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RESEARCH ARTICLE

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PERFORMANCE EVALUATION OF TWO ROW ANIMAL DRAWN SORGHUM PLANTER WITH FERTILIZER APPLICATOR

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ABSTRACT

Sorghum is a staple food crop for many of the Ethiopian's so, millions of poor Ethiopians depend on the crop. As a result, Agricultural sector requires modern techniques and suitable agricultural mechanization which will increase the production and productivity of sorghum, and reduce the level of manual labor, by introducing sorghum row planter to the target area. So, this study was undertaken to design, fabricate and evaluate the performance of a prototype animal drawn planter capable of planting sorghum seed at predetermined spacing and depths. The prototype could plant the seed with two rows, consisting of a frame, seed hopper, seed metering devices, seed tube/spout, drive wheels, furrow opener and furrow covering device. Even though the spacing between rows is adjustable it has been kept 70 cm. The planter have overall dimension 1210 mm x 605 mm x 648 mm and total weight of the machine was 59 kg. The average sphericity of the seed ,seed rate, seed damage and seed germination under laboratory testing of developed sorghum planter were found to be 84.34%, 15.08kg/hr, 0.67% and 99.16% respectively. Field data on performance parameters of the planter was collected and analyzed. The mean value of actual field capacity, field efficiency and planting depth were found to be 2.56 hr/ha, 80.03 % and 5.22cm respectively. Average speed of operation was 3.42 km/h and the average draft required to pull the multi crop planter was 9.6 kgf. The cost of the machine was determined as 7,071.55Birr. So, based on the above result the prototype planter is efficiently, effectively and economically which can be used by the majority of farmers.

Key words: design, development, row planter, prototype

1. INTRODUCTION

Ethiopia is the largest sorghum producing country, sixth globally and second in Eastern and Southern Africa next to Sudan. And the crop is a staple food crop on which the lives of millions of poor Ethiopians depend. In the county, sorghum is the fourth most important food crop after maize, wheat and *tef* in area and the second in total production next to maize and also it is the most important in the drier parts of the country [1].Sorghum is an indigenous crop to Ethiopia where it is grown in a wider area of adaptation ranging from hot, dry lowland to the cold highland environments. Annually, sorghum contributes 17% of the total cereal grain production of the country and is ranked third in both total area coverage and productivity [2].

Sorghum is one of a traditional food crop widely grown in the country, in 13 of the 18 major agro-ecological zones, and in 2014/15 Maher season the

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crop covered an area of more than 1.8 million hectares and the production of the crop was over 43.3millionquintals[3]. Despite this potential, sorghum production in the Ethiopian was 2.1 MT/ha, which is low by comparison with the crop's potential due tothis, the country ranks 34th in yield even though, 5th in area harvested globally. This is because of the production method practiced in Ethiopia is traditional, underdeveloped, subsistence and small-scale[4].

The status of agricultural mechanization in the production line of sorghum such as starting from land preparation implements up to planting, harvesting, threshing and storage are very low. Almost all of the farm operations are performed with hand or using rudimentary hand tools and traditional animal drawn implements. From those the major mechanization problems, planting method is one; it was believed that this problem was created due to lack of suitable sorghum seeder/planter throughout the country. Hence, in most part of the country, manual broadcasting or hand drill method of sowing is still in use. It is obvious that, this traditional method of planting cannot be uniformly distributing the seed and cannot be maintains the optimum plant density in the field.

Furthermore, the problem of using hand broadcasting and hand drill method of sowing is, both are require experienced manpower to broadcast or drill in order to get optimum plant population, so that planting by hand is difficult for inexperienced farmers. As a result, developing agricultural sector requires modern techniques and suitable agricultural mechanization which will increase the agricultural production and reduce the level of manual labor, which represents 85% of the total labor force, involved in agricultural sector [5]. And introducing sorghum row planter to the target area is crucial for sorghum production and productivity.

In this study effort was made to solve problems observed in traditional sorghum planting method through design, fabrication, testing and evaluation of two row animal drawn sorghum row planter.

2. MATERIALS AND METHODS

2.1. Determination of Physical Properties of experimental crop

The sorghum seeds were cleaned manually to remove all foreign matter such as dust, dirt, stones and chaff before determine the mean size of the seeds, used in the study then the grain dimensions were determined by randomly selecting 50 seeds from the representative samples and measuring their three principal diameters length (L), width (W) and thickness (T) using digital caliper of 0.01 mm accuracy andthe 1000 seeds mass was measured by an electronic digital balance to an accuracy of 0.0001g. The geometric diameter, volume and sphericity of the individual seeds were calculated using the measured length, width and thickness of the seeds and equations given below [6].

$$D_g = \sqrt[3]{(L_m \times W \times t)} \quad \text{.......1}$$

$$V_m = \frac{\pi}{6}(L_m \times W \times t) \quad \text{.......2}$$

$$S_m = \frac{\sqrt[3]{(L_m \times W \times t)}}{L_m} \times 100 \quad \text{.......3}$$

Where: L_m = Mean length, (mm)

W = Mean width, (mm)

t = Mean thickness, (mm)

V_m = Mean volume, (mm^3)

D_g = Mean geometric diameter, (mm)

S_m = Mean seed sphericity, (%)

2.2. Design of the planter

2.2.1. Description of the planter Components

The developed two-row sorghum planter consists of frame, seed and fertilizer hoppers, metering mechanisms, furrow openers, furrow covering devices, drive wheels and handle. Generally the total weight of the planter at full loads of the seed and fertilizer hoppers is 59kg so as to create enough traction between the wheels and the ground, and also to avoid any skidding/sliding of the wheels over the ground when the planter is drawn by donkey or a pair of oxen and as shown in the fig. 2 the planter have overall dimension of1210 mm×605 mm× 648 mm.

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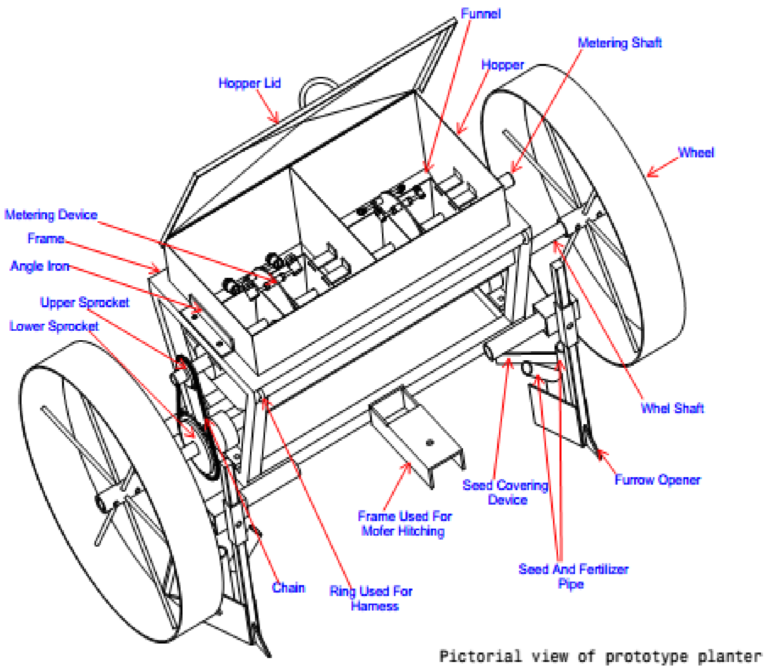

Fig. 1 Pictorial view of the prototype planting machine

2.2.2. Fabrication of the Planter Components

2.2.2.1. Frame: The frame carries the entire components of the machine. The main components which are mounted on frame are hopper, bearings, *mofer* hitching frame and furrow opener. The design of the frame was based on the design of components to be mounted on it. The frame had a trapezoidal shaped structure, 380mm by 660 mm at the top and 210 mm by 660 mm at the bottom and constructed from 30 mm by 30 mm square pipe in order towithstand all types of load during operation. The material of the main frame was selected based on achieving a reasonable weight and required strength and reliability and readily available material

2.2.2.2. Hopper design: The planter hopper has two compartments, one for seed and the other for fertilizer. The hoppers of the seed and fertilizer were designed to contain 7.5 kg and 7.8 kg respectively, and the material used for the construction was mild steel sheet metal with thickness of 1.25 mm.The two design factors considered in the determination of hopper capacity are bulk density and seed rate of sorghum, which are 745 kg/m^3 and 15 kg/ha respectively (informal communication with experts). Based on the above stated of rates of seeding, the volume of the hopper was estimated using the equation given by [7], as follows:

$$V_S = \frac{S_r}{n \times \rho_b} \quad \text{.....} 4$$

Where:S_r = Seeding rate (kg/ha)

n = Number of refilling per hectare (assume, n=2)

ρ_b = Bulk density of the seeds (kg/ m^3)

V_S = Volume of seeds in the hopper (m^3)

Then theoretically the Volume of seed box was calculated by the following formula[8]

$$V_b = 1.1 \times V_S \quad \text{.....} 5$$

Where:V_b = Theoretical Volume of seed box, cm3

V_S = Volume of seeds in the hopper, cm3

Since the designed volume of seed hopper (V_D) is 1.94×10^4 cm^3, which is larger than the theoretical volume V_b (1.1×10^4 cm^3). Therefore, the designed dimensions of the hopper are acceptable.

2.2.2.3. Design of seed metering device: Metering device picks required number of seeds and delivers them into the soil through the tube at required depths created by furrow openers.In the design of seed metering device the size of the seed, the intra row spacing between seeds and desired plant populations were considered. The depth of scoops used for meter the seed was adjustable based on desired rate of planting. The diameter and numbers of scoops were determined on the basis of mean size of sorghum seeds, recommended intra-row spacing of seeds and economical and efficient size (diameter) of driving wheel. The size of the scoops was determined based on the value of the average geometrical mean of the sorghum seed, their length(l), width(w), and thickness(t). The largest dimension/diameter for sorghum which measured in laboratory varied between 2.10 and 4.25 mm, so the scoops to meter sorghum have 8.5 mm diameters because each scoops hold at least two seeds. The ground wheel, through the shafts, provided the desired torque to drive the seed plates through chain-sprocket drive.

The number of scoops, m and distance between consecutive scoops, t on the seed metering plate were obtained using the following expressions [8]

$$m = \frac{\pi \times D_2}{I_{rss}} \qquad \ldots 6$$

Distance between consecutive scoops found t using the following formula [8]

$$D = \frac{\pi \times D1}{m} \qquad \ldots 7$$

Where: D_1 = Diameter of seed metering plate, (20cm)

D_2 = Diameter of ground wheel, (57cm)

m = Number of scoops on a plate (minimum value)

I_{rss} = Intra-row spacing of seeds, 15cm

D = Distance between consecutive scoops, cm

The calculated number of scoops on metering plates was found to be 12 for sorghum planting at the predetermined seed spacing and the consecutive distance between scoops on metering plate was determined to be 10.5 cm.

The minimum depth of seed scoop to accommodate the required amount of sorghum seed during planting sorghum would be found by using the following formula [8]

$$V_{SS} = \frac{\pi \times D_S{}^2 \times d_s}{4} \qquad \ldots 8$$

Where: V_{SS} = Volume of seed scoop, cm^3

D_S = Diameter of seed scoop, cm

d_{ds} = Design depth of seed scoop, cm

The calculated design depth of scoops were 3mm but, the minimum depth of seed scoop used in this design was 5mm because, the largest dimension of sorghum seedwhich measured in laboratory used to test the performance of the prototype was 4.25mm.

2.2.2.4. Design of fertilizer metering device: The diameter of the fertilizer plate would be the same as seed plate, hence the number of scoops and distance between consecutive scoops also similar. But according to the regional Agricultural bureau extension program manual 2006 the recommended DAP (Di Ammonium Phosphate) fertilizer rate for sorghum crop and spacing between rows are 100 Kg/ha and 70 cm respectively, so the size and depth of scoops on the fertilizer plate would be different.

The minimum depth of fertilizer scoop to accommodate the required amount, of fertilizer during planting sorghum would befound by using the following formula [8]

$$V_{FS} = \frac{\pi \times D_F{}^2 \times d_F}{4} \qquad \ldots 9$$

Where: V_{FS} = Volume of fertilizer scoop

D_F = Diameter of fertilizer scoop

d_{dF} = Depth of fertilizer scoop

The minimum depth of fertilizer scoop used in this design was 4 cm to accommodate the required amount of fertilizer and the diameter of scoops to meter fertilizer was 18.5 mm.

2.2.2.5. Adjustable furrow opener: Furrow opener is generally selected to open the furrow for seed and fertilizer application at desirable depth. Soil type, soil condition, angle of attack and depth of planting should be considered in designing furrow openers. The typeof furrow opener used for this design is Shoe type furrow Opener which able to maintain 3.2cm distance between seed and fertilizer because, the center to center distance between the seed and fertilizer pipes is 3.2cm.

2.2.2.6. Furrow covering device: The furrow closer was also designed to be flexible and pivoted on furrow opener wing. It was designed to allow for proper covering of the soil over the seeds in the furrows. The material used for the design was mild steel angle iron of 2 mm thickness. These covering devices were fastened to the rear of the wing of furrow openers.

2.2.2.7. Seed/fertilizer tubes: This was the channel through which seeds or fertilizers are conveyed to the furrow. This may be the collapsible or rigid type. The one for this machine is the rigid type made of plastic tube. Based on the diameter which we want, the tube is directly purchased from the market so, no need to design seed/fertilizer discharge tube.

2.2.2.8. Wheel and metering shaft: The prototype had two shafts which were metering and wheel shafts. The wheel shaft used to transmit the rotational movement of ground wheels to the metering shaft through chain and sprocket and the coming power is transmitted to the metering device from the metering shaft.

2.2.2.9. Wheel: The planter has two ground engaging wheels with external diameter of 57

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cm.Besides the main function of carrying the whole planter units, the wheels areused to produces the necessary force to drive the seed and fertilizer plates through chain-sprocket drive. In this work, the wheel of the planter was made from 3 mm thick and 100 mm wide sheet metal whose maximum shear strength, τ_{max}, is 80 MPa so, the wheels are designed to be a traction wheel to enhance movement on loose soils. Each wheel had six spokes made from reinforcement bars were used to strengthen the wheels with diameter of8 mm and length of 264 mm, and were welded to the rim and hub at the center of the wheel that served as bushing or shaft bearing, at equal interval.

2.2.3. Determination the Weight of Component Parts of the Planter: In order to estimate the loads on each and every component parts of the prototype planter, it was necessary to estimate weight of all component parts.The total weight the prototype planter including seeds, fertilizer, *mofer* and bearing was estimated to be 578.05 N. Allowing 2% margins for the weights of welding bolts, nuts, plastic tube, etc. the total weight was found to be 589.61 N ≈ 590N.

2.2.4. Drive wheel design

2.2.4.1. Wheel strength: The formula used in the analysis was the one that estimates the shear amount in “welded closed thin wall, t<<<d”, as dictated by [9]. And the maximum shear strength of the wheel is τ_{max},= 80 MPa. So, Shear stress on the wheelwould befound by using the following formula[8]

$$\tau = \frac{T}{2A_m \times t_s} \quad \text{.......10}$$

but, $A_m = \pi r_m^2$ and $r_m = r - 0.5t_s$

Hence, $\tau = \frac{T}{2(\pi[r-0.5t_s]^2)\,t_s}$

Where: T = The torque produced by the wheel, 23.49Nm

A_m = The area of the wheel calculated based on the median diameter of the wheel

R = The outer radius of the wheel, 0.285m

r_o= The inner radius of the wheel, 0.282m

r_m= The median radius of the wheel, 0.2835m

t_s= The thickness of the wall/wheel, 0.003m

τ = Shear stress on the wheel, Kpa

Comparing this shear stress with the maximum allowable shear stress of the metal, $\tau(15.51\text{ KPa}) << \tau_{max}$,,80 MPa, which tells us the wheel is safefor operation.

2.2.5. Shaft design

2.2.5.1. Determination of the Drive Shaft Diameter

The diameter of the shaft was obtained using the following equation[10] given as:

$$d^3 = \frac{16}{\pi Ss} \times [(K_b M_b)^2 + (K_t M_t)^2]^{1/2} \quad \text{.......11}$$

Where: d = Diameter of the shaft; mm

M_t = Torsional moment; Nm

M_b= Bending moment; Nm

Ss = Allowable stress; MN/m

K_b = Combined shock and fatigue factor applied to bending moment;

K_t= Combined shock and fatigue factor applied to torsional moment;

For rotating shafts, when load is suddenly applied with minor shock, [11] recommended that values of K_b = 1.2 to 2.0 and K_t = 1.0 to 1.50 to be used. Furthermore, it was noted that for shaft without key way, the allowable stress (Ss) must be 55 MN/m2, and for the shaft with key way the allowable stress (Ss) should not exceed 40 MN/m2.

Torsional moment (Mt) on the shaft was calculated using formula [12]

$$M_t = \frac{P \times 60}{2\pi \times N} \quad \text{.......12}$$

But, P = V × F.......13

Where: P = Power required to drive the machine; w

N = Speed of the shaft, 46.54RPM

V = Forward speed, 5Km/hr = 1.39m/s

F = Force required to drive the machine, 82.43N

Fig.15 shows the load distribution on the shaft. The maximum bending moment on the shaft was determined from the following expressions [9]

$$M_b = \sqrt{(M_V)^2 + (M_h)^2} \quad \text{.......14}$$

Where: M_b = Maximum bending moment, Nm

M_v = Vertical bending momentum, Nm

M_h = Horizontal bending momentum, Nm

The load diagram on the driven wheel shaft is as shown below

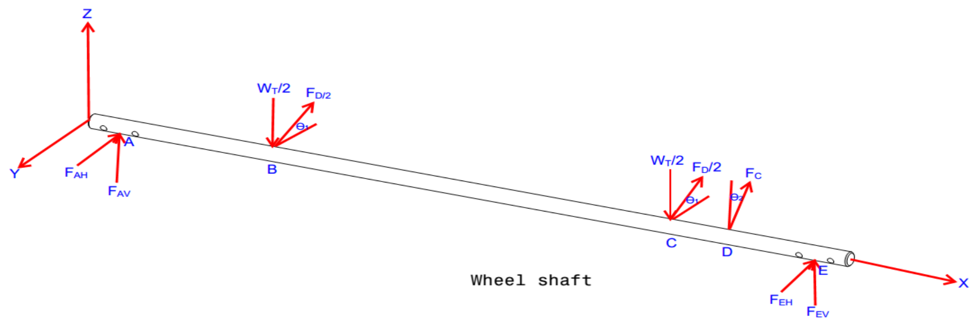


Fig.2 Free body diagram of the wheel shaft

Where: F_{AH} = Wheel reaction in horizontal direction at point A, N

F_{AV} = Wheel reaction in vertical direction at point A, N

W_T = Total weight of the prototype, 590N

F_D = Draft force, 107.91N (11Kgf) from dynamometer reading

F_C = Force due to chain pull, 125.24N

F_{EH} = Wheel reaction in horizontal direction at point E, N

F_{EH} = Wheel reaction in vertical direction at point E, N

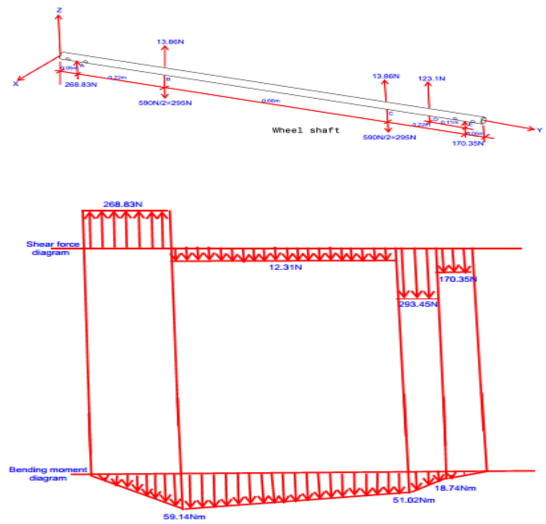
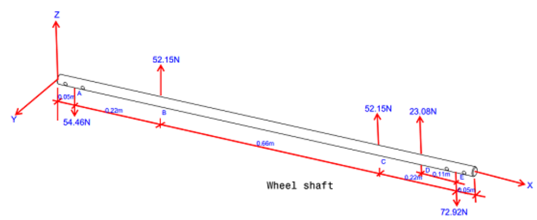


Fig. 3 Shear and bending moment diagrams of the main shaft in ZY plane

Therefore, the maximum vertical bending moment, $\mathbf{M_V}$ **= 59.14 Nm**



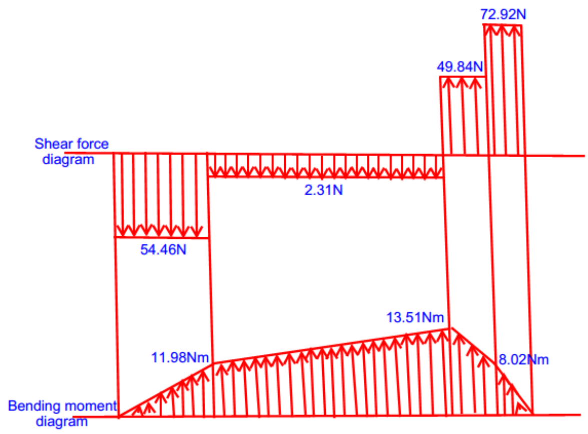


Fig. 4 Shear and bending moment diagrams of the main shaft in ZX plane

Therefore, the maximum horizontal bending moment, $\mathbf{M_h}$ **= 13.51 Nm**

Therefore, the standard size of **25 mm** shaft diameter has been used.

2.3. Evaluation of the planter

2.3.1. Laboratory evaluation

2.3.1.1. Seeding and fertilizer application rate of the planter: Polythene bag was placed on each of the discharge tubes or sprouts to collect the seeds or fertilizers discharged. The seeds or fertilizers collected on each bag were weighedfor the determination of the seeding and fertilizer application rates of the planter and the test was replicated three times on 30m length ground (with negligible gradient and moderate moisture content). Weight balance and stop-watch were the instruments used for measurement.

2.3.1.2. Evaluation of percent seed damage: The test for percentage seed damaged was done on the discharged seeds from each sprout or tubes during the above test for any external damage. The dropped seed was sorted out for healthy seed and damaged seed then the sorted seed was counted. Total three readings were taken for each setting. The average value of these readings showed the

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percentage damage of seed due to metering mechanism. Percentage external seed damage was determined by equation given below [13]

$$\mathrm{Md} = \frac{\mathrm{Stds}}{\mathrm{Sns}} \times 100 \quad \text{.......15}$$

Where: Md = Percentage damaged seed

Stds = Total number of damaged seeds (external)

Sns = Total number of seeds

The seeds which had passed through the seed metering mechanism were also subjected for germination tests so as to know if there were internal damage which may be caused by the metering plate /change in its velocity/and the weights of the seeds in the hopper. The germination rate of the seeds was tested from 50 randomly selected seeds discharged from the tubes using Petri-dish. Ten seeds were placed in each Petri-dish and awaited for a week until most of the seeds start germinating.

2.3.2. Field evaluation

2.3.2.1. Working speed

The working speed was estimated using the expressions below [14]

$$V = \frac{D}{t_a} \quad \text{.......16}$$

Where: V = Working speed,(m/s)

D = Distance of run (m)

t_a = Average time of each pass (second)

2.3.2.2. Field efficiency

The field efficiency was evaluated from equation suggested by [14].

$$Ɛ = \frac{\mathrm{Te}}{\mathrm{Tt}} \times 100 \quad \text{.......17}$$

Where: Ɛ = Field efficiency (%)

Te = Effective operating time (min)

Tt = Total time (min) (effective operating time + time lost for turning)

2.3.2.3. Effective field capacity

The effective field capacity was suggested by [14]

$$E_C = \frac{\mathrm{WS}}{10} \times Ɛ \quad \text{.......18}$$

Where: E_C = Effective field capacity,(ha/hr)

W = Implement effective width, (m)

S = Forward speed, (km/hr)

Ɛ = Field efficiency, % (decimal)

3. RESULTS AND DISCUSSIONS

Table 1 summarized details of the physical properties of the seeds used and performance evaluation of the sorghum row planter.

Over all test result ofanimal drawn sorghum row planter		
Laboratory test results		
Physical properties of seeds	Average length of the seed	4.01mm
	Average width of the seed	3.91mm
	Average thickness of the seed	2.47mm
	Average volume of the seed	$20.31mm^3$
	Average geometric diameter of the seed	3.38mm
	Average sphericity of the seed	84.34%
Average seed rate		15.08Kg/hr
Average seed damage		0.67%
Average germination rate		99.16%
Field test results		
Average planting depth		5.22cm
Average field efficiency		80.03 %
Average field capacity		2.56 hr/ha

4. Conclusion

Based on the experimental results, the performance of the prototype planter in terms of seed rate, seed damage, germination rate, field capacity, field efficiency are observed within the recommended levels, and also labour cost and economics of owning and operating the machine is acceptable. Hence, it can be concluded that the prototype planter can be efficiently, effectively and economically used by the majority of Ethiopian farmers. However, this doesn't mean that it shouldn't be improved.

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