Performance evaluation of a tractor-drawn multi-row garlic clove planter

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Abstract: Garlic (*Allium sativum* L) is a very precious spice crop with its spices and medicinal values. Garlic planting is typically performed manually, requiring approximately 60 laborers per hectare at an estimated cost of 222.22 USD ha^{-1}. The manual planting operation demands a total of 384 labor-hours per hectare, equivalent to 48 person-days, to complete the work. To decrease the production cost and for better yield by achieving the plant population, a tractor-drawn planter for planting garlic cloves had been designed and developed at AMARC (Awash Melkassa Agricultural Research Center), Ethiopia, before this study. This present study was conducted to evaluate the performance of the machine using the Gojjam variety of garlic seeds. The overall size (L×W×H) of the planter was 1500×1250×1114 mm. Sixteen cups on each roller chain with a special attachment for four rows operated through chain sprocket sets were used. The theoretical seed rate per hectare was calculated as 4,44,444 cloves per hectare by taking row width 30 cm and clove to clove spacing as 10 cm. The theoretical seeding mass rate was calculated to be 0.3 ha hr^{-1}. The Percentage of missing seeds slightly increased as the operating speed increased. Seed missing and percentage of double were dependent on hopper fill level and forward speed of operation. Wheel slippage increased as the speed increased. As speed increased, the time to contact the traction wheel with the soil mass of the field reduced, which increased the wheel slippage due to less soil resistance on the traction wheel.2.5 km hr^{-1} is the optimum speed for the operation. The minimum value of theoretical field capacity observed at 2 km hr^{-1} speed was 0.3 ha hr^{-1} and the maximum value at 3 km hr^{-1} speed was 0.45 ha hr^{-1}. The values of effective field capacity at 2 km hr^{-1}, 2.5 km hr^{-1}, and 3 km hr^{-1} were 0.242 ha hr^{1}, 0.271 ha hr^{-1}, and 0.293 ha hr^{-1}, respectively. The minimum field efficiency at 3 km.hr^{-1} operating speed was 64.45%, while the maximum field efficiency at 2 km hr^{-1} was 80.77%. The highest field efficiency of 80.77% was observed at the lower speed. The major reason for the reduction in field efficiency with increasing forward speed was the lower theoretical time consumed compared to other test plots. The following suggestions may be explored to improve the performance of the tractor-drawn garlic planter: 1. Increase the number of rows to enhance field capacity and efficiency, 2. Incorporate a seat chair at the back of the planter for laborers to manually place seeds in cups to reduce missing and double percentages, and 3. Test the planter with different crops and gather feedback for further design refinements.

Keywords: garlic planter, hopper capacity, machine forward speed, verities

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1 Introduction

Garlic (*Allium sativum L.*) belongs to the alliaceous family and is a shallow-rooted vegetable crop (Gomes Viana et al., 2021). For its production

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and economic value, garlic is one of the main Allium vegetable crops in the world and is used as a seasoning in many foods throughout the globe. The oil of garlic is also volatile and has sulfur combining compounds which are responsible for the strong odor, its unique flavor, and pungency as well as for healthful benefits (Salomon, 2002). In addition, garlic has medicinal value, which is well recognized in the control and treatment of hypertension, worms, germs, bacterial and fungal diseases, diabetes, cancer, ulcer, rheumatism, etc. (Samavatean et al., 2011). Garlic is a very significant crop that is grown all over the world, especially in Ethiopia (Asfaw and Tadesse, 2020). As a cash crop, it is used to earn foreign currency by exporting to Europe, the Middle East, African countries, and the USA (Kilgori et al., 2007). In the off-season, the same quantity of garlic is usually sold at twice or three times the value of onion (Getachew, 2000). During the main cropping season of 2020/2021, Ethiopia produced 1.14 million quintals of garlic (Central Statistical Agency, 2021), most of which was marketed in markets other than home consumption. Increased productivity and yield per unit area would allow farmers to earn considerable returns as a cash crop in many sections of the country. Gajakos et al. (2015) found that the weight of the clove, the distance between rows and seeds, climate, and timely sowing all influence the amount of garlic produced per hectare. A variety of soil types can be used to grow garlic crops, but loamy soil that drains effectively is ideal for achieving the best results in terms of bulb size and growth (University of Georgia Cooperative Extension, 2009). Using four to five ploughings with sufficient time between each, the soil should be thoroughly prepared. Garlic crops thrive in soil with acidic. Several techniques are used to cultivate garlic, according to research by Haque et al. (2002). Due to the non-availability of planters, the manual dibbling method, which is a labour-intensive, is popular. The best quality and income come from sowing on ridges, although it can also be done in flat fields and on flat beds. Traditionally, garlic clove is planted in an upright position manually, which is a very laborious and time-consuming job to maintain the seed-to-seed and row-to-row spacing.

After conducting research, Orlowski and Rekowska (1992) concluded that there is no discernible yield difference between cloves sown upright and in any other position. In order to locate the best place to insert the garlic clove, some farmers constructed a roller that resembles a drum and has pre-spaced spikes around the outside. Maintaining row-to-row and seed-to-seed spacing becomes easier for laborers. Nare et al. (2014) employ additional techniques to ensure uniform spacing, which improves field geometry and reduces human error. To obtain a good plant population, about 60–82 man-days are required for manual dibbling to plant one hectare of garlic (row × plant spacing 15 cm × 10 cm) (Ahmad, 2022). According to Yasmeen et al. (2019), advanced technology must be used to provide sufficient production with the least amount of labor and precise seeding. Furthermore, Ashraf et al. (2017) claimed that mechanization in agriculture can lower production costs up to 50%. Garlic cloves must be planted by a planter to control plant population, maximize field capacity, and reduce labor costs while preserving seed to seed and row to row spacing in order to meet the actual demand of the country. Many efforts have been made in developed nations to automate the planting of garlic. Ahmad (2022) designed and developed a seven-row tractor rear-mounted planter for garlic. By taking row width of 17.5 cm and clove to clove spacing of 10 cm, the hypothetical seed rate per hectare was 4,44,444 cloves per hectare. The theoretical seeding mass rate was calculated to be 3.82 q ha^{-1} for the Desi variety and 15.6 q ha^{-1} for the Chinese variety, which was near to the suggested seed rate (4-7 q ha^{-1} for Desi and 15-17 q ha^{-1} for Chinese). The push-style manually operated garlic planter was designed, developed, and evaluated by Kushwaha et al. (2020). The findings were 7.36 cm, 4.98 cm, 1.1%, 4.98%, 13.46%, and 3.31 km h^{-1} for hill-to-hill spacing, seed placement depth, seed density, number of seeds per hill, soil cover over the seed, missing hills, and operation speed, respectively. Zilpilwar et al. (2020) developed tractor-driven garlic clove planters. The miss index, multiple index, quality of feed index, mechanical clove damage, effective field capacity, and field efficiency were 3.64%, 5.64%, 90.72%, 5.70%, 0.32 ha h^{-1}, and 79.02%, respectively. Garlic planting is a labour-intensive process that traditionally requires manual labor, with approximately 60 workers needed per hectare at a cost of around 222.22 USD ha^{-1}. To reduce production costs and improve yield by achieving optimal plant population, a tractor rear-mounted planter for garlic cloves has been designed and developed by Girma et al. (2024) at the Awash Melkassa Agricultural Research Center (AMARC) in Ethiopia. This study aims to evaluate the performance of the tractor-drawn multi-row garlic clove planter using the Gojjam variety of garlic seeds at Awash Melkassa Agricultural Research Center (AMARC), Oromia, Ethiopia.

2 Materials and methods

2.1 Description of the study area

The performance evaluation of the tractor-drawn multi-row garlic clove planter was conducted at the Awash Melkassa Agricultural Research Center (AMARC), located about 117 km southeast of Addis Ababa, Ethiopia. The research center lies at an altitude of 1,466 meters above sea level, with geographical coordinates of 8°24′0″ N latitude and 39°20′0″ E longitude. The area receives an average annual rainfall ranging from 500 mm to 800 mm, while the mean annual minimum and maximum temperatures are approximately 12°C and 36°C, respectively (Melkassa Agricultural Research Center, 2019).The location of the study area is shown in Figure1.

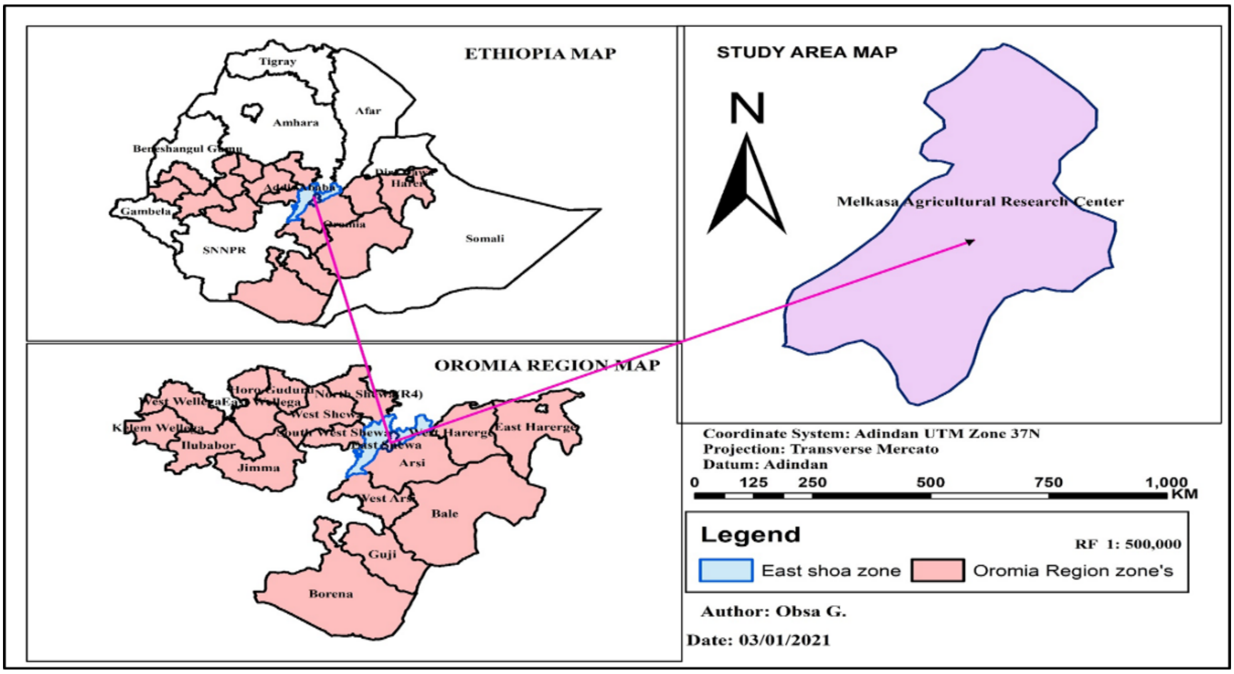


Figure 1 Map of the study area

2.2 Description of the garlic clove planter

The tractor-drawn multi-row garlic clove planter (Figure 2) was designed and developed by Girma et al. (2024). The planter is made up of the following functional components, including frame, clove hopper, clove metering mechanism, drive mechanism, furrow opening, clove covering devices, and three-point hitch. The working principle is for operating the garlic planter in the field; a three-point linkage of the planter was attached to the tractor with the help of a pin. Seed hopper filled with available garlic seed. The whole unit was taken to the field having a well-prepared seedbed. The garlic planter was operated by a tractor. The garlic planter consists of a chain and a cup-type seed metering mechanism, which is driven from the ground wheel. As the planter moves forward, the chain and cup carry seeds in the cup, which are located at some distance from each other. As the chain moves further up, the cup gets inverted inside a chute, which drops the seed. At the same time, the furrow opener opens up a furrow in which the seeds are planted. As the planter moves further, the covering device attachment then covers the seeds.

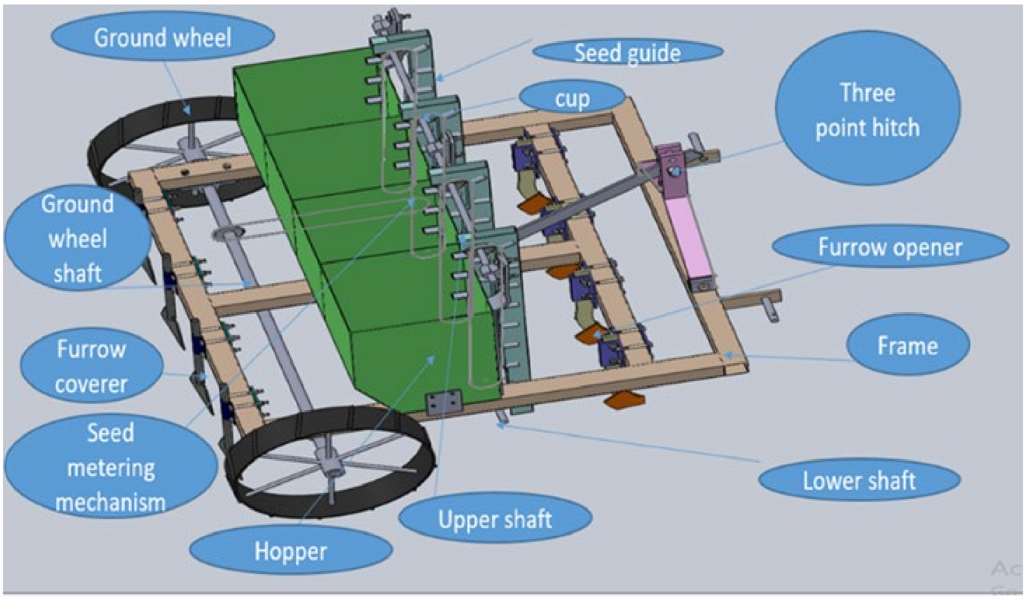
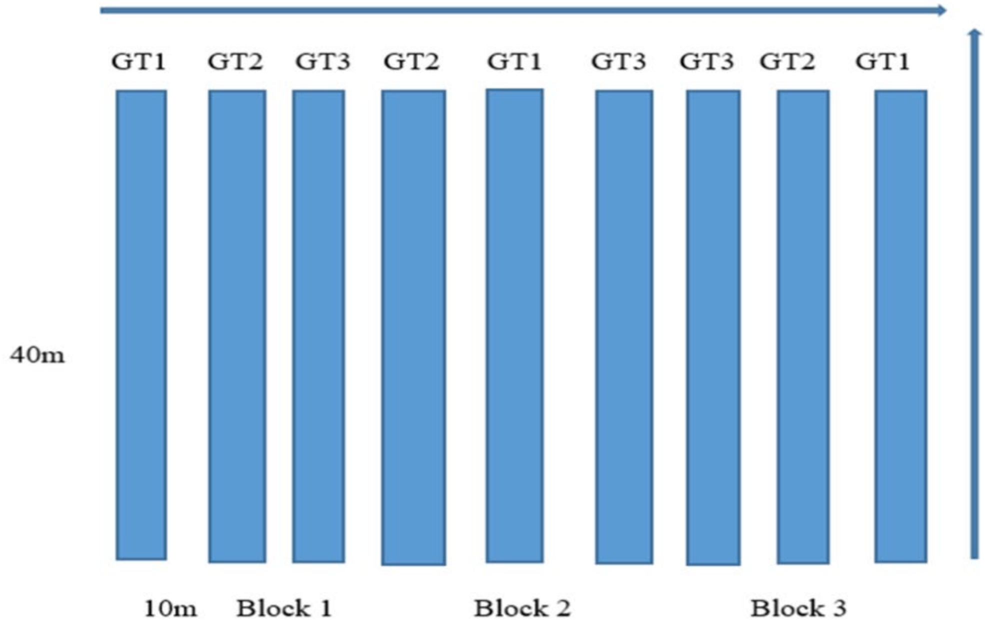


Figure 2 Isometric View of the Garlic Planter



Where: G = Garlic

T = Treatment with index number 1, 2, 3

Figure 3 Experimental design and layout

2.3 Experimental design

The experiment was conducted in the field using the Gojjam garlic variety (G) at three forward tractor speeds: 2 km h^{-1}, 2.5 km h^{-1}, and 3 km h^{-1}, forming three treatments. The selected working speeds were determined based on the manufacturer's recommendations for optimal performance of the tractor-mounted garlic clove planter, previous field studies, and preliminary trials conducted to ensure uniform seed placement, minimize seed damage, and maintain operational efficiency under local soil and field conditions (Ahmad, 2022; Tadesse et al., 2020).

Each treatment was replicated three times using a Randomized Complete Block Design (RCBD), as shown in Figure 3. Data collected from the experiment were subjected to analysis of variance (ANOVA) to test for significant differences among treatments. Means were compared using Tukey's Honestly Significant Difference (HSD) test at a 5% significance level. All statistical analyses were performed using Microsoft Excel 2019 as shown below (Figure 3).

2.4 Experimental procedure

2.4.1 Field preparation

The field was well prepared for sowing by tractor-drawn disc plow and disc harrow operations. The details of the field used for the test are as follows:

Type of soil – sandy loam soil

Soil moisture content in percent – 11.78%

Bulk density – 3.224 gm cm^{-3}

Depth of seedbed – 15 cm

Size of each plot- 40 m x 10 m =400 m^2

The well-prepared experimental field was divided into 9 plots, each having an area of 400 m^2 (i.e. 40 m x 10 m net size of each plot). After preparing the field plots, the garlic planter was prepared and adjusted for sowing operations. The tractor-drawn garlic planter (Figure 4) was adjusted at throttle position, and the sowing operation was carried out for each randomly selected plot sample by taking performance evaluation data.

Figure 4 Garlic Clove Planter under Operation

2.4.2 Seed distribution test

This test was conducted to study furrow-to-furrow variation in seed metering. The total number of seeds collected from each furrow opener was counted. The parameters considered under this test include the percentage of missing seeds, the percentage of double seeds, and the placement of the seed. For determining the percentage of missing seeds, the planter was operated in the field, and the distance between two consecutive seeds was measured in a span of 10 cm. If the distance between two consecutive seeds exceeded 1.5 times the theoretical spacing, then this was considered missing. If the distance between two planted seeds was found to be less than 5 cm during measurement, it was considered a double planting (i.e., two cloves planted too close together). In determining the placement of seeds, the planter was operated in the field under good seedbed conditions. Then the soil was removed carefully without disturbing the seed in several plots in each row. The depth of the seed below the soil surface was measured. All the tests were replicated three times with garlic seeds.

2.4.3. Draft and power requirement test

The draft force of the implement was measured using a digital drawbar dynamometer attached to the front of the tractor on which the implement was mounted. An auxiliary tractor was used to pull the implement-mounted tractor over a measured distance of 20 m, with the implement in its operating position and the tractor in neutral gear. The implement was then lifted off the ground, and the draft was measured again under the same conditions. The net draft force of the implement was calculated as the difference between the two readings, effectively eliminating the rolling resistance of the implement-mounted tractor.

This procedure was repeated for all selected forward speeds to ensure accuracy and repeatability. The methodology aligns with the modified draft-force measurement approach described by Kim et al. (2024), who similarly isolated actual implement draft by subtracting the tractor's rolling resistance from the total measured force.

The tractive power (P) required to pull the implement was calculated using the standard relationship:

$$P = \frac{F*V}{75} \tag{1}$$

Where,

P = power requirement in horsepower (hp);

F= Draft force in kilograms (kg);

V= Forward speed of the tractor in meters per minute (m min^{-1}).

Forward speed in m min^{-1} was calculated from the measured speed in km h^{-1} using the conversion.

The tractor was operated at each forward speed (2, 2.5, and 3 km h^{-1}), and draft force was recorded over the measured distance. The corresponding power requirement was then calculated for each speed using the formula above. This method allows determination of both the draft and power requirements of the planter under field conditions.

2. 4.4. Wheel slippage

A mark was made on the tractor drive wheel with coloured tapes, and the distance the tractor moves forward at every 10 revolutions under the no-load condition and the same revolution with a load on the same surface was measured. Wheel slip for any given load was determined by Equation 2 (Rangapara, 2014).

$$Wheel\,Slippage = \frac{M_1 - M_2}{M_1} X100 \tag{2}$$

Where,

M_1= Distance covered at 10 revolutions of the tractor drive wheel at no load, (m);

M_2 = Distance covered at 10 revolutions of the tractor drive wheel with load, (m).

2.4.5. Fuel consumption

Fuel consumption of the tractor during planting was measured following a standard procedure. The operating speed of the tractor in 3rd gear was used, and fuel consumption was determined for an area of 400 m^2. Before field testing, the tractor fuel tank was filled to its maximum level. After completing the planting operation, the tractor engine was stopped, and the fuel tank was refilled to the same level using a graduated cylinder. The volume of fuel required to refill the tank was recorded and considered the fuel consumption for the planting operation. This method provides an accurate estimate of diesel usage by directly measuring the fuel required to restore the tank to its initial level, consistent with the procedure described by Velasco et al. (2024).

2. 4.6. Time and labour requirements

Time and labor requirements were determined by recording the duration and personnel involved in planting operations at different tractor speeds. A digital stopwatch was used to measure the time taken to cover a 4000 m^2 plot, and the time to cover 1 ha was calculated by scaling accordingly. Two laborers were involved for each operation: one to operate the tractor and planter and the other to refill seeds. Field capacity (ha h^{-1}) was computed by dividing the plot area by the measured time, and total labor requirement (person-hours per hectare) was calculated by multiplying the number of laborers by the time required to cover 1 ha. Measurements were repeated three times per speed, and the average was used for analysis. This method allowed a precise assessment of how operating speed affects both time efficiency and labor inputs during garlic planting.

2. 4.7 Field capacity and field efficiency

The theoretical field capacity, effective field capacity, and field efficiency were computed by using Equations 3-5 given by Hancock et al. (1999) as follows:

$$\text{TFC} = \frac{W \text{ x } S}{10} \tag{3}$$

Where,

TFC = theoretical field capacity (ha hr^{-1});

W= width of planter (m);

S= speed of operation, (km hr^{-1});

10 = conversion factor .

$$\mathrm{EFC} = \frac{A}{t} \quad (4)$$

Where,

EFC = effective field capacity (ha hr^{-1});

A = area of plots (ha);

t = time taken (hr)

$$E_f = \frac{EFC}{TFC}\ x\ 100 \quad (5)$$

Where,

E_f = field efficiency (%);

EFC = effective field capacity (ha hr^{-1});

TFC = theoretical field capacity (ha hr^{-1}) .

2.4.8 Germination Percentage of the seed

Germination percentage was calculated by counting the total number of emerged seedlings in each test plot (400 m^2) and dividing it by the total number of seeds planted. The germination percentage was then computed using the standard formula:

$$\text{Germination Percentage (\%)} = \frac{\text{Number of Germinated Seeds}}{Total\ Number\ of\ Seeds\ Planted} \times 100 \quad (6)$$

This method follows the standard procedure recommended by the International Seed Testing Association (ISTA, 2015), which is widely used for evaluating field germination performance.

3 Result and discussion

Data were analysed using one-way analysis of variance (ANOVA) in Microsoft Excel 2019. Asterisks indicate the level of significance for differences among treatment means: * denotes significant differences at the 0.05 level ($p < 0.05$), and ** denotes highly significant differences at the 0.01 level ($p < 0.01$). No symbol indicates no statistically significant difference ($p \geq 0.05$). Since no post-hoc test was performed, individual pairwise comparisons are not shown.

3.1 Placement of seed

Placement of seeds in all the furrows opened by the planter is shown in Table 1. The average depth of seed was 5.97 cm in furrow openers, which indicated that the placement in the furrow openers was uniform. The depth obtained by the planter was therefore within the desirable limit, and the distance between rows was 29.96 to 30.1 cm, with an average distance was 30 cm.

Table 1 Average depth of seed placement and row-to-row distance under different operating speed

Operating speed (km hr^{-1})	Depth of seed placement (cm)	Row to row distance (cm)
2.0	5.98	30.10
2.5	5.94 *	29.95 *
3.0	6.00 *	29.96 *

Note: Data were analyzed using one-way ANOVA in Microsoft Excel 2019. * indicates significant differences among means at $p < 0.05$. No symbol indicates no significant difference at $p \geq 0.05$. Since no post-hoc test was performed, individual pairwise comparisons are not shown.

Table 2 Average of number of missing and number of double

Speed (km hr^{-1})	Spacing between two consecutive seeds (cm)	Number of missing	% of Missing	Number of double	% of Double
2.0	11.13	1	8.98 *	2	17.96 *
2.5	11.85	2	16.84 *	1	8.43 *
3.0	11.53	2	17.34 *	1	8.67 *

Note: Data were analyzed using one-way ANOVA in Microsoft Excel 2019. * indicates significant differences among treatment means at $p < 0.05$. No symbol indicates no significant difference at $p \geq 0.05$. Since no post-hoc test was performed, pairwise comparisons are not shown.

3.2 Percentage of missing and percentage of double

The percentage of missing and the percentage of double for the planter is shown in Appendix 1. The percentage of missing slightly increased as the operating speed increased, as shown in Table 2. The seed missing and percentage of doubles depended on hopper fill level and forward speed of operation.

The percentage of double slightly decreases with speed increase. It is mainly affected by the hopper fill level and the forward speed of operation.

3.3 Draft and power requirement of planter

The data recorded on the effect of different speeds on the draft (kg) and power (hp) are presented in Appendix 2. Draft increased with the increase in operating speed, as shown in Table 3 and Figure 5. The net draft observed was 229.66, 238, and 243.66 kg at forward speeds of 2, 2.5, and 3 km hr^{-1}, respectively. As speed increased, the volume of soil mass per unit time passing through the planter increased, and therefore soil resistance also increased, which resulted in higher draft values. The tractor required more power at higher speeds to overcome the increased resistance developed at the tractor and the working site.

Table 3 Average draft and power measurement

Operation speed ($km\ hr^{-1}$)	Trials number	Draft (kg)			Power (hp)		
		Load condition	Unload condition	Net draft	Load condition	Unload condition	Net power
2.0	3	337.33	107.67	229.66	2.49	0.79	1.70
2.5	3	349.33	111.33	238.00	3.23	1.03	2.20
3.0	3	361.00	117.33	243.66	4.01	1.30	2.70
	Mean	349.22	152.77	237.10	3.24	1.04	2.20
	SD	11.83	66.65	7.04	0.76	0.25	0.50
	CV	3.389	43.63	2.97	23.43	24.53	22.72

3.4 Wheel slip

The data concerning the effect of different speeds on the wheel slippage are presented in Appendix 3, while the summary of the results is shown in Table 4. From the table, wheel slippage increased as the operating speed increased. As speed increased, the contact time between the traction wheel and the soil mass was reduced, which increased wheel slippage due to lower soil resistance on the traction wheel. The optimum operating speed was 2.5 km hr^{-1}.

Table 4 Average slippage

Speed ($km\ hr^{-1}$)	Treatment number	Distance covered in 10 Revolutions		Slip (%)
		under no load (m)	under load (m)	
2.0	3	17.96	17.17	4.39
2.5	3	17.82	16.84	5.49
3.0	3	17.56	16.21	7.68
Mean		17.78	16.74	5.85
SD		0.20	0.49	1.67
CV		1.14	2.91	28.61

Table 5 Fuel consumption

Speed ($km\ hr^{-1}$)	Treatment number	Fuel consumption to cover 1 m^2 (l)	Fuel consumption ($l\ hr^{-1}$)
2.0	3	0.26	7.66
2.5	3	0.16	4.92
3.0	3	0.43	4.48
Mean		0.28	5.69
SD		0.14	1.40
CV		50.24	24.77

3.5 Fuel consumption

The effect of the tractor's operating speed in 3rd gear on fuel consumption was evaluated over an area of 400 m², and the corresponding results are presented in Table 5. During field testing, fuel usage was measured using the standard refill method, in which the tractor's fuel tank was filled to its maximum level before operation and refilled afterward to determine the exact volume consumed. Based on the field data collected, the tractor consumed 0.277 liters of fuel for each plot under the specified operating conditions.

The results of this study showed that fuel consumption per unit area (l ha^{-1}) decreased as the operating speed of the tractor increased. This trend occurs because higher speeds significantly improve field capacity; that is, more land is covered per unit time, which lowers the amount of fuel required per hectare even if the hourly fuel use remains similar. Comparable findings have been reported in previous studies. Kareem and Sve (2019) observed that increasing tractor forward speed during ploughing operations reduced fuel consumption per hectare due to improved operational efficiency. Likewise, Himoud (2009) documented up to a 39% reduction in area-based fuel consumption when forward speed increased from 0.48 m s^{-1} to 1.68 m s^{-1}. A broader review by Mamkagh (2018) further confirms that higher operating speeds enhance field capacity and consequently reduce fuel consumption per unit area. Therefore, the decreasing trend in fuel use with increasing speed observed in the present study is consistent with established evidence in the literature.

3.6 Time and labor requirement

The data concerning the effect of different speeds on the time to cover 1ha area are presented in Table 6. Time consumed by the planter per unit area (ha) decreased as the speed of the operation increased. As speed increased, the field capacity increased because at higher speed, more area per unit time was covered, hence time per unit area decreased.

The garlic clove planter machine required two persons for the manipulation and operation of the sowing activity of garlic on the well-prepared land. One skilled labourer was required to perform the sowing operation by operating the tractor, while the second was required to refill the seeds. It is clear that as speed increased, the time required to cover 1 ha decreased.

Table 6 time and labour requirements

Speed (km hr^{-1})	Time to cover 4000 m^2(s)	Time to cover 1 ha (hr)	Number of labour
2.0	476.00	4.12	2
2.5	424.33	3.68	2
3.0	397.00	3.44	2
Mean	432.44	3.75	2
SD	40.12	0.34	0
CV	9.28	9.17	0

3.7 Field capacity and field efficiency

The average effect of different operating speeds on the theoretical field capacity, effective field capacity, and field efficiency for covering a 1 ha area is presented in Table 7, while the full dataset is provided in Appendix 4. The results show that as the operating speed increased, effective field capacity increased and field efficiency decreased. Specifically, higher speeds allowed the planter to cover more area per unit time, reducing idle and operational delays, which in turn increased overall field efficiency. This trend aligns with the observed decrease in time and labor requirements at higher speeds and is consistent with findings from previous studies indicating that increased forward speed enhances operational efficiency and productivity in field planting operations (Kareem and Sve, 2019; Himoud, 2009; Mamkagh, 2018).

3.7.1 Theoretical and effective field capacity

Theoretical field capacity and effective field capacity mean values were obtained at different operating speeds shown in Table 7. The minimum value of theoretical field capacity observed at 2 km hr^{-1} speed was 0.3 ha hr^{-1} and the maximum value at 3 km hr^{-1} speed was 0.45 ha hr^{-1}. The values of effective field capacity on 2 km.hr^{-1}, 2.5 km hr^{-1}, and 3 km hr^{-1} were 0.242 ha hr^{-1}, 0.271 ha hr^{-1}, and 0.293 ha hr^{-1}, respectively. Figure 7 shows that the theoretical and effective field capacity increased with an increase in speed.

3.7.2 Field efficiency

The mean field efficiency values obtained are presented in Table 7. The highest field efficiency of 80.77% was observed at the lowest operating speed of 2 km h^{-1}, while the minimum efficiency of 64.5% occurred at the highest speed of 3 km h^{-1}, indicating that field efficiency decreased with increasing operating speed. Rangapara (2014) suggested that smaller field sizes require more planter passes, which increases time losses and lowers field efficiency. In the present study, the reduction in field efficiency at higher speeds was primarily due to the actual time spent in the field being less than the theoretical time, resulting in increased time losses and reduced operational efficiency.

3.8 Plant population in the field

The plant population test was presented in Table 8. The seed germination percentage was varied from 81.5% to 85.06 % across the three plots, each with an area of 400 m².

Table 7 Field capacity and field efficiency

Speed (km hr^{-1})	Treatement number	Total time required to cover 400 m²		Total time to cover 1 ha	Theoretical field capacity (ha hr^{-1})	Effective field capacity (ha hr^{-1})	Field efficiency (%)
		(s)	(hr)				
2.0	3	476.00	0.13	4.12	0.30	0.24	80.77
2.5	3	424.33	0.12	3.68	0.38	0.27	72.35
3.0	3	397.00	0.11	3.44	0.45	0.29	64.45
Mean		432.44	0.12	3.75	0.38	0.27	72.52
SD		40.12	0.01	0.34	0.07	0.03	8.16
CV		9.28	8.80	9.18	20.00	9.52	11.25

Table 8 Seed germination test in the field

Speed (km hr^{-1})	Number of seed planted	Number of seeds germinated	% of germination
2.0	395	336	85.06 %
2.5	388	324	83.5 %
3.0	391	319	81.5 %
CV	0.01	0.02	0.02
Mean	391.30	326.33	83.35
SD	2.87	7.13	1.459

Table 9 Performance of tractor-drawn garlic clove planter compared with the conventional practice of manual planting method

Sr.No.	Parameter	Unit	Tractor-drawn garlic clove planter	Manual planting method
1	Row to row spacing	mm	300	300
2	Plant to plant spacing	mm	100	70-150
3	Effective working wide	mm	Four rows	One row
4	Field efficiency	%	72.52	-
5	Depth of planting	cm	6	5-7
6	Travel speed	km hr^{-1}	2- 5	-
7	Germination count	%	81.5-85.06	70-95
8	Seed rate	kg ha^{-1}	137	100-140

The seed germination rate in the field was not affected by the speed, which indicated that even at a higher speed, the planter places the seed with proper handling or metering of the seeds. The lower the CV, the higher the precision of the experiment for the measured parameter.

3.9 Manual method garlic planting

According to capacity building for scaling up of evidence-based best practices in agricultural production in Ethiopia (CASCAPE, 2017) project demonstration manual planting results, row spacing of 30 cm was found to be optimum for were garlic production which resulted in 9657.6 kg ha^{-1}. The garlic seed row-to-row spacing should be 30 cm, while to planting space of garlic seed should be 7-15 cm.

3.10 Comparing the tractor- drawn garlic clove planter machine with the manual planting method

Table 9 shows the result obtained when comparing the performance of the tractor-drawn garlic planter with the existing manual planting method. In the planting operation using the four-row tractor-drawn garlic clove planter, two persons were required: one person to refill the seed hopper and the other to operate the machine. However, manual planting of garlic seed for one hectare of land required 384 hours (forty-eight persons per day) of human labour. By contrast, only two persons were needed to plant garlic clove using the tractor-drawn planter within 3.75 hr ha^{-1} to accomplish the same work. Hence, the tractor-drawn garlic planter reduced the time requirement per hectare by 380.25 hours and also reduced labor requirements

However, the tractor-drawn garlic planter, estimated to cost 854.46 USD, may be too expensive for a single farmer to own. By renting, farmers can save time, reduce production costs (planting operation costs), and reduce labor drudgery.

4 Conclusion

Tractor-drawn garlic clove planter works with higher efficiency in the field compared the manual planting method, with an optimum operational speed of 2.5 km hr^{-1}. The minimum theoretical field capacity observed at 2 km hr^{-1} was 0.3 ha hr^{-1}, while the maximum value at 3 km hr^{-1} was 0.45 ha hr^{-1}. The values of effective field capacity on 2 km hr^{-1}, 2.5 km hr^{-1}, and 3 km hr^{-1} were 0.242 ha hr^{-1}, 0.271 ha hr^{-1}, and 0.293 ha hr^{-1}, respectively. The minimum field efficiency at 3 km hr^{-1} was 64.45%, while the maximum at 2 km hr^{-1} was 80.77%. The highest field efficiency of 80.77% was observed at the lower speed

The major reason for the reduction in field efficiency with increasing forward speed was the lower theoretical time consumed compared to other test plots. The prototype tractor-drawn garlic clove planter worked satisfactorily and saved time, but increasing the number of rows is required to enhance field capacity and efficiency. Incorporating a seat at the back of the planter for laborers to manually place seeds in cups would reduce the occurrence of missing and double seed placement. Testing the planter with other crops could provide additional field data and feedback to inform design improvements and enhance its performance.

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