Effect of planting density on growth, light interception and tuber yields of potato varieties (*Solanum tuberosum* l.) at Guji highland of southeastern Ethiopia

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ABSTRACT
Planting density is important agronomic management tool for potatoes as it determines light interception, growth, yield and yield components of the crop. However, the information at spasfic location is limited. Thus, the experiment was conducted to determine the optimum plating density for potato varieties and its impact on growth, light interception, yield and yield components. A field experiment was conducted at Bore in the southeastern Ethiopia during the 2021 cropping season. The experiment consists of four levels of planting densities (66667, 44444, 33333 and 26667 plant ha^{-1}) and four potato varieties: three improved (Jalanie, Gudenie, Belete and one local (Gujicha) that were laid out in a randomized complete block design (RCBD) in factorial arrangements with three replications. The result indicated that the main effects of variety and planting density significantly ($p < 0.001$) influenced days to 50% flowering, 90% maturity date, plant height, number of stems per hill, leaf area index (LAI) at 45, 60 and 75, Cumulative Interception Photosynthetic Active Radiation (CIPAR) and total dry matter production. However, tuber yield, tuber weight, average tuber number per hill, marketable yield and total tuber yield were significantly affected by the interaction effects. The overall result indicated that CIPAR increased with increasing planting density, though a maximum marketable tuber yield of 44.92 t ha^{-1} was recorded at 444444 plant ha^{-1} from Gudenie variety. However, the CIPAR was not fit with the maximum marketable and total yield of tuber; this indicates other plant and environmental factors might also significant for plants to express their yielding potential.

Keywords: Cumulative photosynthetic active radiation, Dry matter content, Leaf area index, Tuber yield,

INTRODUCTION

Potato (*Solanum tuberosum* L.) ranks fourth in terms of production after wheat, maize, and rice and third most important crop in terms of consumption, where a total of 376 million tons of potatoes were produced world-wid only in 2021 (FAO, 2023). It is also a priority crop in tropical humid areas because of its contribution to food security, income generation and double cropping advantages and it's utilization in different forms (Degebasa *et al*., 2020). Potato is consumed all over the world and one of the main favorite vegetable in Ethiopia (Fantaw *et al*., 2019). In Ethiopia, potato ranks first in the category of root and tuber crops in terms of area coverage and total production (Degebasa, 2019). The country has about 70% of the available agricultural land suitable for potato production (Birhanu *et al*., 2018).

Though, there are suitable environmental conditions, the average national yield was only 14.18 t ha^{-1} during 2018/19 cropping season which is very low as compared with the world average yield of 20.0 t ha^{-1} (Amdie *et al*., 2020). Reason for low productivity is lack of improved varieties, inappropriate planting materials (includes very small tuber size and sprout condition), prevalence of disease and insect pests, poor soil fertility, poor agronomic managements, impact of climate change, shortage of agricultural input, and poor post-harvest handling practices (Degebasa, 2019). Plant density affects different traits in potatoes (Zabihi *et al*., 2010) including tuber yield and physical quality particularly tuber size (Shayanowak *et al* 2014; Damtew 2021; Mickiewicz *et al*., 2022). Population per unit of land is also varies depending on the intended use of the crop for tuber seed and/or ware potato production (Takele *et al*., 2017). The most common recommended spacing for ware potato production in Ethiopia is 75 cm between rows and 30 cm between plants whereas for tuber seed production 60 cm between rows and 30 cm between plants (Chala & Dechasa, 2015).

According to Getie *et al*. (2015) maximum ware potato yield was reported at 50 x 25cm and 60 x 25 cm plant spacing. On the other hand, plant number per unit area largely affects crop access to resources including solar radiation and nutrients. Therefore, crop population adjustment is considered one of the most important and effective management practice in potato yield improvement (Arab *et al*., 2011). Crop production could be increased either by improving the inherent genetic potential or through application of appropriate agronomic management, such as use of optimum plant density (Binalfew *et al*., 2015). However, the choice of plant spacing is not only related to the objectives of production alone, but also to the choice of potato cultivar to be grown. Improved potato varieties together with improved management proved can give three to four fold yield advantage as compared to local varieties with traditional management practices (Taye *et al*., 2021). In addition, information on light interception is another important trait for light dependent physiological processes that are vital for growth and very variable under field conditions.

Variability in plant development may be due to different management practices and different environmental conditions (Assefa & Debella, 2020). Among environmental factors, radiation is one of the important basic meteorological parameters for crop production. Under favorable conditions, radiation plays a decisive role in vegetative growth and development (Worku and Demisie,2012; Dessa *et al*., 2018;). Light has the key role in net primary productivity. Light availability varies with plant population, spatial arrangements, especially with canopy structures (Liu *et al*., 2012). Abdollahi *et al*. (2018) indicated that the dry matter production of crops depends on the amount of intercepted solar radiation and its conversion to chemical energy. Higher tuber yield in potato cultivars is dependent both on high total plant dry matter production and, to a lesser degree, a large proportion of the dry matter being diverted into the tubers. Overall, the possibility of securing high yields of potato in the area depends much upon a proper consideration of optimum number of plants per unit area. Though, evidences were well documented at potential potato producing area of east and central parts of the country (Tesfaye et al 2012; Chala & Dechasa (2015); Dagne *et al*. (2018)) the information at the southeast parts of the country specially at Guji highlands is very limited.To this effect, the current study is aimed to investigate the impact of planting density on growth, light interception, yield and yield related parameters on potato varieties.

MATERIALS AND METHODS

Description of the experimental site

The experiment was conducted in southeastern highland of Ethiopia at Bore Agricultural Research Center (BARC) during 2021 main cropping season under rain-fed conditions. BARC is located at 06°20'30''N latitude and 38°37'0"E longitude at an altitude of 2744 meters above sea level. During the experimental period the total amount of rainfall received was 898.1 mm out of which 216.5 mm was received in May followed by 197 mm in July. The Average maximum and minimum temperatures of the growing period were 17.9°C and 9.6°C, respectively (Fig 1).

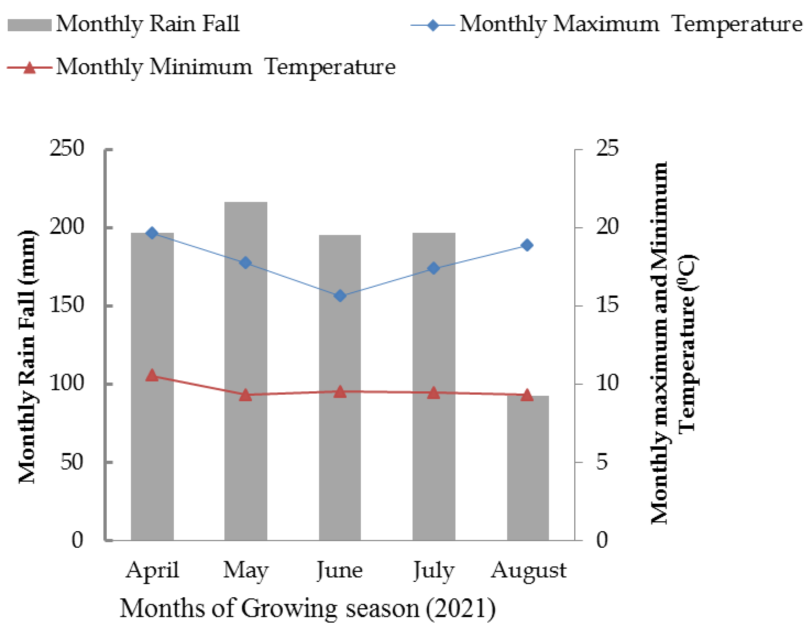

Fig 1. Monthly rainfall, minimum and maximum temperatures from April to August 2021 at Oromia region, west Giji Bore Agricultural Research Center.

Experimental Materials, treatments and Design

Four varieties of potato (Jalanie, Gudenie, Belete and Gujicha (Local variety)) were used as experimental materials (Table 1) that were planted at four planting densities which obtained by adjusting the intra-row spacing. The four planting density includes: 66667, 44444, 33333 and 26667 plant ha^{-1} were obtained from 20*75cm,30*75cm, 40*75cm and 50*75cm plant spacing, respectively. The experiment was laid out in RCBD in factorial arrangement using three replications.

Experimental procedures

The experimental field was plowed during off season then the experimental plots were leveled and ridges were prepared. Uniform medium sized and well sprouted potato tubers seeds were planted manually as per their plant spacing on 20 April 2021 at commencement of rainy season in the study area. All experimental plot received 200 kg ha^{-1} NPSB blended fertilizer (19% N, 38%P_2O_5, 7%S and 0.1%B) at planting and 100 kg Nitrogen ha^{-1} in the form of urea (CH_4N_2O) in split application (1/4 at planting, ½ at 40 days after plant and ¼ at flowering) (Gezahegn *et al.,* 2021). Earthling-up and other agronomic management practices were applied as per the recommendation throughout the growth period of potato (Gebremedhin and Asefa 2021; Fanos *et al.*, 2015).

Table 1. Description of Improved Potato Varieties Used in the Experiment

Potato Varieties	Released Year	Breeder/Maintainer	Recommended Altitude
Gudenie	2006	Holeta Agricultural Research Center	1600-2800
Jalenie	2002	Holeta Agricultural Research Center	1600-2800
Belete	2010	Holeta Agricultural Research Center	1600-280
Local/Gujicha		Landrace variety conserved by local farmers	

Source: *Getie et al., (2018)*

Data collection

Phonological data: Days to 50% flowering and 90% physiological maturity were recorded when 50% of the plants on each plot set flower and 90% of the plants in each plot attained its physiological maturity, i.e. when the aboveground biomass became senescent (Alemayehu and Jemberie , 2018) respectively. Growth parameters: for all growth parameters, five randomly sampled plants from the central rows of each experimental plot were considered to determine plant height, stem number per hill, number of leaves per plant, leaf area (LA) and leaf area index (LAI) (Bekele, 2018). The leaf area was determined by the product of the leaf width (W) and length (L) multiplied by constant (0.674); where, 0.674 is the correction factor. Then LAI was determined by dividing the average leaf area to the respective land area occupied by plants (LAI=LA/A) where A is land area.

Total dry matter production: all above ground and below ground plant parts (leaves, stem, roots, stolons and tubers) were considered to estimate total dry matter production. Sample plants were selected from five plant randomly selected from each plot at 90% maturity stage. The whole sample plants were carefully dug out, cleaned and separate into it's parts (leaves, stem, roots, stolons and tubers) in which the tuber samples sliced and air dried for two days before oven dried at 80˚C for 72 hours (Manrique *et al.*, 1991).

Light interception: the incoming global radiation was calculated indirectly from sunshine hours at Bore Agricultural Research Center using the formula: Rs = w (0.24 + 0.59 n/N) Ra, in which Rs is solar radiation that reaches the earth surface per 24 h, n = the bright sunshine hours per day recorded at the meteorological stations, N = maximum possible sunshine hours per day, Ra = radiation received at the top of the atmosphere and w = weighting factor which reflects the effect of temperature and latitude on the relationship between Rs and evapo-transpiration (ET) was used to convert the sunshine hour into solar radiation and 0.24 and 0.59 is the Ångström coefficients. Calculated evaporation (mm d^{-1}) was converted to radiation using the following conversion factor. 1Joule cm^{-2} min^{-1} (24 hr) = 5.73 mm d^{-1} (Tsegaye & Struik, 2003; Worku and Demissie, 2012; Dessa *et al* 2018). The data for Cumulative Intercepted Photosynthetic Active Radiation (CIPAR) was determined from the incoming global radiation and ground cover data which was collected at fortnight days interval throughout growing period (Worku and Demissie, 2012). Accordingly, the fraction of incoming Photosynthetic Active Radiation (PAR) intercepted by the canopy was recorded by measuring the ground cover at fortnight days interval using grids of 75 cm x 20 cm, 75 cm x 30 cm, 75 cm x 40 cm and 75 cm x 50 cm divided into 100 equal rectangles for planting densities of 66667, 44444, 33333 and 26667 plants ha^{-1}, respectively. At every fortnight days, the grids was put between rows and measurements were taken from four plants at each plot by counting the number of rectangles more than half filled with green leaf and the fraction of intercepted PAR (f) by the canopy was determined assuming 1:1 relationship between percentage of ground cover and percentage of intercepted radiation (Dessa *et al*., 2018). The number of grids filled with ≥50% green leaves was counted by looking vertically from the top. A value of one was given for a grid that was covered with ≥ 50% green leaves and zero for < 50%green leaves. The ground cover percentage was based on the green leaves only and was not include green stems.

$$(\text{IPARi}) = (PARi * GCi)$$ ………………………………………………………..… (1)(Segaye and Struik, 2003; Worku and Demissie, 2012; Dessa et al., 2018)

Where: IPARi = amount of incoming PAR intercepted at ith sampling date; PARi = recorded PAR above the canopy at ith sampling date, and GCi=ground cover of the crop at ith sampling date. The cumulative intercepted PAR (CIPAR) during the growth periods was determined by summing up intercepted light as follows: CIPAR = n [(IPARn.i+IPARn)/2] (tn-tn.i) Where, PARn.i is IPAR at sampling time tn.i and IPARn is IPAR at sampling time $t\text{-}_{n}$.

Tuber yield and yield components

Average tuber numbers per plant was recorded by counting the average number of tubers per plant at harvest from fife sample plant. Average tuber weight was determined on the bases of total tuber weight produced per plant divided by total number of plan sample; Marketable and total yield (ton ha^{-1}) were estimated from three each central rows of experimental plot. Where marketable tuber yield was determined based on size and physical quality of harvested tuber i.e. = free from mechanical and pest injury, un-deformed shape and acceptable size (>25mm) (Asnake *et al*., 2023; Getie *et al*., 2018). All the vegetative growth data were collected during maximum physiological growth stage attained while, the yield data were collected after all the vegetative growth are completed and the above ground biomass withered.

Dry matter content (%): to determine dry matter content fresh five potato samples randomly selected from each plot and weight. The sample tubers were sliced and dried in an oven at 70°C until constant weight attained. Then dry weight was weighed and dry matter present was calculated following the procedure stated in Williams and Woodbury (1968) and Howlader *et al*. (2016) using the following formula:

$$\text{Dry mater content}(\%) = \frac{weight\ of\ sample\ sry\ tuber}{intial\ tuber\ of\ sample\ tuber}\, x100\%$$ .... (2)

Statistical Analyses

Data were analyzed using the general linear model procedure of SAS statistical software (SAS version 9. Means with significant difference were separated using Fisher's Least Significant Difference (LSD) test at 5% significance level.

RESULTS AND DISCUSSION

Analysis of Variance

ANOVA table for 50% flowering dates, 90% physiological maturity dates and different vegetative growth parameters including plant height, number of main stem and LAI (at 45, 60 and 75 days after planting) and their respective significance levels are summarized in Table 2. The result indicates that most of the parameters such as 50% flowering and 90% physiological maturity date, plant height, number of stems per plant, LAI at 45, 60 and 75days after planting were significantly affected by main factors of variety and plant density. However, none of these parameters were influenced by the interaction effects.

Table 2. Mean squares of ANOVA table for Days to 50% flowering, 90% physiological maturity, plant height, number of main stem hill^{-1}, and Leaf Area Index (LAI) at 45, 60 and 75 DAP) of potato as affected by variety and plant population

Dependent Variable	DF	Days to 50% flowering	Days to 90% maturity	Plant height(cm)	Number of main stem hill^{-1}	LAI at 45 DAP	LAI at 60 DAP	LAI at 75 DAP
Variety(V)	3	200.30***	169.02***	783.17***	28.32***	4.71***	21.45***	1.81***
Planting Density(PD)	3	8.72***	19.97***	168.57***	8.76***	2.40***	12.20***	2.47***
V*PD	9	0.40^{NS}	3.89^{NS}	3.76^{NS}	0.10^{NS}	0.14^{NS}	0.60^{NS}	0.07^{NS}
Error		0.3153	2.778	21.03	0.508	0.246	0.596	0.092

, ** and * where significant at P < 0.05, < 0.01 and < 0.001, respectively., Describe DAP=Days after Planting; DF=Days to flowering*

Similarly, CIPAR, total dry matter production (DMP), number of tuber per plant, tuber weight, marketable and total tuber yield as well as total tuber dry matter content were significantly affected by the main factors of variety and planting density except for total dry matter which was affected only by the main effects of variety. On the other hand, most of these parameters were not significantly affected by the interaction factors except the number of tubers per plant, marketable and total tuber yields (Table 3).

Days to 50% flowering

Among the evaluated varieties Jalanie reaches 50% flowering early at 60.83 days whereas, Belete variety was takes longer day (70.50) for 50% flowering. However, Gudenie and the local variety were attained 50% flowering at intermediate between the two (Table 4). Variation among varieties might be due to the fact that flowering is controlled by various factors including genetic and environmental factors. The current result is compatible with the findings of Chala & Dechasa (2015). Similarly, Getie *et al*. (2018) who used Jalanie and Belete in their variety evaluation study reported that theses varieties reach 50% flowering relatively quickly within short and long days, respectively compared to Gudenie variety. On the other hand, as planting density increased, the date of 50% flowering decrease/shortened. The earliest days (64.42) to 50% flowering was observed at the maximum planting density of 66667 plant ha^{-1} which is statistically at par with 44444 plant ha^{-1}. This might be due to the fact that at higher planting density, plants compete for available resource, which enhance early flowering compared to lower density. The result of this finding was in line with the findings of Takele *et al*. (2017) who reported that the closer intra- and inter-row spacing leads the plants to stress and ultimately the plants early flowering instead of prolonged vegetative growth. On the contrary, Bikila *et al.* (2014) reported that plants at closer spacing compete for the available light and may remain in a vegetative stage for a longer period of time than plants grown in a wider spacing.

Days to 90% maturity

As observed in 50% flowering date Jalanie variety attained its 90% physiological maturity in relatively shortest days (113.3) while Belete variety attained it's 90% physiological maturity at 122.4 days. On the other hand, Gudanie and Local variety attained maturity at the middle days that Jalanie and Belete take for maturity (Table 4). Variation in days to maturity among varieties could be due to genetic or/and environmental factors. Bekele (2018) also reported that maturity is a varietal characteristic that can be influenced by planting date, climatic conditions, and adopted cultivation practices. In relation to planting density, 90% of physiological maturity dates increase with decreasing planting density. The late 90% physiological maturity (118.7 days) was observed from the minimum planting density (26667 plant ha^{-1}) whereas, the earliest days (115.8) was recorded at the maximum planting density (66667 plant ha^{-1}) (Table 4). This result is also in agreement with the finding of Tesfaye *et al*. (2012) who obtained the shortest days to maturity from closer intra-row spacing.

Table 3. Mean squares of ANOVA table for Cumulative Intercepted Photosynthetically Active Radiation (CIPAR), total dry matter production (TDMP), number of tuber per plant, tuber weight, marketable, total tuber yield and total dry matter content (TDMC) of potato as affected by variety and plant density

Variable	DF	CIPAR (MJm^{-2})	TDM $plant^{-1}$	Number of tuber $plant^{-1}$	Tuber weight $plant^{-1}$	Marketable tuber yield (ton ha^{-1})	Total tuber yield (ton ha^{-1})	Tuber Dry matter content (%)
Variety (V)	3	4272^{***}	566.8^{***}	422.18**	13014.09***	585.69^{**}	507.58**	27.77*
Planting density (PD)	3	2033^{***}	44.48^{***}	38.37**	1002.61^{***}	181.71**	81.25**	4.9NS
V x PD	9	15.5^{NS}	0.627^{NS}	25.88^{**}	498.73^{NS}	29.83^{**}	41.91^{**}	7.05^{NS}
Error		41.52	3.094		354.41	9.84	19.47	6.91

, ** and * significant at P < 0.05, P < 0.01 and P < 0.001, respectively.The results of all the growth and yield parameters considered in the study are discussed under their respective sub heading in this section of the paper.*

Table 4. Effect of variety and planting density (plant ha^{-1}) on phenology of potato at Bore during 2021 cropping season

Variety	**50% DF**	**90% DPM**	**PH (cm)**	**NMS $hill^{-1}$**
Belete	70.50^{a}	122.4^{a}	60.25c	3.021d
Gudenie	63.58^{c}	116.7^{b}	77.49 a	4.771c
Jalanie	60.83^{d}	113.3^{c}	72.65b	5.688b
Local	65.75^{b}	117.7^{b}	63.05c	6.625a
LSD (5%)	0.4681	1.390	3.824	0.595
Planting density (plant ha^{-1})				
66667	64.42^{c}	115.8^{b}	64.61c	4.062b
44444	64.50^{c}	117.4^{a}	66.57bc	4.625b
33333	65.58^{b}	118.2^{a}	68.94b	5.417a
26667	66.17^{a}	118.7^{a}	73.31a	6.000a
LSD (5%)	0.4681	1.390	3.824	0.595
CV (%)	0.9	1.4	6.7	

Mean values sharing the same letter in each column for each factor have non- significant difference according to Fisher's protected test at 5% level of significance; CV (%) = Coefficient of variation in percentage, LSD (5%) = Least significant difference at 5% probability level. DF= days to flowering, DPM= Days to physiological maturity, PH= Plant height, NMS = Number of main Stems,

Plant Height and Stem Number Per Plant

As observed from Table 4, Gudanie had the tallest (77.49 cm) while Belete scored the shortest (60.25 cm) plant height. While, Jalanie and the local varieties had resulted in intermediate plant height. Various authors revealed that, plant height is one of the quantitative traits mostly controlled by many genes and the difference in plant height among the varieties might be associated with genetic differences (Birhanu *et al*. 2018; Chindi *et al*. 2020). In relation to planting density, plant height increased significantly with decreasing planting density with maximum (73.31) and minimum (64.61 cm) plant heights recorded from minimum (26667)and maximum (66667) plant ha^{-1},respectively (Table 4). The increased plant height in response to decreasing planting density might be attributed to the fact that there is less competition among low planting density plants for nutrients, moisture and light that leading to enhanced vegetative growth and increased plant height. A similar finding was also reported by Arega *et al*. (2018) who observed that wider spacing or low planting density enhanced growth and height of the plant. In contrary, Mvumi *et al* (2018) reported that smaller in-row spacing distances increased plant height which is mainly due to increased plant population promoted plant competition for sunlight and consequently resulted in tall potato plant stalks compared to larger in-row spacing distances. Moreover, an opposite result was also reported on potato by Tesfaye *et al.* (2012) and on taro (*Colocasia esculenyta* L.) by Dessa *et al*. (2018) in which plant height has increased as planting density has increased in which they have justified that increased plant population as a result of increased competition for sun light radiation in higher planting density as well as an adaptation mechanism to increased level of mutual shade.

Stem Number per hill

The maximum stem number per hill (6.62) was recorded from the local variety and the lowest stem number (3.02) was recorded from Belete variety (Table 4). This difference could be due to the inherent variations in the number of buds per tuber of varieties used for the study as reported by Taye *et al.* (2021). Shayanowako *et al.* (2015) also stated that the main stem numbers depend on seed bed conditions, planting method and seed tuber characteristics such as number of eyes or sprouts, size, physiological age and varieties. In relation to planting density number of main stem per plant increased as planting density decreased. Maximum and minimum (6.00 and 4.06) numbers of main stems per plant were recorded from minimum and maximum planting density (26667 and 66667 plant ha^{-1}) respectively (Table 4). That may be due to less stiff competition among mutual plants that may lead to the growth and development of more stems under low planting density. A similar result was also reported by Takele *et al.* (2017) who indicated that the highest main stem number was recorded at the wider inter- and intra-row spacing while the lowest stem number was obtained at the closer spacing (higher planting density).

Leaf area index (LAI)

The patterns of LAI at different growth stages were almost different for all the varieties. The highest LAI was recorded at 60 DAP followed by 45 DAP while the lowest LAI was recorded at 75 DAP for all varieties (Figure 2A). At all growth stages, maximum LAI was recorded from Jalanie (3.52, 4.57 and 1.98) and followed by Gudanie (3.06, 4.27 and 1.70) while the lowest LAI of 2.17, 2.22 and 1.13 were recorded from the local variety at 45, 60 and 75 DAP, respectively (Figure 2A). For all varieties, the minimum LAI was recorded at early growth stages and reached its peak at 60 DAP and declined thereafter. This may indicate that maximum vegetative growth may be attained at 60 DAP and commencement of dry matter partitioning towards the underground part starts at 75 DAP. Rapid early LAI development up to 8 weeks after planting followed by gradual declination until the final harvest was reported by various authors. Howlader & Hoque (2018) stated that LAI increased sharply up to 40 DAP and gradually reached a peak at 60 DAP and declined thereafter. This confirms the production of more leaves per ground area and a faster rate of leaf emergence and leaf expansion between 40 and 60 DAP. Concurrently, Villa *et al*. (2017) reported that the decrease in LAI after 60 DAP was mainly due to the onset of senescence. Leaf area index increased with increasing planting densities. The highest LAI was recorded from the largest planting density and the lowest LAI from the smallest planting density at all stages. Leaf area index was increased from 45 up to 60 DAP and declined thereafter (Figure 2B) at all planting density. This might be attributed to the presence of greater number of leaves at higher planting density compared to lower planting density as well as the growth habits of different varieties. A similar finding was also reported by Sen *et al.* (2014) who revealed that LAI increased progressively as the crop spacing decreased i.e., higher planting density. On the other hand, Chala & Dechasa, (2015) reported that LAI significantly increased with increased plant spacing and decreased significantly with increased plant density.

Light interception

The maximum and minimum PAR were intercepted by Jalanie (198.7 MJ m^{-2}) and the local variety (155.6 MJ m^{-2}) (Table 5). Gudanie and Belete had intercepted intermediate amount of CIPAR. The difference in CIPAR among the varieties may be attributed to the differences in their LAI (Figure 2). Our result is in line with the findings of Laekemariam & Worku (2013) who reported that differences in light interception of plants depend on the extent of variation in morphology and growth duration of the cultivars. On the other hand, CIPAR increased with increased planting density. The highest CIPAR (195.3 MJ m^{-2}) was recorded at a plant density of 66667 plant ha^{-1} while the lowest CIPAR (164.5 MJ m^{-2}) was recorded at a plant density of 26667 plant ha^{-1} (Table 5). This could be due to the fact that at highest plant density, high LAI was recorded which favors higher light interception. Worku & Damisie (2012) reported CIPAR increased with increasing plant density and they also stated increasing in CIPAR is due to higher fractional interception arising from the greater leaf area indices under the higher density. A comparable report by Jin (2013) also indicated that higher plant density intercepted more solar energy than lower ones. However, the result of the CIAPR was not reflected on the total dry matter production and tuber weight per plant (Table 5 and 8). This might be due to the fact that light may not be the only factor for efficient photosynthesis process and dry matter production rather the gene/plant factor/ and other environmental factors might contribute for the result.

Total dry matter production

The highest total dry matter production (TDMP) of (76.79 g/plant) and the lowest TDMP (59.99 g/plant) were recorded from Belete and the local variety, respectively (Table 5). The difference in TDMP could be attributed to the variation observed in LAI (Figure 2A), the capacity of leafy crops to convert solar radiation to TDMP and the duration over the growing season of intercepting radiant energy. A comparable result was reported by Tekalign & Hammes (2005) who indicated that total dry matter yield of crops depends on the size of leaf canopy, the rate at which the leaf functions (efficiency), and the length of time the canopy persists. Increasing plant density significantly decreased TDMP per plant; on the other hand maximum TDMP per plant was recorded at a plant density of 26667 plant ha^{-1} (71.05 g/plant) and relatively lowest DMP per plant was recorded at a plant density of 66667 plant ha^{-1} (66.74 g/plant) (Table 4).

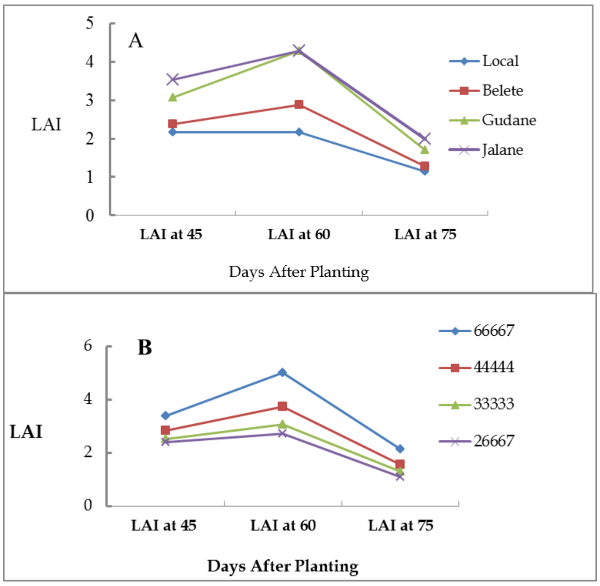

Fig 2. Effect of variety (A) and planting density (B) on Leaf area index (LAI) at 45, 60 and 75 Days After planting (DAP) of potato at Bore during 2021 cropping season

Table 5. Effect of variety and planting density (plant ha^{-1}) on Cumulative Intercepted Photosynthetic Active Radiation (CIPAR) (MJ m^{-2}) and Total dry matter production (TDMP) of potato at Bore during 2021 cropping season

Variety	CIPAR (MJ m-2)	TDMP (g/plant)
Belete	176.0^{b}	76.79^{c}
Gudenie	190.2^{c}	68.66^{b}
Jalanie	198.7^{d}	69.29^{b}
Local	155.6^{a}	59.99^{a}
LSD (5%)	5.372	1.467
Planting density (plant ha^{-1})		
66667	195.3^{d}	66.74^{a}
44444	184.4^{c}	67.56^{ab}
33333	176.2^{b}	69.37^{bc}
26667	164.5^{a}	71.05^{c}
LSD (5%)	5.372	1.467
CV (%)	3.6	2.6

Mean values sharing the same letter in each column for each factor have non-significant difference at 5% probability according to Fisher's protected test at 5% level of significance; CV (%) = Coefficient of variation, LSD (5%) = Least significant difference at 5% probability

The decrease in total dry matter per plant at the higher planting density is due to increased competition between mutual plants, which may lead to decrease in availability of nutrients for individual plant. A similar result was reported by Dessa *et al.* (2018) who indicated that dry matter production per plant decreased with planting density. It was also in agreement with Fayera (2017) who reported that the increment of biomass yield per plant was also more apparent in plants from wider spacing.

Number of tubers per plant

The highest average number of tubers per plant (30.50) was obtained from the local variety at the lowest planting density of 26667 plant ha^{-1} while the lowest average number of tubers per plant (8.17) was recorded from Belete variety at the highest planting density of 66667 plant ha^{-1} which was statistically at par with Gudanie variety at 66667 plant ha^{-1} planting density (Fig 3). The highest average numbers of 12.56 and 10.39 tubers number per plant were recorded from Gudanie and Belete varieties at a plant density of 44444 ha^{-1} whereas, highest average numbers of 30.50 and 11.83 tubers number plant were recorded from Jalanie and the local variety at a planting density of 26667 plant ha^{-1} (Fig 3). The highest tuber numbers produced per plant at the lower planting density are attributed to less competition for light and nutrients, which enhance stolons' development and resulted in a greater number of tubers production per plant. In addition, genetic and other macro and micro environmental factors might play a vital role in stolons' development and tuberization processes. The current result is in agreement with the findings of Arab *et al.* (2011) who reported that increase in plant density reduced the number of tubers per plant, But, it is in contradiction with the findings of Arega *et al.* (2018) who reported that production of the total number of tubers per plant increased as plants were grown at narrow spacing and decreased at wider plant spacing. Such variation might be due to the genetic variability among the variety used in the two independent experiments. Thought the experiment was conducted in similar environment Arega *et al.* (2018) have used single Potato variety 'CIP-393371.58' with seven spacing level.

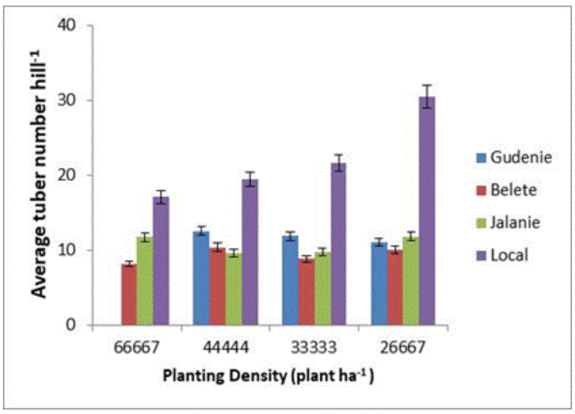

Fig 3. Average tuber number hill^{-1} of potato as influenced by the interaction of variety and planting density (plant ha^{-1}) at Bore during 2021 cropping season

Average tuber weight

The maximum average tuber weight (ATW) of 110.17 g was recorded from Belete and Gudanie (94.428 g) Jalanie while the lowest ATW of 33.980 g was recorded from the local variety (Table 7). The difference in ATW among varieties might be due to genetic variation. A similar finding was reported by Bekele (2018) with maximum ATW recorded from Belete and Gudanie. The ATW increased significantly as planting density decreased. The maximum and the minimum ATW of 86.6 g and 67.14 g were recorded at a plant density of 26667 and 66667 plant ha$^{-1,}$ respectively (Table 7). The maximum ATW from the closer planting density might be due to relatively less competition within plants for nutrients, moisture and light that intended for ultimate dry matter accumulation in tuber. The result is similar to the finding of Harnet *et al*. (2014) who found a decrease of mean tuber weight in response to increasing planting density. Demelie *et al*. (2019) also reported an increasing average root weight in sweet potato (with increasing plant spacing/decreasing planting density.

Table 7. Effect of variety and planting density (plant ha^{-1}) on average tuber weight (g hill^{-1}) of potato at Bore during 2021 cropping season

Variety	Average tuber weight (g hill^{-1})
Belete	110.169^{a}
Gudenie	94.428^{b}
Jalanie	84.43^{b}
Local	33.980^{c}
LSD (5%)	15.696
Planting density (plant ha^{-1})	
66667	67.14^{b}
44444	83.89^{a}
33333	85.37^{a}
26667	86.6^{a}
LSD (5%)	15.697
CV (%)	23.3

Mean values sharing the same letter in each column for each factor have non-significant difference at 5% probability according to Fisher's protected test at 5% level of significance; CV (%) = Coefficient of ariation, LSD (5%) = Least significant difference at 5% probability

Marketable tuber yield

The highest marketable tuber yield (MTY) of 44.92 t ha^{-1}) was obtained from Gudanie at a plant density of 44444 plant ha^{-1} whereas; the lowest MTY of 20.18 t ha^{-1} was recorded from the local variety at 33333 plant ha^{-1} (Table 8). The decrease in MTY at the lower planting density was attributed to the lower number of tubers produced at the low planting density than at the higher planting density. This result is in agreement with Binalfew *et al*. (2015) who reported higher MTY at high planting density. Dagne *et al*. (2018) also recorded higher MTY at closer spacing and visa visa. Chala & Dechasa (2015) similarly reported higher MTY at wider plant spacing compared to narrower plant spacing. The Gudanie variety has better adaptation to Guji highland condition that might make the selection and recommendation of this variety to the area compared to Jalanie and Belete. From the result Gudanie variety best fit to the environment as it is observed from the interaction table (Table 7, 8 and 9).

Table 8. Marketable tuber yield (t ha^{-1}) of potato as influenced by the interaction of variety and planting density (plant ha^{-1}) at Bore during 2021 cropping season

Variety	Planting density (plant ha^{-1})			
	66667	44444	33333	26667
Gudenie	36.60^{bcd}	44.92^{a}	39.79^{abc}	29.87^{ef}
Belete	34.03^{cde}	36.27^{bcd}	35.77^{bcd}	26.85^{fg}
Jalanie	31.00^{def}	40.64^{ab}	31.91^{def}	27.54^{f}
Local	21.95^{gh}	21.86^{gh}	20.18^{h}	21.54^{gh}
LSD (5%)	5.23			
CV (%)	10			

Where, LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation. Means in columns and rows followed by the same letters are not significantly different at 5% level of significance

Total tuber yield

The highest TTY of 51.16 t ha^{-1} was recorded from Gudanie at 44444 (plant ha^{-1}) planting density, whereas the lowest TTY of 29.18 t ha^{-1} was recorded from the local variety at 33333 plant/ha planting density (Table 9). Except for the local variety, all improved varieties recorded their lowest TTY at lower planting density (26667) (Table 9). Şanlı *et al*. (2015) also reported the highest mean TTY from the closest inter-row spacing than from the wider inter-row spacing. Similarly, Getie *et al*. (2015) found that the maximum TTY from high planting density.

Table 9. Total tuber yield (t ha^{-1}) of potato as influenced by the interaction of variety and planting density (plant ha^{-1}) at Bore during 2021 cropping season

Variety	Planting density (plant ha^{-1})			
	66667	44444	33333	26667
Gudenie	44.63^{abc}	51.16^{a}	48.39^{ab}	39.08^{cde}
Belete	42.56^{bcd}	45.90^{abc}	46.14^{abc}	42.47^{bcd}
Jalanie	35.68^{def}	46.46^{abc}	39.33^{cde}	33.83^{ef}
Local	34.33^{def}	29.43^{f}	29.18^{f}	32.77^{ef}
LSD (0.05)	7.359			
CV (%)	11.0			

Where, LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation. Means in columns and rows followed by the same letters are not significantly different at 5% level of significance

Tuber dry matter content

The highest tuber dry matter of 27.88% was recorded from Belete, followed by Gudanie (25.26%) while the lowest tuber dry matter of 24.46% was recorded from the local variety (Table 10). However, the tuber dry matter content recorded for Gudane, Jalanie and the local varieties was statistically at par. The present result is in concordance with the findings of Dagne *et al*. (2018) who confirmed that plant spacing did not significantly affect the tuber dry matter content of potatoes. The variations in tuber dry matter percentage between varieties might be due to the genetic differences between potato varieties. Concurrently Bekele & Haile (2019) and Bilate & Mulualem (2016) indicated variation in tuber dry matter content, which may be attributed to inherent genetic differences among the potato varieties. Over all in Gudanie variety has better adaptation to Guji highland condition that might make the selection and recommendation of this variety to the area compared to Jalanie and Belete.

Table 10. Effect of variety and planting density (plant ha^{-1}) on tuber dry matter content, of potato at Bore during 2021 cropping season

Main effect Variety	Tuber dry Matter content (%)
Belete	27.880^{a}
Local	24.468^{b}
Gudenie	25.263^{b}
Jalanie	25.000^{b}
LSD (5%)	2.1924
planting density (plant ha^{-1})	
66667	26.220
44444	24.738
33333	25.766
26667	25.887
LSD (5%)	NS
CV (%)	10.25

Mean values sharing the same letter in each column for each factor have non-significant difference at 5% probability according to Fisher's protected test at 5% level of significance; CV (%) = Coefficient of variation, LSD (5%) = Least significant difference at 5% probability

CONCLUSION

The genetic background and agronomic management are decisive factors for vegetative growth and the ultimate production of crops. In the current study, the highest CIPAR (195.3 MJ m^{-2}) was obtained at the highest planting density (66667 plant ha^{-1}) while the smallest CIPAR (164.5 MJ m^{-2}) was recoded from the lowest planting density (26667 plant ha^{-1}) but maximum marketable and total tuber yields per ha were scored at 44444 plant ha^{-1} from Gudanie variety. Though, plant density is a vital management practice that significantly affects light interception that might not the only factor to determine tuber yield in potato plant. In the current study *CIPAR* was not aligned with the result of marketable and total yield recorded. But, the current finding gives clue for further work to consider other plant architectural and environmental factors regarding potato physiology studies in relation to light interception, light use efficiency and dry matter production.

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REFERENCES

Abdollahi, M., Soleymani, A., & Shahrajabian, M. H. (2018). Evaluation of Yield and Some of Physiological Indices of Potato Cultivars in Relation to Chemical, Biologic and Manure Fertilizers. *Cercetari Agronomice in Moldova*, ***51*:** 53–66. https://doi.org/10.2478/cerce-2018-0016

Alemayehu, M. & Jemberie M. (2018). Optimum rates of NPS fertilizer application for economically profitable production of potato varieties at Koga Irrigation Scheme, Northwestern Ethiopia. *Cogent Food & Agriculture*, **4:1**, DOI: 10.1080/23311932.2018.1439663

Amdie A, N Dechassa and Mohammed W. (2020). Response of Potato (*Solanum tuberosum* L.) to Blended NPS and Potassium Fertilizers at Bore, Southern Ethiopia. *Inter J Agri Biosci*, **9(5)**: 232-245. www.ijagbio.com

Arab, H. R., Afshari, H., Daliri, M. S., Laei, G., & Toudar, S. R. (2011). The Effect of Planting Date, Depth and Density on Yield and Yield Components of Potato in Shahrood (Iran). *JRAS*, **7(2)9**:141- 149

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. *Journal of Advancements in Plant Science*, **1(1)**: 1–11. https://doi.org/10.18875/2639-1368.1.102

Assefa, A., & Debella, A. (2020). Review on Dry Matter Production and Partitioning as Affected by Different Environmental Conditions. *Int. J. Adv. Res. Biol. Sci*. **7(3)**: 37-46

Bekele, T. (2018). Adaptability study of improved potato (*Solanum tuberosum* L.) varieties at Shebench District, South-western Ethiopia. *Acad. J. Agric. Res.* **6(10)**: 333-339.

Bekele, T., & Haile, B. (2019). Evaluation of improved potato (Solanum tuberosum L.) varieties for some quality attributes at Shebench Woreda of Bench-Maji Zone, Southwestern Ethiopia. *African Journal of Agricultural Research*,**14(7)**,: 389-394, DOI: 10.5897 http://www.academicjournals.org/AJAR

Bikila Akassa, Derbew Belew, & Adugna Debela. (2014). Effect of Inter and Intra Row Spacing on Potato (*Solanum tuberosum* L.) Seed and Ware Tuber Seedling Emergence and Establishment at Bako, Western Ethiopia. *Journal of Agronomy*,

13(3):127–130. https://doi.org/10.3923/ja.2014.127.130

Bilate, B., & Mulualem, T. (2016). Performance evaluation of released and farmers' potato (Solanum tuberosum L.) varieties in eastern Ethiopia. *Sky. J. Agric. Res*. **5(2)**: 034 - 041,

Birhanu, T., Nigussie, D., & Wassu, M. (2018). Growth and yield of potato (*Solanum tuberosum* L.) Cultivars as influenced by plant spacing at Haramaya and Hirna, Eastern Ethiopia. *Journal of Horticulture and Forestry*, **10(5)**: 52–62. https://doi.org/10.5897/JHF2018.0532

Chala, G., & Dechasa, N. (2015). Performance of Potato (*Solanum tuberosum* L.) Cultivars and Spacing at Different in Central Highlands of Ethiopia. *Ethiopian Journal of Applied Science and Technology*, ***6*(1)**:23–47. https://journals.ju.edu.et/index.php/ejast/article/view/947

Dagne, Z., Dechassa, N., & Mohammed, W. (2018). Influence of Plant Spacing and Seed Tuber Size on Yield and Quality of Potato (*Solanum tuberosum* L.) in Central Ethiopia. *Adv Crop Sci Tech, **6(6)**: 4066(6): 406* DOI: 10.4172/2329-8863.1000406

Degebasa, A. (2019). Review of Potato Research and Development in Ethiopia: Achievements and Future Prospects. *Journal of Biology, Agriculture and Healthcare*. **9(19)**:2224-3208 , DOI: 10.7176/JBAH/9-19-04

Degebasa, A., Negash, K., Tolessa, E., Giorgis, G., Abebe, T., Gebretinsay, F., Abebe, N., Mohammed, W., & Kebede, Z. (2020). Adaptability and Performance Evaluation of Potato (*Solanum Tuberosum* L.) varieties under irrigation for Tuber Yield. *World Journal of Agriculture and Soil Science*. **4(2)**: 2020. WJASS.MS.ID.000582. https://doi.org/10.33552/WJASS.2020.04.000582

Demelie, M., Tewolde, F. T., Aragaw, A., & Gelmesa, D. (2019). Effect of Plant Population and Variety on Yield and Yield Related Traits of Sweet Potato *(Ipomea batatas) Under Irrigated Areas of Middle Awash Valley of Ethiopia*. *Acad. Res. J. Agri. Sci. Res* **7(7)**:380-384 ID: 214608714,

Dessa, A., Tessfaye, B., Worku, W., Gobena, A., & Hvoslef-Eide, K. (2018). Response of taro (*Colocasia esculenyta* (L.)) to variation in planting density and planting dates on growth, radiation interception, corm and cormels yield in Southern Ethiopia. *African Journal of Agricultural Research*.**13(23)**:1186-1197. http://www.academicjournals.org/AJAR

Fanos T, Below D., and Nebiyu A (2015) Effect of Planting Depth and Time of Earthling-up on Potato (*Solanum tuberosum* L.) Yield and Yield Components at Jimma University College of Agriculture and Veterinary Medicine, South West Ethiopia. *International Journal of African and Asian Studies* 15(61),ISSN 2409-6938 www.iiste.org

FAO (2023) Global Potato Statistics - Latest (FAO) Food and Organization Data published 21 January 2023.

Fayera, W. N. (2017). Yield and yield components of potato (*Solanum tuberosum* L.) as influenced by planting density and rate of nitrogen application at Holeta,, West Oromia region of Ethiopia. *African Journal of Agricultural Research*, ***12*(26)**: 2242–2254. https://doi.org/10.5897/AJAR2016.11840

Gebremedhin, H., and Asefa A. (2021). The Effects of Flower Removal and Earthing Up on Tuber Yield and Quality of Potato (*Solanum tuberosum* L.). *Journal of Agricultural Sciences* (Belgrade) **66(2)**:121-137. https://doi.org/10.2298/JAS2102121F UDC: 635.21(63) DOI: 10.2298/JAS2102121F

Getie, A. T., Dechassa, N., & Tana, T. (2015). Response of Potato (*Solanum tuberosum* L.) Yield and Yield Components to Nitrogen Fertilizer and Planting Density at Haramaya, Eastern Ethiopia. *Journal of Plant Sciences*, ***3*(6):**320-328. https://doi.org/10.11648/j.jps.20150306.15

Getie, A. T., Madebo, M. P., & Seid, S. A. (2018). Evaluation of Growth, Yield and Quality of Potato (*Solanum tuberosum* L.) Varieties at Bule, Southern Ethiopia. *African Journal of Plant Science*, ***12*(11)**:277-283. https://doi.org/10.5897/ajps2018.1698

Gezahegn Assefa, Yibekal Alemayehu, and Wassu Mohammed. (2021).Effects of Blended NPSB Fertilizer on Yield and Yield Related Traits of Potato(*Solanum tuberosum* L.) Varieties in Oda Bultum District, Eastern Ethiopia. *American Journal of Bioscience and Bioengineering*. **9(1,)**: 21-32. DOI: 10.11648/j.bio.20210901.14

Harnet, A., Derbew, B., & Gebremedhin, W. (2014). Effect of inter and intra row spacing on seed tuber yield and yield components of potato (*Solanum tuberosum* L.) at Ofla Woreda, Northern Ethiopia. *African Journal of Plant Science*, ***8*(6)**: 285–290. https://doi.org/10.5897/AJPS2014.1153

Howlader, O., & Hoque, M. (2018). Growth analysis and yield performance of four potato (*Solanum tuberosum* L.) Varieties. *Bangladesh Journal of Agricultural Research*, ***43*(2)**:267–280. https://doi.org/10.3329/bjar.v43i2.37330

Jin, H. (2013). Impact of Plant Density on the Formation of Potato Minitubers Derived from Microtubers and Tip-Cuttings in Plastic Houses. *Journal of Integrative Agriculture*. **2(6)**: 1008-1017

Laekemariam, F., & Worku, W. (2013). Growth, Light Interception, Radiation Use Efficiency and Productivity of Mungbean [Vigna Radiata (L.)

Wilczek] (Fabaceae) Cultivars as Influenced by Sowing Date. *Ethiopian Journal of Biological Sciences*, ***12*:** 117–133.

Liu, T., Song, F., Liu, S., & Zhu, X. (2012). Light interception and radiation use efficiency response to narrow-wide row planting patterns in maize. *Journal of Sciences*, ***10*(2)**: 87–102. https://doi.org/10.4314/eajsci.v10i2

Mvumi, C., Mawoko, A., Muropa, A., & Tsindi, A. (2018). Effects of in-row spacing on growth and yield of irish potato (*Solanum tuberosum* L.) varieties in Eastern Highlands of Zimbabwe. *Int. J. Agron. Agri. R.* **12(5)***:19-26.*

Şanlı, A., Karadogan, T., Erbaş, S., & Tosun, B. (2015). The Effects of Plant Density and Eye Number Per Seed Piece on Potato (*Solanum tuberosum* L.) Tuber Yield. *Scientific Papers. Series A. Agronomy*. LVIII:. SSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

Sen, D., Rakshit, A., & Ghosh, D. C. (2014). Effect of Transplanting Dates and Plant Population on Growth Parameters of Potato (*Solanum Tuberosum* L.) Raised from True Potato Seed (Tps). *Cercetari Agronomice in Moldova*, **47(1)**: 97–106. https://doi.org/10.2478/cerce-2014-0010

Shayanowako, A., Mangani, R., Mtaita, T., & Mazarura, U. (2015). Influence of Main Stem Density on Irish Potato Growth and Yield: A Review. *Annual Research & Review in Biology*, **5(3**):229–237. https://doi.org/10.9734/ARRB/2015/9973

Shayanowak, A., Mangani R. , Mtaita T and Mazarura U.,(2014) Effect of stem density on growth, yield and quality of potato variety amethyst. *Afr. J. Agric. Res* **9(17**): 1391-1397, DOI: 10.5897/AJAR2014. 8570 http://www.academicjournals.org/AJAR

Solomon, F., Asrat, A. and Workie, A.(2019). Yield Performance of Potato (Solanum tuberosum L.) Varieties under RainySeason at Wogera District, Northwestern Ethiopia. *J. Acad. Indus. Res.* **7(11)**: 144-149.

Takele, A., Tamiru, B., & Gadisa, E. (2017). Consequence of Inter and Intra-Row Spacing on Growth and Yield Components of Potato (*Solaniumtubersom* L.) under Irrigation at North Shewa Zone of Oromia Region, Ethiopia. *Journal of Biology*. **.7:19**, ISSN 2224-3208 (Paper) ISSN 2225-093X (Online)

Taye Buke, Asefa, T., & Woldemariam Woelore. (2021). Effect of Plant Spacing on Yield and Yield Components of Potato (*Solanum tuberosum* L.) Cultivars at Wolaita Sodo University, Ethiopia. *International Journal of Current Research and Academic Review*, **9(1)**: 103–125. https://doi.org/10.20546/ijcrar.2021.901.010

Tekalign, T., & Hammes, P. S. (2005). Growth and productivity of potato as influenced by cultivar and reproductive growth. *Scientia Horticulturae*, ***105*(1)**:29–44. https://doi.org/10.1016/j.scienta.2005.01.021

Tesfaye Getachew, Derbew Belew and Solomon Tulu, (2012). Yield and Growth Parameters of Potato (*Solanum tuberosum* L.) as Influenced by Intra Row Spacing and Time of Earthing Up: In Boneya Degem District, Central Highlands of Ethiopia. *International Journal of Agricultural Research,* **7: 255**-265.

Tsegaye, A., & Struik, P. C. (2003). Growth, radiation use efficiency and yield potential of enset (*Ensete ventricosum*) at different sites in southern Ethiopia. *Annals of Applied Biology*, ***142*(1)**:71–81. https://doi.org/10.1111/j.1744-7348.2003.tb00231.x

Villa, P. M., Sarmiento, L., Rada, F. J., Machado, D., & Rodrigues, A. C. (2017). Leaf area index of potato (*Solanum tuberosum* L.) crop under three nitrogen fertilization treatments. *Agronomía Colombiana*, ***35*(2)**: 171–175. https://doi.org/10.15446/agron.colomb.v35n2.62110

William MA, Woodbury GW (1968). Specific gravity dry matter relationship and reducing sugar changes affected by potato variety,production area and storage. *American Journal of Potato* **45(4)**:119-131

Worku, W, Demisie W (2012). Growth, light Interception and Radiationuse efficiency response of pigeon pea (*Cajanus cajan*). *Journal of Agronomy* **11(4)**:85-93.

Zabihi-e-Mahmoodabad, R., Jamaati-e-Somarin, S., Khayatnezhad, M., & Gholamin, R. (2010). Quantitative and Qualitative Yield of Potato Tuber by Used of Nitrogen Fertilizer and Plant Density. *American-Eurasian J. Agric. & Environ. Sci.*, **9 (3):** 310-318.