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Performance Evaluation of a Two Row Animal Drawn Maize Planter with Fertilizer Applicator

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ABSTRACT

In most parts of Ethiopia, planting of maize is done by hand, and it is a tedious, time consuming and less efficient operation. A two-row animal drawn that is cost-effective for farmers, easy to repair, and user friendly was developed and evaluated. The components of the prototype are seed hoppers, fertilizer hoppers, mainframe, seed metering plates, wheels, furrow openers and closers, seed discharge tubes, and handles. The majority of the parts were made of mild steel. In order to optimize the planter's design, the physical properties of maize seeds were taken into account. The parameters used for evaluating the prototype's performance were multiple index, miss-index, precision-index, feed-quality-index, field capacity, field efficiency, planting depth, plant population count, labour cost, and economy. A factorial design was used for the experiment (4x3x3). The result indicated that the percentage of mechanical seed damage, seed sphericity, and seed germination were 1.01±0.37%, 71.56±7.10% & 94.58±0.21, respectively. Performance results showed planter's forward speed during operation had a significant effect on the seed's multiple index, miss-index, feed-quality-index and precision-indexes (at $p < 0.05$). Average values of field capacity, field efficiency & depth of planting were 0.21 ha h^{-1}, 86% and 4.61±0.30 cm, respectively. The performance evaluation results showed that Ethiopian farmers who grow maize would find the prototype planter simple to use, efficient, and economical.

Keywords: *Planter design, Row planter, Seed spacing, Field capacity, Field performance*

INTRODUCTION

Maize, scientifically named *Zea mays* L., is among the leading crops that is grown in about 170 nations and covers 197 M ha, with significant areas in Asia, Latin America, and Sub-Saharan Africa (FAOSTAT, 2021). Maize is known for providing both people and livestock with protein and energy, and due to this, it is regarded as a strategic food and feed crop globally (Erenstein *et al.*, 2022).

Ethiopian farmers primarily cultivate maize for sustenance. Agricultural households consume about 75% of the country's total maize production. The crop currently is the lowest source of calories, supplying 21% of the country's per-person calorie needs (IFPRI, 2010). Maize is a staple food usually used for preparing beverages locally. In addition, the leaves and stalks are usually used for animal feeding and construction purposes. Maize production is also valuable because the post-harvest waste can be utilized for energy production, enhancing both agricultural and renewable energy sectors in the future (Ertuğrul *et al.*, 2024).

The level of agricultural mechanization in maize production is on the lower side. The majority of agricultural work is done either manually or with animal-drawn traditional implements (MOARD, 2010; Kelemu, 2015). Because of the absence of appropriate row planters, farmers primarily use broadcasting to plant maize seeds. The conventional planting/broadcasting method takes a lot of time and scatters seeds unevenly. Maintaining an ideal plant population in the outdoors is therefore challenging.

In Ethiopia, about 60% of farmers cultivate less than 0.90 ha in very fragmented lands (Rapsomanikis, 2015). However, smallholder farming is responsible for a large proportion of Ethiopian food production. It cultivates more than 90% of the total cropland and provides more than 90% of agricultural output (Paul and wa Gĩthĩnji, 2017). Crop yields in the smallholder farms are very low compared to their potential capacity and are also substantially lower (less than 50%) than the yields obtained in experimental farms and research stations (Taffesse *et al.*, 2013). The gap is especially remarkable for maize, with an average yield of 2.6 t ha^{-1} compared with the potential yield of 7.8 t ha^{-1} obtained in on-farm trials (Central Statistical Agency, 2018). Agricultural mechanization can provide much more efficient work if it can be acquired by farmers with financial power. In fact, the level of agricultural mechanization can be considered as an indicator of the development of the agricultural system (Ozgunaltay Ertugrul *et al.*, 2019). The smallholder farmers are mostly unable to afford and use the costly planting machines that can provide optimal plant density. These smallholder farmers were unable to afford and use the costly planting machines that established optimal plant density. However, the majority of farmers own animals that can readily be used as power sources for planting activities. Therefore, the development of an animal-powered maize planter is beneficial in terms of affordability, reliability and ease of use.

Melkassa agricultural research center developed a tillage-cum-planter for planting sorghum and maize crops. The planter is pulled by oxen and has two ground engaging wheels where one of them produces the necessary force to drive the seed and fertilizer plates through chain-sprocket drive. The planter was developed to be attached to a ripper so that it can be utilized in conservation agriculture practice. The problem of the planter is that it was mainly developed for conservation agriculture and requires additional draft for ripping the soil (Abebe, 2017). Another sweeper attached planter was manufactured and distributed by the research center. It is a pair of oxen drawn implement which is designed to place seed and fertilizer in the furrow created by the sweeper. The problem of the machine is its seed and fertilizer metering system. The seed and fertilizer metering are done by the operator himself by swinging a lever, connected to the metering unit. This creates difficulties in achieving uniform seed spacing and seeding rate within the row. Besides, guiding the draft animals is difficult as the operator must use both of his hands simultaneously for agitating/swinging the metering unit and for exerting a force on the handle of the implement to manipulate the depth of sowing (AIRIC, 1998).

It was the above limitations of the available animal drawn planters that led to the conclusion that a better animal drawn planter should be developed for the poor farmers. The objective of this study was to design, develop and evaluate an animal-drawn maize planter so that the overall efficiency of maize production can be improved.

MATERIALS and METHODS

Study Area

The research was conducted in the Oromia region, Melkassa district, Melkassa agricultural research center, approximately 118 km southeast of the capital, Addis Ababa, Ethiopia. It is located in the great central rift valley at 8° 24' N latitude, 39° 21' E longitude, and altitude of 1466 m above sea level. The area is among the semi-arid regions and has sandy loam soil. The majority of maize crop varieties grow in the area due to its favorable agro-climate.

Prototype Planter

The prototype planter was built at Melkassa agricultural research center workshop and is drawn by draft animals. It plants two rows in a single pass. It consists of two seed hoppers, one fertilizer hopper, four vertical metering plates, two furrow openers, two furrow coverers, mainframe, and two driving wheels.

Laboratory and field tests were carried out to evaluate the prototype planter's performance. The physical properties of maize seeds were measured. Investigations on seed damage, seed rate, and seed spacing were also made. To determine its performance and capacity, the prototype was drawn on a fine-tilled farm field. The farm field was plowed and pulverized by an ard plow.

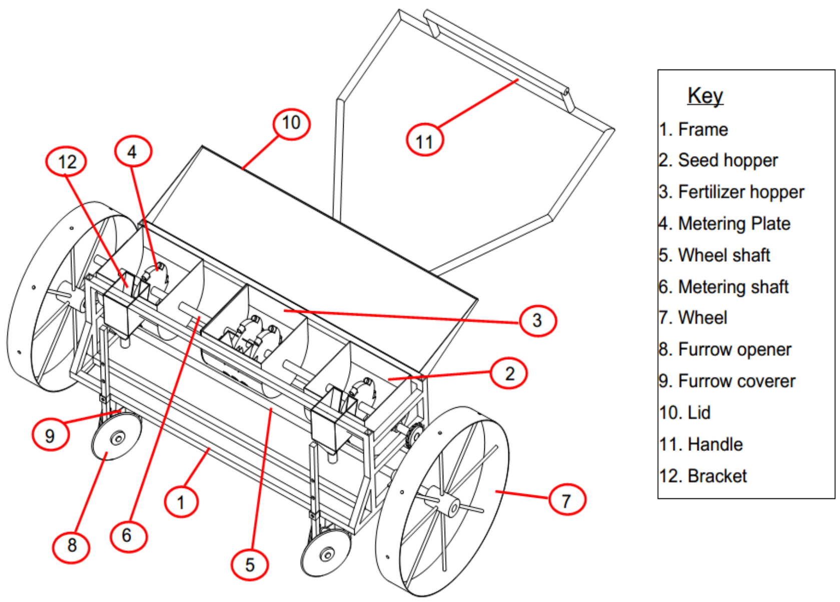

Figure 1. *Major parts of the prototype*

Performance Evaluation of the Prototype Maize Planter

Laboratory Evaluation

Physical Properties of Maize Seed

The physical properties of maize seeds were determined using three axial dimensions of the seed. The dimensions were length (longest intercept), width (equatorial width perpendicular to L) and thickness (breadth perpendicular to L and W). The dimensions were measured by a manual Vernier-caliper with accuracy of 0.02 mm for randomly selected 100 seeds. Mean dimensions of maize seeds, geometric mean diameter, volume and sphericity and thousand seed weight of grains were calculated using Mohsenin (1986).

Calibration

To calibrate the planter (Figure 1), it was elevated and jacked up to a platform, and a 2.5 kg maize seed was added in each of the two hoppers of the planter. The wheels were marked and rotated to measure the number of revolutions. During the rotation, the discharged seeds were collected in polythene bags. The wheels were then rotated 20 times at 0.5 m s^{-1} forward speed. The rotation was selected by taking into account the donkey's pulling forward speed in a farm field.

Evaluation of Percent Seed Damage

To examine the performance of the metering rollers, after the 20^{th} revolution, the collected seeds were put and weighed up on a sensitive balance. It was then checked for any visible external breakage. In addition, to examine internal damage, seed samples were randomly picked and tested for germination. The following formula was used to determine percent seed damage:

$$M_d = \frac{S_{nds}}{S_{ns}} \times 100 \tag{1}$$

Where; M_d: percent seed damage,

S_{nds}: number of maize seeds damaged externally,

S_{ns}: number of maize seeds.

Evenness of Seed Spacing

A sand leveled bed that has a 25 cm depth and 2 m width was prepared for the test. The planter was then pulled over the bed at donkey's working forward speed on farmland, i.e., 2.5 km h^{-1}, and furrow openers were lowered to a depth of 5 centimeters. Both the number of seeds and the distance between adjacent seeds were counted and recorded. Three replications were used.

Field Test

Evaluation of Seed Spacing

To evaluate spacing between seeds, the seed hoppers were filled to 25%, 50%, 75%, and 100% loading capacities while the machine was pulled at forward speeds of 1 km h^{-1}, 3 km h^{-1}, and 5 km h^{-1}. The field was carefully prepared using local ard plough. A carefully dug, fine sand covered, leveled, gently packed, and well-watered soil was used to test the uniformity of seed placement. After each test run, the soil surface was re-leveled, watered, and spacing between dropped seeds was measured by a measuring tape. A guide man and a well-trained donkey were used to operate the planter. Each test runs were replicated thrice over a 10 m distance. The soil type of the test field was sandy loam.

Multiple index, miss index, mean spacing, quality of feed index, and precision in spacing of seed were calculated using measured values. To determine the pattern of dropped seeds and their distribution uniformity in the rows, mean and standard deviation values of spacing were calculated. Equations (2), (3), (4), and (5) were used to calculate seed spacing uniformity (Kachman and Smith, 1995; Önal and Ertuğrul, 2011; Xiong *et al*., 2021; Nikolay *et al*., 2022).

$$MISI(\%) = \frac{n_{III}+n_{IV}+n_{v}}{N} \times 100 \tag{2}$$

Where; *MISI:* seed miss index,

n_{III}, n_{IV}, n_{V}: number of spacings of seed in three different divisions,

n_{III}: spacing having >1.5 Xref (theoretical spacing),

N: total number of spacings.

$$MULI\ (\%) = \frac{n_{I}}{N} \times 100 \tag{3}$$

Where; *MULI:* multiple index,

n_{I}: the number of spacings < 0.5 Xref,

N: total number of spacings.

$$QTFI\ (\%) = \frac{n_{II}}{N} \times 100 \tag{4}$$

Where; *QTFI:* the quality feed index

n_{II}: number of spacings having a value between 0.5 to 1.5Xref.

N: total number of spacings

$$PREC(\%) = \frac{S_{II}}{X_{ref}} \times 100 \tag{5}$$

Where; *PREC:* the seed precision index,

S_{II}: “n” observations standard deviation in zone II,

X_{ref}: theoretical spacing.

Field Capacity and Field Performance Determination

The field test was carried out on a fallowed rectangular plot having an area of 180 m^2 (Figure 2). A sandy loam soil having 14.20% moisture content (w.b.), and an ard plow implement was used for preparing the field. The planting depth of the planter was recorded along the row at three random points spaced 6m meters apart.

According to Kepner *et al.* (1978), field capacity and efficiency were calculated using parameters such as turning time, effective operation time, and time losses on the field. To assess field efficiency and capacity, a plot having a size of 10 m width and 18 m length was prepared. Forward speed, effective field capacity, and efficiency were calculated as shown in Equation (6), (7) and (8) (Kepner *et al.*, 1978);

$$V = \frac{D}{t_a} \tag{6}$$

Where; V: forward speed (m s^{-1}),

D: run distance (m),

t_a: the average time of each pass.

$$e = 100 \times \frac{T_e}{T_t} \tag{7}$$

Where; e: the percentage of field efficiency,

T_e: time of operation (effective),

T_t: the total time.

$$C_e = \frac{W_e \times S_{mf} \times e}{10} \tag{8}$$

Where; C_e: field capacity (effective) (ha h^{-1}),

W_e: width of the implement (effective) (m),

S_{mf}: average forward speed (km h^{-1}),

e: field efficiency (decimal).

Statistical Analysis

The experiment was conducted using a split-plot factorial design. Four levels of hopper filling and three levels of planter forward speed represented the main plot and the sub plot, respectively. The experimental design was laid as 4×3 having three replications. As a result, a total test run of 36 (i.e, 4×3×3=36) was used. Analysis of variance (ANOVA) of different performance data was performed using Statistix-8 software. A confidence interval of 95% was utilized to indicate a level of significance. The analysis was done based on the design of experiments (Gomez and Gomez, 1984; Ertuğrul and Önal, 2006; Fang *et al.*, 2018).

Figure 2. *Maize planter prototype and seedling planted by the planter.*

RESULTS AND DISCUSSION

Table 1 gives mean values of parameters that express physical properties of maize seed.

Table 1. *Physical properties of Melkassa-13 Maize seed.*

[1]	Physical properties	[2]	Number of samples	[3]	Mean	[4]	SD
[5]	Length of seed (mm)	[6]	100	[7]	10.30	[8]	1.29
[9]	Thickness of seed (mm)	[10]	100	[11]	4.50	[12]	0.63
[13]	Width of seed (mm)	[14]	100	[15]	8.55	[16]	0.47
[17]	Volume of seed (mm^3)	[18]	100	[19]	206.39	[20]	37.26
[21]	Sphericity of seed (%)	[22]	100	[23]	71.56	[24]	7.10
[25]	Seed geometric diameter (mm)	[26]	100	[27]	7.29	[28]	0.46
[29]	Thousand seed weight (gm)	[30]	1,000	[31]	271	[32]	4.11

SD = Standard deviation

From the results obtained in Table 1, it can be confirmed that the shape of the maize seed was nearly spherical (71.56±7.10%). Hence, a circular shaped metering cup that accommodates the spherical seeds was developed and utilized.

Performance Evaluation

Evaluation of seed damage

Fifty Melkassa-13 Maize seed samples that passed through seed metering plates were randomly selected and examined for damage. The number of bruised, crushed, or skin removed seeds was examined, and the mean value of seed damage percentage (1.01±0.37%) was less than the findings obtained by Oduma *et al.* (2014) and Gupta and Herwanto (1992) (2.34% and 3% respectively).

Germination tests conducted at the laboratory as given by Ertuğrul *et al.* (2024) showed that the mean germination percentage was 94.58±0.21%. The variety of seeds used for the test, Melkassa-13, had a mean germination rate of 95%. The quality of the metering roller, friction between seed metering devices and maize seeds, and variability of the seeds can all contribute to the difference. The difference was 0.42% and it showed that the mechanical damage was within the acceptable level.

Seed spacing analysis

Seed miss index

ANOVA showed that the planter's forward speed of operation and its interaction with the level of seed filling significantly affected the planter miss index ($p<0.05$).

Table 2 indicated the effect of planter forward speed, seed filling level of the hopper, and their combined effect on the percentage of mean miss-index. In addition, figure 4 indicated a relationship between the forward speeds and the mean miss indexes. Önal and Ertuğrul (2011) found that rotational speed of metering units can affect the seed distribution performance of the metering units since the rotational speed is sequentially change with the change of forward speed.

Table 2. *Analysis of variance for seed miss index (MISI%).*

Source	DF	SS	MS	F	P
REP	2	0.0015	0.0008		
HOPPER	3	2.1823	0.7274	481.10	0.0000
Error REP*HOPPER	6	0.0091	0.0015		
SPEED	2	31.0600	15.5300	11480.1	0.0000
HOPPER*SPEED	6	1.4905	0.2484	183.63	0.0000
Error REP*HOPPER*SPEED	16	0.0216	0.0014		
Total	35	34.7651			

Grand Mean = 4.9475, CV (REP*HOPPER) = 0.79, CV (REP*HOPPER*SPEED) = 0.74, DF = Degree of freedom, SS = Sum of squares, MS = Mean sum of squares, F = F-statistic, P = P-value

The forward speed of operation significantly affected the percentage miss-indexes of seed ($p<0.05$). As the forward speeds increased from 1 to 5 km h^{-1}, the percentage of seed miss indexes also increased.

Generally, the percent miss index proportionally increased with an increase of forward speed. At a forward speed of 5 km h^{-1}, a maximum miss index percentage value, 6.130, was recorded, whereas at a forward speed of 1 km h^{-1} a lowest percentage miss index value 3.861, was recorded. The result clearly showed that higher forward speed provides a higher seed miss index value.

Table 2 indicated that the loading level of the seed hopper had a significant effect on the percentage miss index. The seed hopper-loading level and forward speed had a combined significant effect on the percentage seed miss index. Nevertheless, the effect occurred mainly because of variations in forward speeds than the hopper level of the filling. The effect, however, was more attributable to forward speed variations than to hopper fill levels.

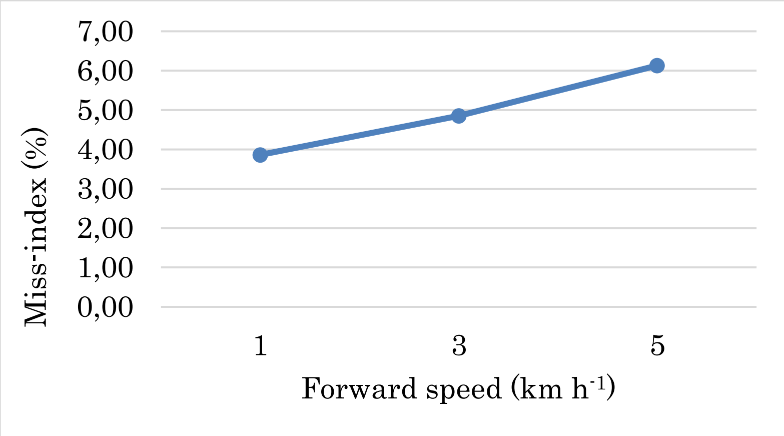

Figure 3. *Effect of forward speed on miss index of seed.*

Seed multiple index

ANOVA showed that (Table 3) the forward speeds of the prototype planter significantly affected percentage multiple indexes ($p<0.05$) whereas, the seed hopper loading levels and their interaction with the planter forward speeds didn't significantly affect seed multiple indexes ($p>0.05$). A similar trend was observed by Nielsen (1995) during performance evaluation of planting speed effects on stand establishment and grain yield of corn.

Table 3. *Analysis of variance for seed multiple index (MULI%).*

Source	DF	SS	MS	F-Value	P-Value
REP	2	0.0421	0.0211		
HOPPER	3	2.2620	0.7540	69.87	0.0000
Error REP*HOPPER	6	0.0647	0.0108		
SPEED	2	33.9400	16.9700	2793.42	0.0000
HOPPER*SPEED	6	0.2754	0.0459	7.55	0.0006
Error REP*HOPPER*SPEED	16	0.0972	0.0061		
Total	35	36.6815			

Grand Mean = 16.696, CV(REP*HOPPER) = 0.62, CV(REP*HOPPER*SPEED) = 0.4 DF = Degree of freedom, SS = Sum of squares, MS = Mean sum of squares, F = F-statistic, P = P-value

Table 3 indicated the effects of the planter's forward speed, seed filling level of the hopper, and their combined effect on the multiple index. The relationship between the forward speed and percentage of multiple index of the planter was also shown in Figure 5. As indicated from Table 3, the effect of the planter's forward speeds on multiple indexes of seed was significant, whereas the combinational effect of filling levels and planter's forward speeds on the percentage of multiple indexes was not significant.

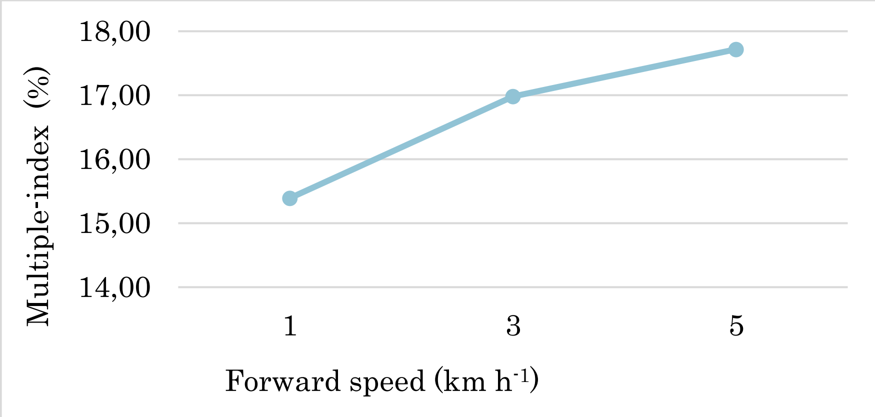

Figure 4. *Effects of planter forward speed on seeds multiple index.*

At 5 km h-1 forward speed of the planter, the highest percentage of seed multiple index was achieved. On the other hand, 1 km h-1 forward speed of the planter provided the lowest values. As shown from Table 3, the filling levels did not significantly affect the multiple indexes of the seed.

Quality of seed feed index

ANOVA results showed that the planter's forward speeds significantly affected feed-indexes quality ($p<0.05$). On the other hand, both seed hopper filling levels and interactions between forward speeds and filling levels did not significantly affect the quality of feed index.

The effects of the planter's forward speeds and filling levels on feed-indexes are shown in Table 4. In addition, Figure 3 depicted the relationship between the linear forward speed of the planter and the percentage of feed index quality. At a forward speed of 5 km h-1, forward speed significantly affected the percentage of quality of the seed feed index. However, the seed hopper filling levels did not significantly affect feed-indexes quality. This result indicated that the percentage of feed index quality is detrimentally affected by the forward speed of the prototype planter, which in turn is directly related to the forward speed of a metering plate of the planter (Culpin, 1987; Nielsen, 1995).

Table 4. *Analysis of variance for quality of seed feed index (QTFI%).*

Source	DF	SS	MS	F	P
REP	2	0.043	0.0214		
HOPPER	3	1.326	0.4419	25.92	0.0008
Error REP*HOPPER	6	0.102	0.0170		
SPEED	2	127.403	63.7016	6891.84	0.0000
HOPPER*SPEED	6	1.781	0.2968	32.11	0.0000
Error REP*HOPPER*SPEED	16	0.148	0.0092		
Total	35	130.803			

Grand Mean = 78.357, CV (REP*HOPPER) = 0.17, CV(REP*HOPPER*SPEED) = 0.12 DF = Degree of freedom, SS = Sum of squares, MS = Mean sum of squares, F = F-statistic, P = P-value

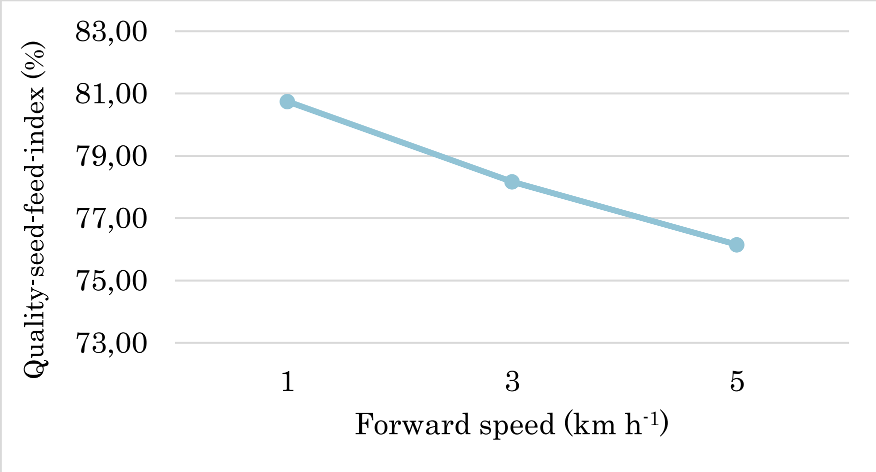

Figure 5. *Effects of forward speed of planter on quality of seed feed index.*

Seed precision index

ANOVA showed the forward speeds of the planter significantly affected the precision-indexes of seed. However, filling levels and their interaction with forward speeds had no significant effect on seed precision.

The effects of forward speeds and filling levels are shown in Table 5. Figure 7 shows the relationship between the linear forward speed of the planter and the precision index of seed. The analysis results showed planter's forward speeds significantly ($p<0.05$) affected precision-indexes. However, filling levels did not significantly affect precision-indexes. At 5 km h^{-1} forward speed, the combination of filling levels and forward speeds significantly affected the precision-indexes.

Table 5. *Analysis of variance for seed precision index (PREC%).*

Source	DF	SS	MS	F	P
REP	2	0.5162	0.2581		
HOPPER	3	0.5968	0.1989	3.24	0.1028
Error REP*HOPPER	6	0.3687	0.0614		
SPEED	2	27.3037	13.6518	123.43	0.0000
HOPPER*SPEED	6	0.2824	0.0471	0.43	0.8512
Error REP*HOPPER*SPEED	16	1.7697	0.1106		
Total	35	30.8375			

Grand Mean = 15.837, CV(REP*HOPPER) = 1.57, CV(REP*HOPPER*SPEED) = 2.10 DF = Degree of freedom, SS = Sum of squares, MS = Mean sum of squares, F = F-statistic, P = P-value

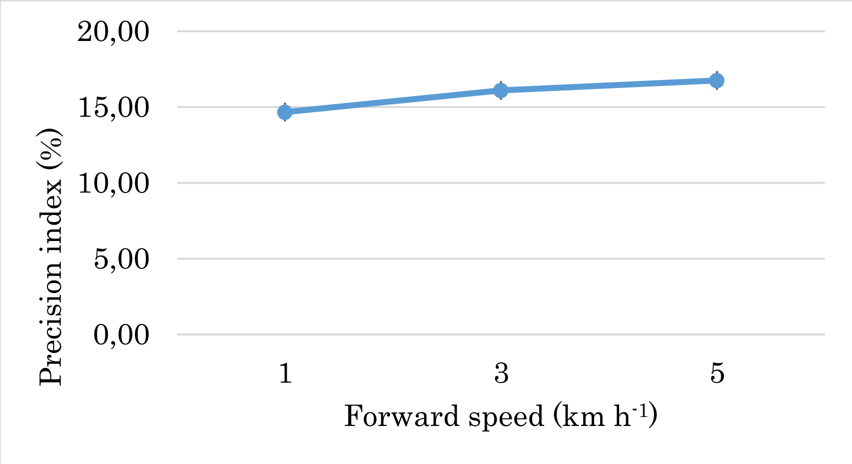

Figure 6. *Effects of forward speed on precision index.*

At the forward speeds of 1 km h^{-1}, 3 km h^{-1}, and 5 km h^{-1}, the seed precision index percentage values were 14.667, 16.091 and 16.754, respectively. This result obviously showed that spacing variations of over 16% would occur at planter forward speeds of higher than 3 km h^{-1}. In comparison to higher values, lower values of the precision index indicated better performance (Kachman and Smith, 1995).

Field capacity and efficiency

The machine registered an average field capacity of 0.21 ha h^{-1}, whereas its field efficiency was 86%. Kepner *et al.* (1978) recommended a field efficiency range of 65-75% for planters, indicating that the planter operates within an acceptable efficiency level.

Depth of Planting

In the field evaluation, a mean depth of seed placement, 4.60±0.30 cm, was achieved. This value is a bit lower than the recommended maize planting depth (5-7 cm). However, the small deviation is in the acceptable range and can easily be adjusted by the furrow opener.

Stand Count

The metering plates were adjusted to drop two seeds per hill to avoid seed misses. For maize, 16 plants were required in a row of 2 meters long, assuming two seeds per hill. After 15 days of planting, a stand count was made. In rows of 2 m length, the average number of maize seedlings was 17.21±1.88. The result indicated that there were few more seedlings than desired; as a result, they should be thinned.

Economic Evaluation

Planting maize with the prototype planter required two people; one person guided the donkey and the other operated the machine. On the other hand, manual planting of maize requires at least three persons for plowing, seed planting and spreading of fertilizer. The time required for planting seeds and spreading fertilizers using the manual method was 26 h ha^{-1} (Melesse, 2007). To accomplish the same work using the machine, a single person required only about 4.77 h ha^{-1}. Hence, using the planter, one can reduce the time and labour required for planting by more than eight folds. It was estimated that the planter will cost 8053.07 Ethiopian Birr (price in USD may be added). Therefore, maize producing small-scale farmers could jointly purchase or rent out and use the planting machine.

CONCLUSION

The evaluated two-row donkey drawn maize planter is a low-cost planter that was developed locally using easily available materials. The technology could be owned and used by small and medium scale maize producing farmers. The machine relieves maize farmers from the planting operation backache. In addition, the machine is user friendly, and requires no special technical skill for operating it. Evaluation of the planter in terms of field capacity, field efficiency, depth of planting, optimum plant population, labour cost, and economics showed acceptable results. The forward speeds of the planter significantly affected the field capacity, field efficiency, seed uniformity, planting depth and related performances of the planter. For an optimum and more precise planting, the planter should be adjusted to a 50% hopper filling level and 1 km h^{-1} speed. Most importantly, the planter can be used by most Ethiopian smallholder farmers to plant maize seeds efficiently, effectively, and economically.

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DECLARATION OF COMPETING INTEREST

I declare that I have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Meseret Abebe: Investigation, methodology, conceptualization, formal analysis, data curation, validation, writing-original draft, review, and editing visualization.

ETHICS COMMITTEE DECISION

This article does not require any Ethical Committee Decision.

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