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Development and evaluation of animal-drawn, single row tillage-cum-multicrop planter

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Sorghum and maize are the leading cereal crops in Ethiopia in terms of production amount and area coverage. However, their productivities are below world standard owing to the traditional method of production farmers have been using for the last centuries. One of the major problems in sorghum and maize production is the broadcasting seed sowing method farmers are using. Though recently, in most parts of the country, farmers have started to adopt row planting of the crops, availability of efficient, affordable and less drudgery seeding equipment are limited. The available seeding equipment are characterized by their low field capacity and higher energy requirement (in the case of manually operated planters), poor performance in achieving agronomic requirements of the crop and high drudgery to the operator (in the case of draft animal drawn types) and high machinery purchase and operation costs (in the case of tractor operated ones). Moreover, the available planters are developed to be crop specific which limits their application area to a certain crop. To alleviate the existing problem, a new, multicrop type single row maresha attached planter (MAP) was developed and evaluated on both maize and sorghum crops against hand row planting technique (HRPT) that farmers are using. The trials were conducted at Melkassa Agricultural Research Center (MARC) on well prepared plots having 10x40m^2 areas and following RCBD experimental design with three replications. The labor force used in the case of HRPT was four and the parameters for the evaluations were seeding pattern, field capacities, plant population densities and draft requirement. On maize crop trial, MAP achieved 22.98±5.03cm seeding spacing, 73.92±12.71% seed per hill uniformity (ability to drop two seeds per spot as per the design) and 7.31±0.57cm seeding depth. Whereas, the seed spacing and seeding depth achieved by HRPT were 25.15±1.31cm and 6.22±0.70cm respectively. Significant variation was also observed on field capacity between MAP (0.185±0.04ha.hr^{-1}) and HRPT (0.091±0.01ha.hr^{-1}). However, on plant population density, no significant variation was observed between MAP (45087±2067No.Ha^{-1}) and HRPT (47352±3399No.Ha^{-1}). On sorghum trial, the seeding depth and seeding and fertilizer application rates obtained by MAP were 4.95±0.66cm, 14.51±0.77kg.ha^{-1} and 108.37±4.74kg.ha^{-1} respectively. Whereas, HRPT achieved 3.79±0.48cm, 12.26±0.45kg.ha^{-1}and 101.42±2.93kg.ha^{-1}seeding depth, seeding and fertilizer application rates respectively. Here also significant variation on field capacity was observed between MAP (0.191±0.01 ha.hr^{-1}) and HRPT (0.128±0.03 ha.hr^{-1}). On plant population density, it was found that MAP (81556±2629 No.Ha^{-1}) excelled HRPT (80593±2773 No.Ha^{-1}) owing to the higher seeding rate of the planter though there was no significant variation observed. The field efficiencies of the planter found to be 74.47% (for maize trail) and 76.52% (for sorghum trial) owing to the variation of speed of operations. The field draft requirement of the planter (combined with the tillage implement) was also found to be 534.62±27.95N.

Key words: planter, seeding pattern, field capacity

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INTRODUCTION

Background and justification

Sorghum and maize in Ethiopia are the leading cereal crops grown over a wide range of environmental conditions and have been utilized as food and supplements majority of the human diet in the country.

Sorghum comprises 15-20% of the total cereal production in the country. It is the dominant crop in the semi-arid areas and is one of the major food crops in Ethiopia with approximately 297,000ha production area per annum (CSA, 2015). Whereas, maize grows from moisture stressed to high rainfall areas and also from lowlands to the highlands. Its total annual production and productivity exceed all other cereal crops, though it is surpassed by tef inarea coverage (Kebede*et al.*, 1993). Considering its importance in terms of wide adaptation, total production and productivity, it is one of the high priority crops to feed the increasing population of the country**.**However, the productivity of both sorghum and maize crops are 1.0 $t.ha^{-1}$ and $2.5t.ha^{-1}$ respectively which is below world standard (CSA, 2015).

The major reasons for the poor productivities of the crops is the traditional method of production, especially seed sowing technique, farmers have been using for centuries. In most parts of the country, farmers are still using broadcasting seed sowing techniques for all crops. Different research outputs showed that the broadcasting seed sowing technique wouldlead to non-uniform application, higher application of seeds and fertilizer, high competitions among seedlings for nutrients and sunlight and also greater drudgery/difficulty for successive management practices especially when the technique is employed without efficient equipment. Recently, farmers have started to adopt row planting of crops and different animate and tractor operated planters are being developed/imported and introduced to farmers by research institutes and non-governmental organizations to assist the initiatives.

JICA introduced a single row manually operated maize planter with field capacity of 0.027 $ha.hr^{-1}$ and seed spacing performance of 13.21±2.14cm. CIMMYT introduced a manually operated jab planter which would be used in zero tillage farming. Rotary jab planter which work manually and using draft animals were introduced to light soil areas of the country. Fitsum (2017) developed ripper attached maize planter which could be used for strip tillage practices. Meseret (2017) developed and introduced animal drawn two row maize planter with field capacity of $0.21ha.hr^{-1}$. Tamirat (2017) developed a pair of oxen drawn two row sorghum seed drill which had field capacity of $0.39ha.hr^{-1}$ and seeding rate of $15.08kg.ha^{-1}$. AIRIC (1992) developed a non-wheeled type tillage-cum-planter which could work on any soil type and condition. However, the acceptance of the technology was poor as the planter had limitations on keeping uniformity of seed per hill and achieving the recommended seed spacings of the crops owing to the complications it had on metering seeds.

Generally, adoption rate of the most of the existing planters by farmers is limited. The manually operated planters need a well prepared seedbed to perform to their best which farmers couldn't deliver using the traditional tillage tools they employ. Besides, the field capacities of such planters are poor and do not insure on time completion of sowing seeds. Their energy requirement on not well prepared seedbed is also tremendous which cause drudgery to operators. The same is true for most of the available animal drawn planters in terms of adoption rate. Most of the animal drawn planters do not meet the agronomic requirements of the crops and they are difficult to manage during operation especially when they are designed to be more than single row type. Moreover, the available animate type planters in general are developed to be crop specific which enforces the resource poor farmers to purchase other planters if they grow more than a single crop.

Walk behind tractor operated planters have also been introduced to farmers by different stakeholders. Most of these planters developed to be multi-crop type and they meet the agronomic requirements of the crops they designed for. However, the cost of operation, owning the equipment and the power source is too expensive for farmers. Besides, as most of these planters have low field capacities (owing to their large weight), their use in areas exhibiting low precipitation amount and erratic distribution is limited. Thus, new, affordable, manageable and multi-crop type tillage-cum-planter needs to be developed and introduced to farmers so that row planting technique shall be adopted.

METHODOLOGY

Description of the planter

The planter is designed to address both maize and sorghum crops. It is a wheeled planter with 13kgnet weight which can be attached to local maresha or any tillage implement. The wheel of the planter is made of 3mm thick rolled mild-steel sheet metal with diameter of 48 cm and width of 8cm. It is the wheel which produces the necessary force to rotate the metering units of the planter through chain-sprocket arrangement. Its hopper has trapezoidal shape with seed and fertilizer compartments and effective capacity of 4.8L for each. The seed and fertilizer metering plates are made from 16 cm diameter circular plates with depth/volume adjustable cups attached/welded to them along their edges. The number and diameter of the cups are different for the crops and the fertilizer. The cups on the fertilizer metering plate are four in number (with diameter 2cm each) which are arranged 90^0 apart and provides 100kg.ha^{-1}rate. The scooping cups on the seed plate are also four in number (with diameter 1cm) which are arranged 90^0 apart and provides 25kg.ha^{-1} and 12kg.ha^{-1}seed rates for maize and sorghum crops respectively by adjusting the volume/depth of the cups.The planter is equipped with a flexible arm for connecting it with the beam of the tillage implement and thus, because of this arm the operator doesn't feel the weight of the planter when he raise/lower the tillage implement to shade off soil and to manipulate the depth of tillage and also when he makes turns at headlands.

Since it is tillage implement attached planter, the furrow opening is done by the maresha itself. However, the seed covering is done by depth and width adjustable furrow covering device which is connected to the bottom of the hopper with 20x20mm hollow pipe (see figure 1-4).

<u>Components of the planter</u>

1. Hopper: - seed and fertilizer containing derive which made from 1.5 mm thick, mild sheet metal. It has trapezoidal shape with openings on its wall
2. Flexible connecting rod: - connects the planter with the beam of the tillage implement
3. Wheel: - a 3mm thick rolled sheet metal which supports the hopper and also drives the metering unit through chain-sprocket arrangement.
4. Metering unit: - a scoop type seed and fertilizer metering device which regulate the seeding rate and also the spacing between plants as desired.
5. Chain and sprocket drive: - transfers the motion of the wheel to the metering with .The gear ratio is 1:3.
6. Gate on the hopper wall: - 2x4cm window for passing the metered seeds and fertilizer
7. Hose: - ½ inch flexible plastic pipe which transport seed and fertilizers from the hopper to the furrow openers
8. Covering device: - depth adjustable, v shaped sheet metal connected with bottom of the hopper with 20x20mm hollow pipe (9)

Experimental site

The study was conducted at Melkassa Agricultural Research Center on maize (Melkassa 2 variety) and Sorghum (Melkam) crops in 2017.

Melkassa is located in the Central Valley of Ethiopia. The place is situated at an altitude of 1466 m above sea level and lies on the geographical coordinates of 8° 24' 0" N, 39° 20' 0" E Latitude and Longitude respectively. It receives 763 mm mean annual rainfall, of which 70% falls during the major cropping season: June to September. The dominant soil type in the area is sandy loam.

Adjustment of the planter

As the field evaluations were conducted on both maize and sorghum crops, adjustment of the seed and fertilizer metering units of the planter had to be done. For maize crop planting, two of the seed scooping cups (arranged 180^0)of the metering unit,were adjusted to have enough volume/depth to hold two seeds and the other two cups were kept at zero depth/volume so that they cannot scoop seed from the hopper. This adjustment was needed in order to achieve two seeds per hill having 25cm hill spacings.For the sorghum crop planting, since drilling of the seeds was needed, all the four seed scooping cups of the metering units were adjusted to operate and provide 12kg.ha^{-1} seeding rate. The four scooping cups on the fertilizer metering unit were also adjusted to provide 100kg.ha^{-1} rate for both crops. The two wooden parts of the tillage implement, called *"diggir"* in Amharic language, was also replaced with two metallic rods in order to significantly reduce the width of cut of the plow to 12cm average.

Experimental setup and Field evaluation

The planter was evaluated against hand row planting technique on well prepared 10x40m^2 plots arranged in Randomized Complete Block Design /RCBD/ with three replications. The average cone-penetration indexes of the maize trial site were 0.21±0.02KN and 0.46±0.07KN at 0-10cm and 10-20cm soil depths respectively. For the sorghum trail site, the penetration indexes were 0.19±0.04KN and 0.41±0.09KN at 0-10cm and 10-20cm soil depths respectively. The germination rates of maize and sorghum varieties used for the trail were 97% and 93% respectively. The geometric means of the seeds were 7.66mm (for maize) and 4.13 mm (for sorghum) and the 1000 seed weight were 274.55gm (for maize) and 216.24gm (for sorghum).The test sites were weeded completely using roundup chemical prior to the evaluations.In the case of hand row planting technique, four labor forces were involved for making the furrows, seed sowing, fertilizer applications and soil covering the sown seeds in both trials. Maize was sown keeping the recommended seed spacing; 25cm, and sorghum was drilled using the labor force. However, in the case of the planter, the planting furrows making was done by the maresha connected to the planter and the seed covering was done by the planter itself. Thus, no labor force, except the operator himself, was involved. The average speeds of operation of the planter for maize and sorghum trials were around0.92m.s^{-1} and 1.11 m.s^{-1} respectively. (see Table 1 & 2)

The parameters for comparison of the treatments were seeding pattern, field capacity and plant population density. Actual draft requirement of the planter was also determined.

Figure 1. Isometric drawing of the designed tillage-cum-planter

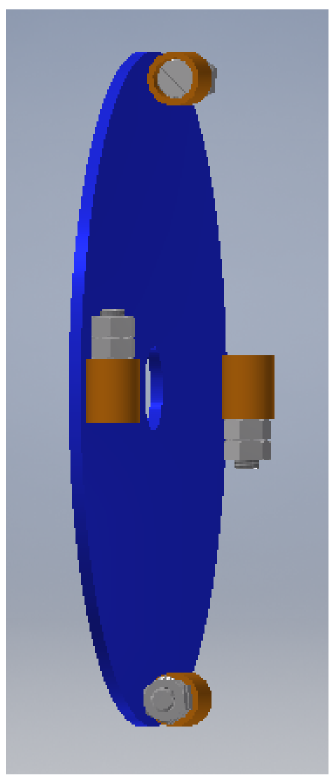

Figure 2. Metering unit of the planter

Seeding pattern

For maize trail, the seed spacing and the number of seeds per hill were measured from 1.5m sample lengths of the four middle rows of a plot during seed sowing. The rows were purposely left opened for a while until measurements were taken and then covered manually. The sample locations had consecutive staggered

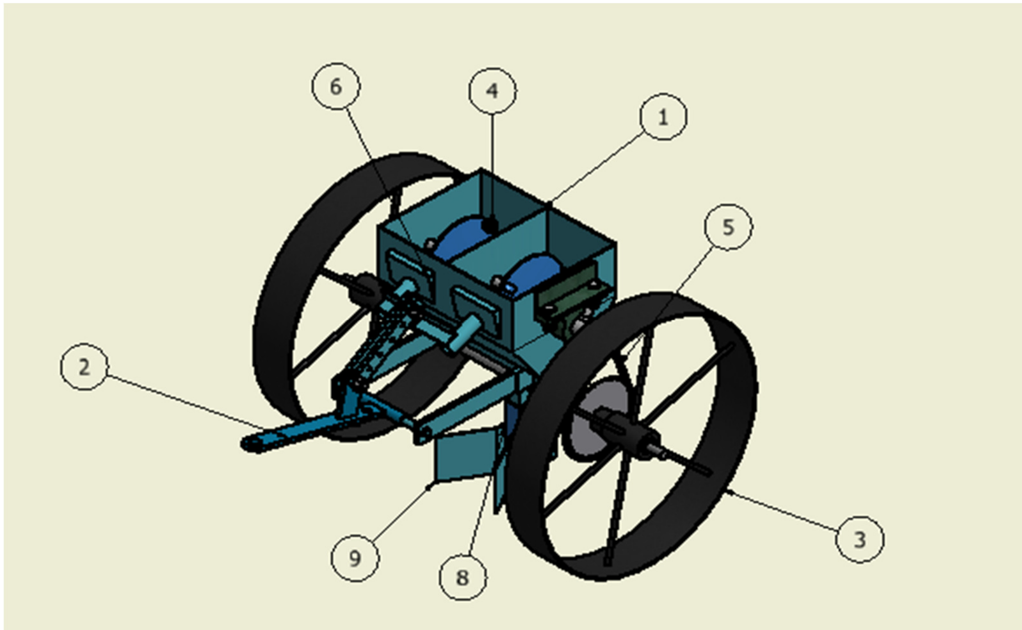

Figure 3. Components of the planter

Figure 4.the developed tillage-cum-planter in operation

arrangement to account field variation caused either by field preparation or gradient. Data regarding depth of seed placement achieved was also measured from the same locations using steel tapes and steel scale.During seed spacing measurement, miss/skip/was assumed/considered whenever the spacing between two hills was greater than 1.5 times the theoretical spacing, i.e. 25cm (Katchman and Smith, 1995). The same data were taken for sorghum trail except that instead of measuring the seed spacings and seeds per hill, the seeding and fertilizer application rates of the planter were measured (as the seeds were drilled) by comparing the

Table 1. Treatments for sorghum trial

No.	Treatment	Crop type	Planting		
			Furrow making	Seed and fertilizer application	Labor involved, No.
1	Hand row planting technique (HRPT)	Sorghum	Manually	manually	4
2	Maresha attached planter (MAP)		Maresha, attached with the planter	the planter itself	-

Table 2. Treatments for maize trial

No.	Treatment	Crop type	Planting		
			Furrow making	Seed and fertilizer application	Labor involved, No.
1	Hand row planting technique (HRPT)	Maize	Manually	manually	4
2	Maresha attached planter (MAP)		Maresha, attached with the planter	the planter itself	-

weights of seeds and fertilizer first filled in the hopper with the remaining amounts at the end of the trial for each plot.

Field capacity

Effective field capacity (*efc*) for each test was calculated by dividing the total area worked by the period of time spent from the beginning of the first furrow pass to the end of the last one. The field efficiency (ε_f) was calculated as the ratio of the actual field capacity to the theoretical one (*tfc*).

$efc=[A/T_T]$ ______________(Equation 1)

$tfc=0.36\,[W \times V]$____________(Equation 2)

$\varepsilon_f=100[efc/tfc]$ __________(Equation 3)

$T_T=T_{net}+T_{refill}+T_{rep}+etc$_______ (Equation 4)

$W= N_R \times R_S$ ______ (Equation 5)

Where efc = actual field capacity, hahr^{-1}; ε_f = field efficiency, %; tfc =theoretical field efficiency, hahr^{-1}; T_T=total time spent for the operation, hr; T_{net}= net time spent for the operation, hr; T_{refill}= time spent for refilling the hoppers, hr; T_{rep}= time spent for maintenance and repair during operation, hr; W= nominal working width, m; N_R= number of rows, N; R_S= row spacing, m; V= average speed of operation, ms^{-1}

Plant population density

Plant population, or rather seed emergence, counts were measured from the middle eight rows of each plot when the crops were at three-four leaves stages. When the counts were made, two or more seeds emerged at a spot were considered as one (in case of maize trail) because tinning work shall be performed eventually in order to avoid competitions among the germinated seeds.

Draft requirement test

The draft requirement test of the planter was conducted on a clean, dry concrete track and on actual field using a portable dynamometer. On track test, the evaluation was conducted on the planter (without coupling it with the tillage implement). Whereas, during the field evaluation, the planter was coupled with the tillage implement. The average moisture content of the field was 23.83% and the average angle of pull was 16.37° from the horizontal for both cases.

Data analysis

All the data collected during the evaluations were analyzed using Statistix 8 software. Statistix 8 is a commercial software package developed by the United States Department of Agriculture (USDA). During the analysis, the confidence interval level used was 95% and the four observations done in seed spacing and seed per hill measurement for each plot were combined and analyzed together.

RESULT AND DISCUSSION

Seeding pattern

Maize trail

Seed spacing, seeds per hill and seeding depth

In seed spacing, statistically significant variations were observed between the means of the treatments. The reason for the planter not to perform as per the design could either be the seed bounce created during seed placement in the furrow or it could be because of the variation of speed of operation. The seed bounce might be created due the variation of the forward speed of the planter and the seed velocity relative to the planter in the direction of the motion/planting. This led the seed not to have zero velocity relative to the ground/furrow. Such phenomenon created when the angle of the seed tube at the exit was not properly maintained(Ajit K. et.al. 2012). Operation speed variations might also affected the seed spacing between plants due to the rotational speed variation of the metering unit which leads to non-uniform initial/launching velocity of the seed. This causes the seed to have non-uniform transit time in the tube (Ajit K. et.al. 2012). Staggenborg et al. (2004) also determined that variation in corn planting speed adversely affected plant spacing uniformity performance in northeast Kansas. However, though significant variations was observed between the treatments, the seed spacing achieved by the planter was close to the recommended seed spacing of the crop and also it was within the quality feed index range. (Table 3)

In seed drop per hill, no significant variation between the treatments was observed. However, the capacity of the planter applying two seeds per hill (as per the adjustment made prior to the test) was found to be 73.92±12.71%. The missed spots (6.42±10.21%), which is small compared to most planters, could be related with the variation of speed of operation. As the speed of operations increases, the probability of picking seeds from the hopper reduces. The multiple seed drop per spot (7.47±9.13%) could be related with the variation of seed sizes and geometry. In general, seed drop efficiency could be related with the variation of seed sizes, geometry, position at the picking zone and also the speed of operation. The good thing of the planter is that the provision of volume adjustable seed scooping cups on the metering unit. This helps to easily maintain the required amount of seeds per spot through adjusting the volume/depth of the scooping cups. (Table 4)

The seeding depth achieved by MAP found to be within the recommended range for the crop (4-8cm) though significant variation was observed between the treatments. The seeding depth variation of MAPcould be related with the uniformity of seedbed preparation and the capacity of the operator to maintain uniform furrow depths while guiding the draft animals on the right track at optimum speed.

Sorghum trial

Seeding rate, fertilizer application rate and seeding depth

In seeding and fertilizer application rates, significant variations between the means of the two treatments were observed. The higher application rates of MAP could also be related with the variation of speed of operation, size and geometry of the seeds and the fertilizer granules and the adjustment of the scooping cups. With proper scooping cups volume adjustment and maintaining uniform speed of operation, the planter could achieve the recommended seed and fertilizer application rates. (Table 5)

Here also the recommended seeding depth of sorghum crop (3-5cm) was achieved by the planter though a significant variation was observed between the treatments. The uniformity of seedbed preparation and the experience of the operator could be the factors for seeding depth of MAP. Had the planter equipped with its own furrow opener and seeding depth adjustment, the variation arose by uniformity of seedbed preparation and the experience of the operator could have beenreduced significantly.

Field capacity

In both crops trial, significant variations were observed in field capacities between the treatments. The lower performance of HRPT could be related with successive operations of furrow making, seeding and soil cover which had to be done manually. All such operations in MAP case were done by the planter itself and the tillage implement it is attached with. Its being a single row and the flexible arm the planter connected with the tillage implement had also contributed to its higher performance through lowering the time spent for turning at headlands. The presence of the flexible arm for connecting the planter with the tillage implement had also reduced the drudgery of carrying the whole implement at headlands during turning. At headlands, during turning, all the operator had to do was raising the arm of tillage implement and guide the animals to make turns without carrying the planter.(Table 6)

The variation of field capacity of MAP on the two crops was due to variation in frequency of hopper refilling, condition of the trial sites and speed of operations. The refilling frequency for maize trial was higher than that of sorghum trial. The seedbed preparation level and the soil condition had also effect though it was insignificant. The

Table 3. Field test result of seed spacing, seed per hill and seeding depth of the treatments for maize trial

Treatment	Mean±SDv.		
	Seed spacing,cm	***Seeds per hill, no.***	***Seeding depth, cm***
HRPT	25.15±1.31a	2.00±0.00a	6.22±0.70a
MAP	22.98±5.03b	2.13±0.84a	7.31±0.57b
C.V	*15.32*	*28.85*	*9.16*

Table 4. Seed per hill uniformity test result of the treatments for maize trial

Seed drop uniformity	* Percent per 1.5m row length	
	MAP	***HRPT***
Missed/skipped spots	6.42±10.21	-
Single seeds	12.19±12.56	-
Double seeds	73.92±12.71	100
Multiple seed	7.47±9.13	-

** mean ±SDv, n = 12*

Table 5. Field test result of seeding and fertilizer application rates and seeding depth of the treatments for sorghum trial

Treatment	Mean±SDv.		
	Seeding rate, kg.ha^{-1}	***Fertilizer application rate. kg.ha^{-1}***	***Seeding depth, cm***
HRPT	12.26±0.45a	101.42±2.93a	3.79±0.48a
MAP	14.51±0.77b	108.37±4.74b	4.95±0.66b
C.V	*4.49*	*4.05*	*13.01*

Table 6. Field capacities and efficiencies of the treatments for maize and sorghum trials

Treatment	Mean±SDv.			
	Maize trial		***Sorghum trial***	
	Field capacity, Ha.hr^{-1}	***Field efficiencies, %***	***Field capacity, Ha.hr^{-1}***	***Field efficiencies, %***
HRPT	0.091±0.01a	-	0.128±0.03a	-
MAP	0.185±0.04b	74.47	0.191±0.01b	76.52
C.V	*11.43*		*10.29*	

variation of average speed of operations on the two trail sites due to the soil condition and depth of furrowing had also had effect on the field capacity.

The variation of field capacity of HRPT on the two crops was mainly related with the seed sowing technique. For the maize trail, the seed sowing was done manually keeping the recommended seed spacing of the crop; 25cm as much as possible. In the case of sorghum trial, however, seed drilling technique was employed.

Plant population

No significant variation was observed in plant population densities between the means of treatments for both trials. However, though there weren't significant variations, there were differences between the two treatments. The higher plant population density obtained by MAP on sorghum trail was mainly related with the relatively higher seeding rate used. Whereas, the lower plant population density obtained by MAP on maize crop could be due to the miss/skip spots.

However, the plant population densities of the two crops are lower than the expected amount; 53200 (for maize) and 88667(for sorghum). This was mainly due to the relatively lower amount and erratic distribution of precipitations obtained during the trail year. (Table 7)

Draft requirement

The field draft requirement of the implement in general found to be 534.62±27.95N which is less than the draft output of a pair of local breed oxen (890N). The draft requirement was not large enough to induce stress on the pulling animals. This was the result of the presence of ground engaging wheels and their designed width dimension (12cm) which helped the planter to rotate over the surface of a ground without significant sinkage into the soil. (Table 8)

Table 7. Field test result of plant population densities of the treatments for maize and sorghum trials

Treatment	Mean±SDv.	
	Maize trial, No.ha^{-1}	***Sorghum trial. No.ha^{-1}***
HRPT	47352±3399a	80593±2773a
MAP	45087±2067a	81556±2629a
C.V	*5.56*	*3.05*

Table 8. Horizontal draft requirement of the planter

Description	*Track test*	Field test
Mean±SDv, *N*	31.49±2.88	534.62±27.95
Minimum draft requirement, *N*	27.36	491.28
Maximum draft requirement, *N*	*36.45*	*577.88*

n=10

Generally, the planter has shown excelled performance in many of the parameters over the hand row planting technique which farmers are using. Its field performances on seed spacing, seeding depth and seed and fertilizer application are closer to the agronomic recommendations of the crops. Its seed per hill efficiency is almost as per the design and its field capacities are higher. Its draft requirement is much below the maximum draft output of the power sources; a pair of oxen. Moreover, it is a multi-crop type which helps farmers to use it for various crops they grow just by adjusting the metering unit using screw driver. Above all, since it is tillage-cum-planter, it can be used in strip tillage practice which asserts less soil disturbance, high soil fertility and greater water conservation especially in moisture stressed areas where mulch materials are limited.

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