a}	40.31^{a}	84.07^{a}
LSD (0.05)		1.67	1.39	1.67	3.95
CV (%)		1.60	0.80	3.10	3.50

This means sharing the same letter is not significantly different at ($p<0.05$), CV= Coefficient of Variance, LSD= Least significant difference, PF= number of days to 50% plant flowering, PM= number of days to 90% plant physiological maturity, LA= plant leaf area, PH= plant height.

3.1.2. Number of Days to 90% Physiological Maturity

The result of this study revealed that the main effects of inter-row and intra-plant spacing as well as the interaction have a significant ($P<0.05$) effect on the number of days required to reach physiological maturity (Table 3). The earliest number of days to 90% physiological maturity (95 days) was recorded from the closest plant spacing (65*25 cm), while the prolonged number of days to 90% physiological maturity (105 days) was observed from the widest plant spacing (80*35 cm), and they were delayed by about 10 days in the wider spacing. This indicates that the plant that grows at the closest spacing has reached tuber initiation, and the crop starts to mature earlier. This may be due to the low availability of nutrients and light interception, so there is high competition among plants for survival, and the plant could be easily early matured as compared with the widest spacing. In addition, during increased plant spacing, the plant can get sufficient nutrients from the soil and absorb solar radiation intercepts, which stimulates vegetative growth, prolongs the growing period, and delays tuber formation (crop maturity). In line with [1, 16]; - reported that a crop with closer plant spacing will mature earlier in the season than a crop with the widest plant spacing because early tuber growth is related to fast haulm growth and early maturity due to high competition for food in the closest spacing than in the wider one. Even while late growth is linked to longer haulm development, this could be because there are more nutrients available in a larger plant distances and the number of days needed for potato flowering and maturity is much later.

Similarly, other researchers also confirmed that increased plant spacing can lead to delays in days to physiological maturity that are similar to days to flowering, due to enough availability of nutrients that led to an increase in the leaf area of the crop, which increases the amount of solar radiation intercepted and enhances vegetative growth. While high planting density stimulates early maturity in potatoes [22].

3.2. Effects of inter and Intra-row Plant Distances on Growth Parameters of Potato

3.2.1. Leaf Area Per Plant

The main and interaction effects of inter-row and intra-plant spacing are highly significant (P<0.001) affected leaf areas per plant of potato (Table 3). The highest leaf area per plant (40.31 cm^2) was obtained from the wider distance between row and within-plant distances of 80*35 cm, while the lowest leaf area per plant (27.51 cm^2) was recorded from the closer inter-row and intra-plant spacing of 65*25 cm. These results indicated that, at the wider inter-row and intra-plant spacing, due to the presence of minimum competition, plants absorbed the sufficiently available resources, increased the amount of solar radiation intercepted, and increased their photosynthetic efficiency, which further increased the vegetative growth and ultimately resulted in an increased leaf area per plant. Whereas, there is limited resource availability for each plant as plant density increases, which limits the amount of assimilate available for leaf development. Similarly, [1, 19], verified that a closer within plant distances results in a smaller leaf area than a wider within plant distances, which produces a larger leaf area.

3.2.2. Plant Height

The mean plant height of potatoes was highly significantly (P<0.001) affected by the main as well as interaction effects of inter-row and intra-plant spacing (Table 3). The highest plant height (84.07 cm) of potato was recorded from the wider inter-row and intra-spacing with 80*35 cm. The lowest plant height (54.87 cm) of potatoes was recorded from the closest plant spacing (65*25 cm) of the treatment combination. This indicates that the increase in plant height may be due to better availability of nutrients in the wider plant spacing than the closest one, which enhances vegetative growth by increasing cell division and elongation with good strength and uniform growth. Whereas, in the closer plant spacing, due to high competition between and within the plant for resources, the plant growth was weak in strength and not uniform in height. So, the highest plant height was obtained with a wider spacing than with a closer spacing. This is in agreement with [1, 24], who reported that wider plant spacing enhances growth and plant height. On the contrary [25], concluded that closer inter-row and intra-plant spacing (higher plant density) resulted in the highest plant height.

In general, at closer plant spacing, due to a shortage of nutrient resources that restricts the growth of all plant organs, including roots, stems, leaves, and flowers, and stunted plant growth leads to low plant height. Likewise, [11], reported the significant effects of spacing on plant height as a result of the availability of wider inter-row spacing for growth factors and that all the essential nutrients are available at the seedling stage, increasing measured variables like plant height as compared to the closer one.

4. Conclusions and Recommendations

In conclusion, the Gudane cultivar was highly grown in the Horo district which was preferred by farmers. Thus, the results of phonological and growth parameters of potato crops were influenced by the interaction effect of both inter and intra-row plant spacing. This means that good agronomic management including optimum plant spacing is a desirable factor for both phonological and vegetative growth.

The earliest number of days to 50% flowering (59 days) and days to 90% plant maturity (95 days) of potato was obtained from the closest plant spacing (65*25 cm). While the highest number of days to 50% flowering (69 days) and days to 90% plant maturity (105 days) of potato was obtained from the widest plant spacing (80*35 cm). This is the reverse for both leaf area and plant height parameters results.

This may be due to the prolonged time days to flowering and maturity was, due to the widest plant spacing having sufficient nutrients available and could be attributed to the enhancement of vegetative growth and the storage of sufficient reserved food materials for the differentiation of buds into flower buds and tuber.

In general, potato seedling requires wider plant spacing for better phonological and growth variables. However, indefinite increases in plant spacing between the plants as well as between the rows do not result in further change in this variable rather than prolonging the days to flowering and days to plant maturity. Therefore, for better phonological and growth parameters of potato crops for both seed and ware production according to this research an inter-row plant spacing of 75-80 cm and intra-row spacing of 35 cm can be considered as the best combination.

Abbreviations

HARC Holeta Agricultural Research Center
BARC Bako Agricultural Research Center

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Conflicts of Interest

The authors declare no conflicts of interest.

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