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Development and Performance Evaluation of a Tractor-Drawn Multi-Crop Planter

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ABSTRACT

The study was undertaken development and performance of the planter capable of planting maize, common bean and sorghum seeds at predetermined spacing and depths. Physical properties of seeds involved in the study were investigated to optimize the design of the planter's components. The planter, consists of a frame, seed hopper, seed metering devices, seed tube, adjustable furrow opener, adjustable furrow covering device, and drive wheels. The investigation revealed that the sphericity of maize, common bean and sorghum were 64.8, 72.4 and 81%, respectively. Percentages of mechanically seed damaged by the planter were zero for all crops. Germination test was conducted to assess the magnitude and extent of invisible seed damage inflicted by the planter indicated mean percentage seed germination of 98.5, 94.5 and 97.3% for maize, common bean, and sorghum, respectively. The reduction in percentage germination of maize, common bean and sorghum were zero, when compared with that did not passes through the machine for all the seeds tested. Based on the above results, it is concluded that the planter can be efficiently and effectively used by the majority of the farmers and other stakeholders in the study area.

INTRODUCTION

Planting is an art of placing seeds in the soil to have good germination. It was began with the use of hands and later the use of stones, hand tools and mechanized form of planting (Yasir *et al.*, 2012). Manual methods of planting resulted in low seed placement, low spacing efficiency, and health issues for the farmer considering the size of the farm land (Kumar *et al.*, 2015; Soyoye *et al.*, 2016). Seed planting machine is a device which helps in sowing seeds in a desired position, there by assisting the farmers in saving time and reducing cost.

The basic objective of sowing operation is to put the seed in rows at desired depth and seed to seed spacing, cover the seeds with soil and provide proper compaction over the seed (Soyoye *et al.*, 2016). However, in fabricating the form of this mechanized planting equipment, some properties of the plant which is to be planted must be determined in order to accurately specify the design considerations (Jouki and Khazaei, 2012). The physical properties such as seed size, shape, axial dimensions, roundness and sphericity helps to determine the maximum size of the cup in the seed plate, the weight help in the material selection for the frame of the planter, the bulk density and moisture content helps to know the interaction between the seed and the material used for the hopper of the planter at maximum heat level (Jayan and Kumar, 2004).

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MATERIALS AND METHODS

Experimental Site and Experimental Crops

Fabrication of the prototype planter was done at Fadis Agricultural Research Center (FARC) metal workshop (Harar) maize, common bean and sorghum seeds were used to design the planter that was fabricated at FARC metal workshop. The crops, maize, common bean and sorghum, were selected for the study because of their dominance among row planted crops in the study areas. Hence, the planting machine was designed to plant these seeds. The varieties of maize, common bean and sorghum seeds were Melkassa-2, Awash-2 and Melkem, respectively. Selected seeds were taken from Fedis Agricultural Research Centre, crop research process and the seeds had germination percentages of 98.5%, 94.5%,

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and 97.33%, for maize, common bean and sorghum, respectively.

The Planting Machine

The machine was designed for four wheels 30 hp tractor and has three different replaceable seed metering cups that were designed to handle maize, common bean and sorghum seeds. Since the planter was designed for three different crops and was adjustable as particular crop's row spacing requirements.

Physical Properties of Selected Crops

The physical properties of seeds are important factors for the design of crop planter. Performance of seed metering mechanism in terms of picking, metering and dropping was influenced by the physical and Mechanical properties of seeds. Therefore, seed properties relevant to the design of planter were identified and determined. The general procedure was used in determining seed physical parameters i.e. Geometric mean diameter (Ds), Sphericity (S) and Volume were computed by taking a specified number of randomly selected seed. Then their three principal diameters (major, intermediate and minor lengths) denoted as mean length (L), mean width (W) and mean thickness (T) respectively were measured using a micrometer of 0.01 mm accuracy. The measured values were then used to determine Geometric mean diameter (Ds) using equation (1) by (Singh *et al.*, 2005) as well as Mean volume (V) and mean seed sphericity (Sm). Thirty (30) grain samples were selected randomly from the sample and dimensions were measured. Length, width and thickness of the seed were taken using digital vernier caliper. The mean and standard deviation of dimensions were calculated.

Size, Sphericity and Surface Area

The volume and sphericity of the individual seeds were calculated using the measured larger diameter, medium diameter and smaller diameter of the seeds and equations given below (El-Raie *et al.*, 1996).

Physical property, that is, geometrical mean

$$Dg = \sqrt[3]{(L \times W \times T)} \quad (1)$$

$$V = \pi/6 \ (L \times W \times T) \quad (2)$$

$$Sm = (\sqrt[3]{(L \times W \times T)}/L) \times 100 \quad (3)$$

Where:

L=Length (mm)

W = width (mm)

T = Thickness (mm)

V = volume (mm^3)

Dg = geometric diameter (mm)

Sm = seed sphericity

Bulk Density of the Crops

The bulk density was found by taking crops in a container of cylindrical shape. The volume of the container was found by measuring diameter and height for cylindrical container. The weight of the grain in the container was found separately. The bulk density was calculated, three samples from each selected crops were taken and average bulk density was calculated (Varnmakasti *et al.*, 2007) as shown equation (4)

$$B_d = (W_C)/V_C \quad (4)$$

Where:

Bd = Bulk density in kg/m^3 or g/cm^3

Wc = Weight of sample in kg or g

Vc = Volume of sample in m^3 or cm^3

Angle of Repose of the Crops

The equipment used for measuring angle of repose consisted of a funnel with an adjustable throat opening mounted on a stand. The funnel was filled with seeds by keeping its adjustable throat closed. The throat was fully opened to allow free flow of seeds over and around the plate mounted beneath the funnel. At the end of process, a heap-cone of the seed was formed on the plate. From the heap-cone, base diameter and height of cone were measured. For free-flowing agricultural grains, angle repose is assumed to be approximately 28. For free-flowing grains the angle of repose can be assumed to be equal to that of the angle of internal friction. The angle of repose was calculated using the equation (6), (Varnmakasti *et al.*, 2007)

$$\theta = \tan^{-1}(2H/D) \quad (5)$$

Where:

θ = is angle of repose, degree

H =is height of cone, mm

D =is base diameter of cone, mm

Thousand Grain Mass

In the laboratory thousand (1000) grains were selected randomly and then weighed on the sensitive weight balance to obtain the thousand grain mass in gram. The ten sample of each crop was weighed and mean thousand grain mass of each crop was found out.

Moisture content of soil

The samples were collected from 0 to 15 cm depth of soil surface before operations for determination of moisture content and bulk density. The soil moisture was determined by oven dry method. Five samples were collected randomly from the test plots. The samples were kept in oven for 24 hours at temperature of 105°C and weighed before and after drying. The moisture content (Dry basis) was determined by the following formula (Rangapara, 2014).

$$Mc\ (\%) = (W_s - W_d)/W_d * 100 \quad (6)$$

Where:

Mc=Moisture content of the Soil sample

Ws= Weight of the soil sample, and

Wd= Weight of dry soil sample

Bulk Density of Soil

To determine bulk density of a soil, metallic core sampler was used to take sample from field having 8cm diameter and 12 cm height. The samples were weighed and dry weights of the samples were calculated with the help of moisture content (d.b.). The ratio of dry weight of soil to the volume gave the bulk density. Bulk density of soil was calculated by using following formula (Rangapara J, 2014).

$$Bds = (W_S\,(g))/(V_S) \quad (7)$$

Where :

Bds= Bulk dencity of soil in (g/cm^3)

Ws = weight of soil samples (g)

Vs= volume of soil in core sampler (cm^3)

Description of the Machine and Design Considerations

Overall Structure of the Machine

The developed Tractor drawn multi-crop planter consists of the frame, seed hoppers, drive/ transport wheels, seed metering devices seed discharge tubes, furrow openers, and furrow covering devices. Tractor drawn multi crop planter was designed as a functional and experimental unit. The design of machine components were based on the principles of operations. It was compared with the conventional method, to give a correct shape of the planter components. The mechanical design details were also given with due attention so that it gaves adequate functional strength for the design of the machine. To achieve the best performance from the planter, the important factors were optimized by proper design and selection of the components required to suit the requirements of the crop needs and Figure 1 and Figure 2 shows assembly parts and detail views of the planter respectively. 1) Ground wheel (2) Hopper (3) Frame (4) Furrow covering (5) Tractor hitching position (6) Ground wheel shaft.

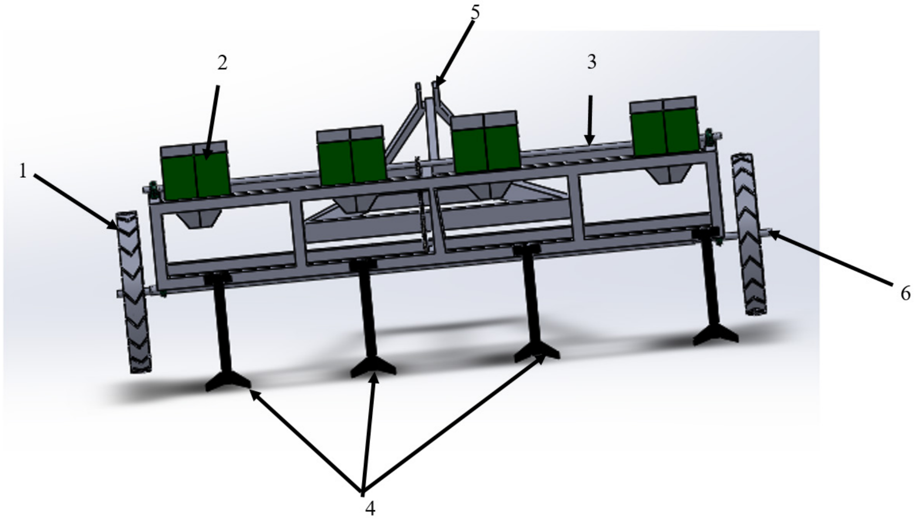

Figure 1: Assembly drawing of the prototype planter.

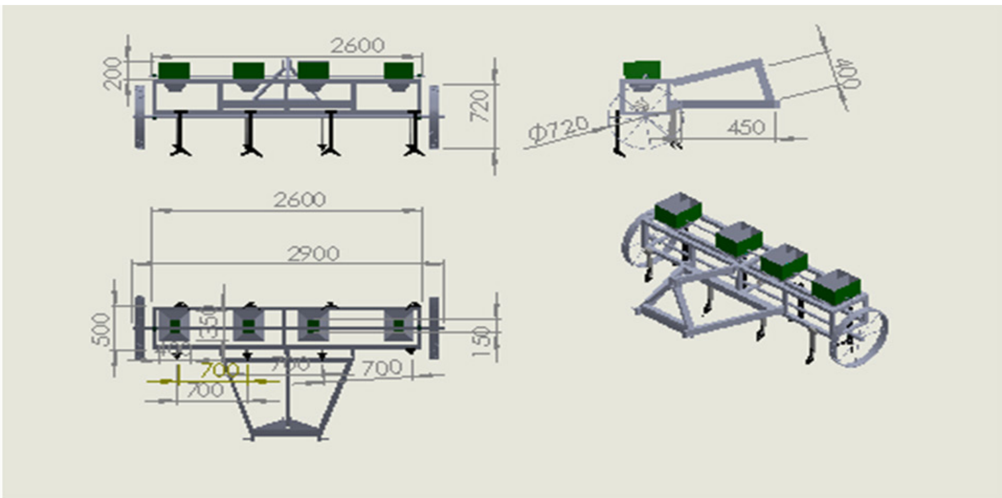

Figure 2: Detail views (Top, front and side) of the prototype planter

Working Principles of the Machine

The seed metering mechanism of the planter is a cup type vertical drive. As the tractor moved forward the seed-metering device is rotated by a chain-sprocket arrangement through drive wheels. One operator was required to operate the machine. Seed to seed spacing in the field is regulated by the rate of rotation of the seed-metering plates. As the metering plate rotated i.e. the seed spacing of crops were maintained by the planter drive wheel diameter and the size of sprockets attached to the planter drive wheel and shaft of the seed-metering plate and the teeth ratio was 2:1 drive to driven sprocket.

Design Considerations for the Machine

The following factors were considered in the design of the planter, such as the physical properties of the agricultural material like length, width, thickness etc. which varies in shape, density and size. The ease of fabrication of component parts, the safety of the operator, Resistivity of metering device to corrosion and, the operation of the machine shall be simple for small scale or rural farmers. Availability of the component parts shall also be available at the local market.

Performance Test and Evaluation

After development and assembly of the prototype a preliminary test run was conducted to check that the machine is functionally acceptable or not . Fortunately, the planter had good stability in terms of operation and performed for the intended job accordingly. Two sets of tests were performed; laboratory investigation to calibrate the machine in terms of seed rate, seed damage, and seed spacing, and field test carried out to obtain actual overall performance of the machine.

Laboratory Tests

Calibration of the Machine

The multi-crop planter was calibrated in the laboratory to determine the seeding rate, and mechanical damage of crops for a particular area. The calibration of the planter was conducted to test and adjust the planter to obtain desired plant population. The diameter of the ground wheel was 72 cm. The nominal width of the planter was calculated by:

$$W = n \times RS \qquad (8)$$

$W = 4 \times 0.7m = 2.8$ m

Where :

W= width of the implement

n= number of furrow opener

RS= row spacing

Evaluation of Seed Damage

Each of the hoppers was loaded with 4 kg of seeds and drive wheels were rotated 20 times with speed of corresponding to 1.6 m/s. A stop watch was used to measure the time taken to complete the revolutions. Paper bags were placed on each of the seed tubes/ spouts to collect the seeds metered and discharged. The seeds collected in the paper bags at the end of the 20th revolution of the wheel were examined for any external damage or visible crack to establish the performance of the metering cups. Germination test, on randomly selected seed samples, were conducted at Fedis Agricultural Research Center laboratory to assess the level of internal damage by the metering mechanism. Percentage external seed damage was determined by equation given below.

$$M_d = (S_{tds}/S_{ns}) \times 100 \qquad (9)$$

Where:

M_d = percentage damaged seed

S_{tds} = total number of damaged seeds (external)

S_{ns} = total number of seeds

Field Performance Evaluation

Evaluation of Seed Spacing/Distribution

The prototype planter was evaluated in the field using seeds of maize, common bean and sorghum at forward speeds of 2, 4 and 6 km/h. At the end of each test run, measurement of successive seed spacing was made, seeds spacing were measured from the soil surface and preparation for the subsequent tests. Each test run was replicated three times over a distance of 2 m. Measurements made were used to calculate the mean seed spacing, seed miss index, seed multiple index, quality of feed index and precision in spacing. Mean values and standard deviation of seed spacing were determined to pattern and uniformity of seed distribution in the rows (Kachman and Smith, 1995).

Theoretical spacing, xref, in the design of wheels and metering devices was used as actual seed spacing and the measured and its mean values of spacing were compared against the theoretical values.The observed spacing were classified into five divisions:-

Division I = 0 to 0.5 of xref, this indicated multiple seeds dropped at the same spot or seed spacing less than or equal to half of the desired spacing.

Division II = 0.5 to 1.5 of xref, this indicate single seed spacing close to the theoretical seed spacing.

Division III =1.5 to 2.5 xref, these are single skips.

Division IV = 2.5 to 3.5 xref, these are double skips.

Division V = over 3.5 xref, these are triple skips etc.

Seed spacing accuracy estimation was based on the following parameters and equations (Kachman and Smith, 1995):

Missing Index (MISI)

The missing index was estimated using distance measured between seeds dropped in the row and spaced at a distances greater than 1.5 times the theoretical (nominal) spacing and calculated using the equation below:

$$MISI\ (\%) = (n_{III} + n_{(Iv)} + n_v/N) \times 100 \qquad (10)$$

Where:

MISI = missing index

n_{III}, n_{IV}, n_V = the number of spacing in division III, IV, and V

N = total number of spacing

Multiples Index (MULI)

The multiple index was estimated by measuring the distance between consecutive seeds, the spacing less than or equal to half of the theoretical (nominal) spacing and calculated as follows:

$$MULI\ (\%) = (n_I/N) \times 100 \qquad (11)$$

Where:

MULI = multiple index

n_I = the number of spacing in region I and

N = total number of spacing

Quality of Feed Index (QFI)

Quality of feed index, as an indicator of uniformity of seed distribution in the row, was estimated using the data obtained by measuring the consecutive distance between seeds in the row with spacing more than half but no more than 1.5 times the theoretical spacing and calculated using the equation given below:

QTF I (%) = $(n_{II}/N)\times100$ (12)
Where:
QTFI = quality of feed index
n_{II} = the number of spacing in division II and
N = total number of spacing

Precision Index (PREC)
Precision index is the coefficient of variation of the spacing between the nearest seeds in a row that were classified as singles after omitting the outliers consisting of misses and multiples (Singh *et al.*, 2005). Precision is similar to a coefficient of variation for the spacing that are classified as singles (i.e. seeds in division II). The percentage precision in spacing was calculated as follows:
PREC (%) = $(S_{II}/Xref)\times100$ (13)
Where:
PREC = precision
SII = the standard deviation of the n observations in zone II
Xref = the theoretical spacing.

Field Performance and Capacity
Field test was conducted on a soil prepared using disc plough and harrowed by disc harrow. The depth of planting was measured along the row at a distance of 2m at three randomly selected locations/points. The Planter was operated without covering mechanism. Field capacity and efficiency were determined in accordance to the recommendation made by Kepner (1978) and using relevant parameters that included effective operating time, turning time and time losses due to obstructions on the field. A plot of 20 m by 30 m was used for each crop, on average, about nine passes with inter-row spacing of 0.7 m was used to assess field capacity and field efficiency for both maize and sorghum. From the data gathered, working speed (km/h), effective field capacity (ha/h) and field efficiency (%) were estimated using equations 104, 105 and 106.

Field Capacity and Field Efficiency
When the implement has been satisfactorily set, each test plot should be completed without stopping unless this is necessary due to adjustments, breakdowns. Measurements are made of draft, forward speed and wheels lip. Where applicable, width and depth of work and total working area and time should be recorded.
The time lost in the field due to turning and other factors including failure to use the full width of the implement will affect field efficiency (FAO, 1994). This is calculated as follows:

Field Capacity
Field capacity was determined using the following formula (Hunt, 1995)
Theoretical field capacity, $C_{th} = (W\times S/10)$, (ha/h) (14)
Where:
W = rated width of the planter (m)
S = rated forward speed of machine (km/h)
Effective field capacity, $C_{eff} = A/10{,}000T$, (ha/h) (15)
Where:
T = total time for the planting operation, hr
A = total area planted, ha

Field Efficiency
Field efficiency,(%) e $=(C_{eff}/C_{th})\times100$ (16)
Where :
e= field efficiency
C_{th}= theoretical field capacity
C_{eff} = effective field capacity

Wheel Slip
The wheel slip was calculated by recording total number of revolutions at no load and total number of revolutions at full load. Wheel slip represents a loss of forward motion of the implement and it represents the loss of power. Wheel slip for any given load is determined by the expression of (Rangapara J., 2014).
Wheel slip=$(m_o-m_1/m_o)\times100$ (17)
Where:
m_o = wheel revolution with no load
m_1 = wheel revolution with load

Experimental Design
The experimental design was a split-plot design according to the principle of factorial experiment with three replications. The three levels of seed types was assigned to main plot, and the three levels of forward speed of planter was assigned to sub plot, and each with three replications. The experiment design was laid as 3^2 with three replications and had total of 27 test runs (3x3 x3 = 27).

Statistical Analysis
The data were subjected to analysis of variances following a procedure appropriate for the design of the experiment and using SAS statistical software. The treatment means that were different at 5% levels of significance were separated using least significant difference (LSD 5%) test. The least significant difference (LSD) test was performed for the mean values of actual seed spacing, seed miss index, seed multiple index, quality of feed index and precision spacing in relation to seed type, and forward speed.

RESULTS AND DISCUSSIONS
This study was undertaken to develop and the performance evaluation of the planter capable of planting maize, common bean and sorghum seeds at predetermined spacing and depths. Physical properties of seeds involved in the study were investigated to optimize the design of the planter's component parts. Performance indicators such as spacing indices that include seed multiple index (MULI), seed miss index (MISI), quality of feed index (QTFI) and precision (PREC) in seed spacing were used to assesses performance of the planter. This section provides the physical properties of the seeds, soil and the results of the performance evaluation of the machine.

Physical Properties of Soil of Experimental Site
Moisture Content and Bulk Density of Soil
During conducting the experiments, the soil conditions of the experimental field were studied and different

Table 1: Moisture content and bulk density of soil

Observations	Weight of a soil(gm)	Weight of soil after oven dried(gm)	MC (%)		Bulk Density (gm/cm³)
			%Wb	%Db	
1	875.25	712.05	17.43	21.1	1.41
2	892.26	730	18.18	22.2	1.48
3	886.2	728.5	17.8	21.65	1.47
4	890.32	729.5	18.0	22.04	1.48
5	892.2	731	18.0	22.05	1.48
Average	**887.24**	**724.21**	**17.88**	**21.1**	**1.46**
SD	**9.08**	**8.26**	**0.23**	**0.81**	**0.31**

parameters were calculated (Table 1). Moisture content on dry basis of soil was measured by oven dry method. Five soil samples were taken randomly at 5 different locations in the plot using core sampler of 8.0 cm diameter and 12 cm height.

Moisture content at 5 different places was found to be 17.43, 18.18, 17.8, 18 and 18% on wet basis. The average moisture content of the experimental field was 17.88%. Bulk density of soil was calculated from data obtained by core sampler. Bulk density of soil was found to be 1.41, 1.48,1.47, 1.48 and 1.48 gm/cm^3, respectively (Table:3). Average value of bulk density of experimental plot was obtained 1.46gm/cm^3

Physical Properties of the Seeds

The varieties of crops used in the study were Melkassa-2 (maize), Awash 2 (common bean) and Melkem (sorghum). Table 2 gives the mean values and the standard deviations of Length, width, thickness, volume, geometric diameter, sphericity, and thousands seed weight.

Table 2: Physical properties of maize, common bean and sorghum seeds

Physical properties	Sample size	Maize	Common bean	Sorghum	Unit
Larger dia (x)	30	10.84±0.15	9.26±0.07	4.72±0.1	mm
Medium dia (y)	30	8.48±0.15	6.36±0.12	4. 27±0.18	mm
Smaller dia (z)	30	3.66±0.11	5.11±0.66	2.78±0.10	mm
Volume (V)	30	175.95±54.50	157.58±21.04	29.34±4.70	mm³
Geometric dia	30	6.95±0.46	6.70±0.29	3.83±0.16	mm
Sphericity	30	64.8± 7.14	72.4±2.87	81±2.8	%
Thousands seed weight	10	294±3.14	161±1.44	29±0.70	gm

The sphericity of maize, common bean and sorghum were 64.8, 72.4 and 81 %, respectively (Table 2), indicating that all seeds had more or less spherical shape. Hence, it was decided to have metering devices with cells of circular shape with depths equal to the length or major diameters of the seeds of the crops. In general, the dimensions of metering device cells were dependent up on length or major diameter of maize, common bean and sorghum seeds.

Field Performance Evaluation

Seed Spacing

The Seed Missing Index

The analysis of variance (ANOVA) revealed that the planter forward speed and the interaction of planter forward speed with seed type had significant effect ($p < 0.05$) on seed missing index. Table 3 show the effect of speed of operation, seed type and the combined effect of speed on mean percent of seed miss index.

Operational speed had significant effect on percent of missing index at $p < 0.05$. However, the level of effect varied with crop type. Increasing speed of operation from 2 km/hr. to 4km/hr. had no a significant effect on the percent missing index on both maize and sorghum

Table 3: Effects of planter operating speed on missing index (MISI)

Parameter	Source of variation				Measure of differences	
	Speed level (km/hr)	Crop type			LSD (5%)	SE
		Maize	Common bean	Sorghum		
Missing (%)	2	5.87^{a}	2.70^{a}	5.59^{ab}	3.06	0.99
	4	6.33^{bc}	6.00^{b}	5.10^{ab}		
	6	10.77^{d}	9.00^{cd}	7.00^{bc}		

Means followed by the same letter (or letters) do not have significant difference at 5% level of probability crops, while the effect of increasing operational speed from 2 km/hr to 6 km/hr for common beans and maize had significant effect while for sorghum did not show statistically significant effect on percent missing index (Table 3). In general, increase in operational speed tended to increases percent missing index when planting both maize and common bean, while did not show significant effect on sorghum seed using the planter. The highest percent seed missing index of 10.77, 9.00, and 7.00% were recorded with maize, common bean and sorghum seeds, respectively, at the planter forward speed of 6 km/hr, whereas the lowest percent seed missing index of 5.87, 2.70 and 5.10% were obtained from maize, common bean and sorghum seeds, respectively, at the operational speed of 2 km/hr for maize and common bean ,while at 4km/hr for sorghum crop. This clearly indicated that forward speeds greater than 5 km/hr would result in percent missing index of approximately equal to ten and above for maize which exceeds the acceptable level of percent missing index (Chhinnan/ *et al*., (1975) and Karayel and Ozmerzi, 2001).

The Seed Multiple Index

The highest percent seed multiple index occurred at operational speed of 6 km/hr for maize, common bean and sorghum. The lowest values, of the same, were recorded at operational speed of 2 km/h. The planter operating speed and the percentage seed multiple index are directly related as that of the percent seed missing index (from the following results or Table 4).

Table 4: Effects of operational speed on multiple index (MULI, %)

Parameter	Source of variation				Measure of differences	
	Speed level (km/hr)	Crop type			LSD (5%)	SE
		Maize	Common bean	Sorghum		
Missing (%)	2	9.6[a]	8.3[a]	13.0[ab]	10.02	5.44
	4	11.7[ab]	12.67[ab]	13.93[ab]		
	6	15.37[ab]	21.1[b]	18.2[ab]		

The Quality of Seed Feed Index

Appendix Table A3 shows the results of statistical analysis on the effects of operational speed of the planter, and seed type on the quality of seed feed index. The analysis of variance (ANOVA) revealed that , seed type had significant effect ($p < 0.05$) on quality of feed index whereas planter forward speed and the interaction of planter forward speed and seed type had no significant effect ($p > 0.05$) on quality of feed index. Table 5 shows the effects of operational speed of the planter and seed type on percent of quality of seed feed index. Figure 17 shows the relation between planter linear speed and seed type and percent of quality of seed feed index. The forward speed of the planting machine had significant effect on the percent quality of seed feed index at the planter speed of 6 km/hr regardless of the type of seeds used.

The percent quality of seed feed index decreased with increasing planter forward speed for all types of seeds used in the study. However, the lowest reduction in percent quality of seed feed index was observed for Sorghum seeds. The highest percent quality of seed feed index of 75.33, 71.67, and 68.87% were observed for maize, common bean and sorghum, respectively, when the planter was operated at forward speed of 2 km/hr. The lowest percent quality of seed feed index of 62.33, 63.00 and 59.94 were observed with maize, common bean and sorghum, respectively; when the planter was operated at speed of 6 km/hr. From results in Table 5, it could be concluded that the planter at speeds greater than or equal to 6 km/hr would reduce the plant population/ ha, hence could lead to reduction in yield at the end of the day (Karayel, 2009).

Table 5: Effects of operating speed, on quality of feed index (QTFI, %)

Parameter	Source of variation				Measure of differences	
	Speed level (km/hr)	Crop type			LSD (5%)	SE
		Maize	Common bean	Sorghum		
QTFI (%)	2	75.33[a]	71.67[a]	68.87[a]	6.17	3.27
	4	72.87[a]	69.33[a]	66.87[a]		
	6	62.33[b]	63.00[b]	59.94[b]		

Precision Index

Table 6 show the effects of operational speed of the planter and seed type on mean percent seed precision index. The results indicated that seed type had significant effect on the percent seed precision index; means that variation, in seed spacing within a row, increased as planter linear forward speed increased for maize, i.e. as the speed of operation is increased, one should expect high variability in seed spacing, which is not a desired trait. But for both common bean and sorghum does not show direct relation. The combined effect of seed type and forward speed of the planter, on the percent seed precision index, was significantly difference at the planter forward speed of 6 km/hr.

The percent seed precision index, at the planter linear operating speeds of 2, 4 and 6 km/hr. were 1.77, 3.04

Table 6: Effects of operating speed, on seed precision index (%)

Parameter	Source of variation				Measure of differences	
	Speed level (km/hr)	Crop type			LSD (5%)	SE
		Maize	Common bean	Sorghum		
PRCE (%)	2	1.77[a]	7.54[e]	5.51[cde]	2.09	1.44

and 3.60; 7.54, 4.97 and 5.74; and 5.51, 4.25 and 5.45% for maize, common bean and sorghum, respectively. This particular result clearly indicated that planter forward speed greater than 6 km/hr would result in seed spacing variations of over 3.60%, for maize and the variations for sorghum and common bean were greater than 5 % at planter speed of 6 km/hr. However, a practical upper limit for precision is 29%. Lower values for the precision indicate better performance compared to higher values (Kachman and Smith, 1995)and Table 7 below shows planter performance indicators.

The mean field capacity and efficiency of the planter were 0.59 ha/hr. (1.73 hr. /ha) and 75.87 %, respectively. This shows that the planter can plant a hectare of land in slightly in less than two working hours. In another words, the planter can best suit majority of the Ethiopian farmers who have opportunity to use the tractor. The field efficiency of the planter, as recommended by Kepner *et al.* (1978) is within the acceptable level. The mean depth of planting was 5.95 cm with coefficient of variation of 0.128 (12.8%).The time taken to finish one hectare of land was 1:55 hr. that means by taking 8 hr. working hour per day, the farmer can plant about 5.16 hectare of land in one day by using this planter. Table 7 result the proposed plant spacing was 20 cm-25cm and the maximum result obtained from the experiments was 22.91 cm from Maize so it is good in terms of plant spacing which was with the proposed range. This depth of planting was greater than the desired depth of planting of 5 cm as recommended for Maize by agronomists. Nonetheless, the deviation and the variability being too small and with acceptable range, also, it can be adjusted to the desired depth of planting. The stand count made after 15 days of planting gave mean number of plants of 7.87,12 and 16 plants within rows of 2 m length for maize, common beans, and sorghum, respectively. The design or desired number of plants, within a row of 2 m long, for maize, common bean and sorghum were 8, 13 and 10, respectively. Hence the planter reasonably satisfied the requirement for the establishment of optimum plant population for all seed types.

Table 7: Field performance indicators of the planter

Crop types	Field length(m)	Width Field (m)	Time taken (min)	Time lost (min)	Theoretical field capacity (ha hr^{-1})	Effective Field capacity (ha hr^{-1})	Field efficiency (%)
Maize	30	20	4.09	1.5	0.84	0.65	77.3
Common bean	30	20	5.52	2.15	0.64	0.46	71.8
Sorghum	30	20	4.23	1.23	0.84	0.66	78.5
Mean	**30**	**20**	**4.61**	**1.63**	**0.77**	**0.59**	**75.87**

CONCLUSION

This work focused on the development and performance evaluation of a tractor drawn multi-crop planting machine that easy to use, easy to maintain, requires less labour and costs. From the developed and results values obtained in the study; it has been found that the developed planter gives:

- The planter works effectively in planting maize, common bean and sorghum at a given study area.
- A significant field capacity was obtained by using the developed machine when compared to manual planting methods.
- This shows that the planter can plant a hectare of land in slightly in less than two working hours.
- Therefore, the planter can best suit majority of the Ethiopian farmers who have opportunity to use the tractor.
- Hence, one can note that the time requirement per hectare is reduced by 1/16 amount and labour requirement reduced by the same amount by using this planter, when compared to manual planting.
- However, the speed of the planter should be limited to less than 6 km/hr in order not to seriously and negatively affect the percentage of recommended plant population of experimental crops.

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