International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in; editorijoer@gmail.com

Vol.5., Issue.5, 2017
Sept-Oct

RESEARCH ARTICLE

ISSN: 2321-7758

DESIGN AND DEVELOPMENT OF TWO ROW ANIMAL DRAWN MAIZE PLANTER WITH FERTILIZER APPLICATOR

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ABSTRACT

This study focused on the design and development of a two row animal drawn maize planter that is cheap, easilyaffordable, easy to maintain and easy to use. The planter consists of mainframe, handle, seed and fertilizer hopper, seed meteringdevice, adjustable furrow opener, adjustable furrow closer, drive wheels, seed tube and ball bearings. Most ofthese were fabricated from mild steel material. Physical properties of maize seeds were investigated to optimize the design of the planter's components. The mean field capacity, field efficiency and depth were 0.21 ha/hr, 86 % and 4.6± 0.3 cm respectively.The fabrication and development cost of the planter was minimum. Based on the performance evaluationresults, it is concluded that the prototype planter was easy, efficientandaffordable by maize producing farmers of Ethiopia.

Key words: design, development, row planter

1. INTRODUCTION

Maize (*Zea mays* L.) is an important grain crop of the world and it ranks second, after wheat in hectarage (177,379,567 ha) and first in total production (872,066,770 MT) and productivity (4.9 t ha^{-1}) (FAOSTAT, 2013). Maize is recognized worldwide as a strategic food and feed crop that provides an enormous amount of protein and energy for humans and livestock.

Over half of all Ethiopian farmers grow maize, mostly for subsistence, with 75 % of all maize produced being consumed by the farming household. Currently, maize is the cheapest source of calorie intake in Ethiopia, providing 20.6 % of per capita calorie intake nationally (4). In maize producing areas, it is staple food and is also used for making local beverages. Additionally, the leaves are used to feed animals and the stalks are used for construction and fuel.

The status of agricultural mechanization in the production line of maize is very low. Almost all of the farm operations are performed with bare hand or using rudimentary hand tools and traditional animal drawn implements (8). Due to lack of suitable row planting machine maize farmers normally use hand-broadcasting method for planting maize seeds on the field. It is obvious that this traditional method of planting is time consuming, distributes the seed non-uniformly and cannot maintain the optimum plant population in the field.

In Ethiopia, about 69% of smallholder farmers own farmlands less than or equal to one hectare in size and average grain yield for various crop is less than one metric ton per hectare (1). It is very difficult for these farmers to own and operate costly plantingequipments that can establish the optimum plant population. However, most of Ethiopian farmers have draught animals that can be used as the cheapest sources of draught power for agricultural operations. Hence, developing animal

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drawn maize planter, which is reliable, economical and simple to use and transport is important.

In this study, effort was made to solve problems observed in traditional maize planting method through design and fabrication of technically and economically compatible animal drawn two row maize planter with fertilizer applicator.

2. MATERIALS AND METHODS

2.1. Description of the Prototype Planter

The prototype planter is a two row animal drawn (donkey drawn) maize row planter with fertilizer applicator designed to serve as an intermediate technology between the hand tools and the tractor drawn row planter. It consists of seed and fertilizer hoppers, metering mechanisms, furrow openers, furrow covering devices, frame and drive wheels.

To operate it, seeds are poured into the hopper; the planter is then positioned at the desired starting point, and pushed along the row. About two seeds are picked up by the metering plate and introduced into the chute. The furrow opener continuously opens the soil and the seeds metered into the chute fall into the opened furrow which are simultaneously closed by the furrow closer. As the planter is pushed along the row, it continuously places seeds at 25 cm intra row spacing and 70 cm inter row spacing (USDA recommended spacing for maize), until the seeds in the hoppers are finished to a level requiring refilling of the hoppers.

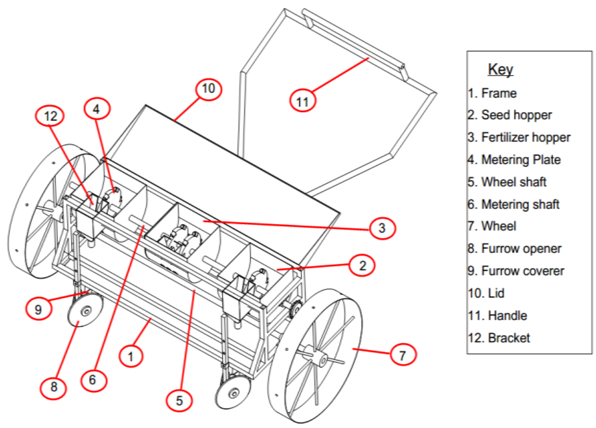

Figure1. Major components of the prototype planter

2.2. Design Analysis of Major Components of the Planter

2.2.1. Design of main frame

The material of the main frame was selected based on achieving a reasonable weight and required strength. A square hollow pipe bar of 20 mm x 20 mm mild steel was used to give the required strength and rigidity. The frame and other component parts of the planter were connected using appropriate sizes of bolts, nuts and holes. During the design and fabrication of the frame, provisions were made to fix adjustable furrow openers at 70 cm spacing, i.e. the spacing between two rows. The design of the frame was also based on the design of components to be mounted on it.

2.2.2. Design of seed and fertilizer hopper

The material used for the construction was mild steel sheet metal with thickness of 1.25 mm, which is readily available in market and relatively affordable.In the design of hopper capacity, seeding rate of 42 kg/ha for maize was considered; and the bulk density of maize at a seed storage moisture content of 15% was considered as 720 kg/m^3 (14). Equation given below (9) was used to estimate the volume of the hopper as follows:

$$V = \frac{S_R}{n \times BD} \quad (1)$$

Where: S_R = seeding rate (kg/ha)

n = number of refilling per hectare (let, 10 times)

BD = bulk density of the seeds (kg / m^3)

2.2.3. Design of seed metering device

The metering devices were made from mild steel vertical discs with six cups/scoops on the periphery. Cup feed mechanism was used so that there should not be mechanical damage due to mechanical handling. The dimension/diameter for Melkassa-138 maize variety varied between 8.0 mm and 12.5 mm. The cells to meter maize had 15 mm diameters and 15 mm depth. The number of cells and distance between consecutive cells on the seed metering roller were obtained using the following expressions (13);

$$n = \frac{\pi \times D}{i \times X} \quad (2)$$

Where: n = number of cells on a roller (minimum value)

D = Diameter of ground wheel

i = gear ratio (1:1)

x = required seed to seed spacing

$$t = \frac{\pi \times D_m}{n} \quad (3)$$

Where: t = distance between consecutive cells

D_m = Diameter of seed metering roller

n= number of cells on a roller (minimum value)

2.2.4. Design of furrow opener

The discs of the furrow openers were fabricated from 6 mm thickness mild steel sheet metal with 70 mm diameter. The discs were chamfered throughout the circumference to have sharp edge and arranged at an angle in which one disc leads the other.

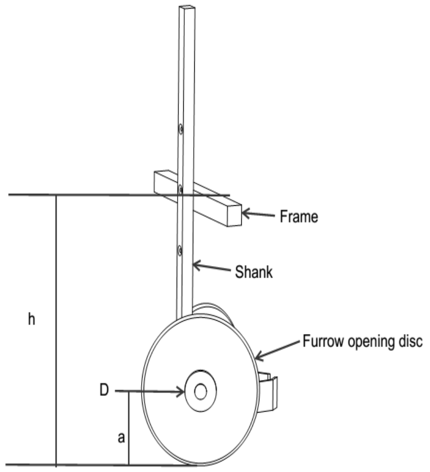

Figure 2. Parts of furrow opener

In the design of the furrow opener, the pull performance of a donkey was considered. It was assumed that the draft force was applied to the two furrow openers of the planter.

Distance of draft application on furrow opener tyne is (13);

$$a = h/3 \quad \text{.......... (4)}$$

Moment arm length = (h-a) .... (5)

Bending moment in shank = D × (h-a) ....(6)

Take factor of safety = 2

Therefore, the maximum bending moment in the shank (tyne) = 2 × Bending moment in shank

The section modulus of the shank can be computed from the following equation(13):

$$Z = Mb / fb \quad \text{.......... (7)}$$

Where: h = Total length of furrow opener and tyne /shank (taken as 250 mm)

D = Draft force on furrow opener, 24 kgf

a = Distance of draft application on furrow opener tyne

Mb = maximum bending moment, N-mm

f_b = bending stress (56 N/ mm^2 for mild steel)

Z = section modulus of tyne, mm^3

t = thickness of flat, mm

b = width of M.S flat, 35 mm (available in the market)

$$Z = \frac{1}{6} \times t \times b^2 \quad \text{.......... (8)}$$

Therefore, a Mild steel flat tyne of 35× 6 mm size was used.

2.2.5. Estimation of force required for driving the planter

The total weight of the prototype planter was determined using the thickness, area, volume and density of mild steel and taking 2% margins for the weights of welding bolts, nuts, chains, etc.

A rolling resistance force (F), which is assumed to act horizontal at the wheel and ground interface or ground and wheel contact patch, was estimated using (10).

$$\mathrm{F} = (C_R + \mathrm{i}) \times \mathrm{N} \quad \text{.......... (9)}$$

$$\mathrm{F} = \left(\left(\frac{\mathrm{z}}{\mathrm{d}}\right)^{0.5} + \mathrm{i}\right) \times \mathrm{N}$$

Where: C_R = coefficient of rolling resistance

d = wheel diameter,

z = maximum wheel sinkage depth (on a soft surface z = 0.05d)

N = weight of the planter on each wheel

i = gradient of the ground, let i = 5%

2.2.6. Torque on the ground wheel

The torque on the ground wheel was calculated as (13);

$$\mathrm{T} = \mathrm{F}\left(\frac{\mathrm{d}}{2}\right) \quad \text{.......... (10)}$$

Where: T = Torque on the ground wheel

2.2.7. Power requirement of the planter

The power required to operate the planter was calculated as (13);

$$\mathrm{P} = \mathrm{T} \times \mathrm{Nw} \quad \text{.......... (11)}$$

Where: N_w= wheel revolution

2.2.8. Wheel design

Two ground engaging wheels, with external diameters of 47.75 cm, were designed as an integral part of the seed metering mechanism. The rim of wheel was made from mild steel flat iron 6 mm thick and 80 mm wide. Each wheel had eight spokes made from mild steel rods with diameter of 8 mm and length of 257 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.

The wheel of the planter was made from mild steel sheet metal whose maximum shear strength, τ_{max}, is 80 MPa. For the simplicity of the analysis, it was assumed that the stress occur on the wheel was pure torsion. Therefore, the formula used in the analysis was the one that estimates the shear amount in "welded closed thin wall, t<<<d", as shown below (11).

$$\tau = \frac{T}{2A_m t_s} \text{.......} (12)$$

$$\tau = \frac{T}{2(\pi r_m{}^2)t_s}$$

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

Where: T= the torque produced by the wheel

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

r= the outer radius of the wheel

r_o=the inner radius of the wheel

r_m=the median radius of the wheel

t_s=the thickness of the wall/wheel

Comparing the result; $\tau_{ac} <<< \tau_{max}$, indicated the wheel was safe.

The angle of twist can be estimated using the equation below (11).

$$\theta = \theta_1 L \text{.......} (13)$$

$$\theta = \left(\frac{TL_m}{4GA_m{}^2 t_s}\right) \times L$$

Where: L= length or width of the wheel

T= torque produced by the wheel

L_m=the length of the median line of the wheel

θ_1=the angle of twist

G= modulus of rigidity, 80GPa for stainless steel

The angle of twist produced by the wheel was very small, so considered negligible.

The width of wheel specified in the design was 8 cm.The wheels will rotate onthe surface of the ground without sinking into the soil.

2.2.9. Shaft design

The design of the wheel shaft was based on ductile material (mild steel) whose strength is controlled by maximum shear stress. For a shaft having little or no axial loading, the diameter of the shaft was obtained using the ASME code equation,(ASME, 1995) given as follows:

$$d^3 = \frac{16}{\pi S_s}\sqrt{[(K_b M_b)^2 + (K_t M_t)^2} \text{.......} (14)$$

Where: d = diameter of the shaft; mm

M_t= torsional moment; Nm

M_b= bending moment; Nm

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

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

S_s= allowable stress; MN/m^2

For rotating shafts, when load is suddenly applied with minor shock,(7) 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 (S_s) must be 55 MN/m^2, and for the shaft with key way the allowable stress (S_s) should not exceed 40MN/m^2.

Torsional moment (M_t) on the shaft was calculated using equation below(12).

$$M_t = \frac{P \times 60}{2\pi N} \text{.......} (15)$$

$$P = F \times V \text{.......} (16)$$

Where: P = power required to drive the machine;

N = speed of the shaft

V = forward speed

F = force required to drive the machine

Figure 3 shows the load distribution on the shaft. The maximum bending moment on the shaft was determined from the following expressions (11);

$$M_b = \sqrt{M_v{}^2 + M_h{}^2} \text{.......} (17)$$

The vertical, horizontal, driving and chain forces acting on the wheel shaft are shown in figure 2.

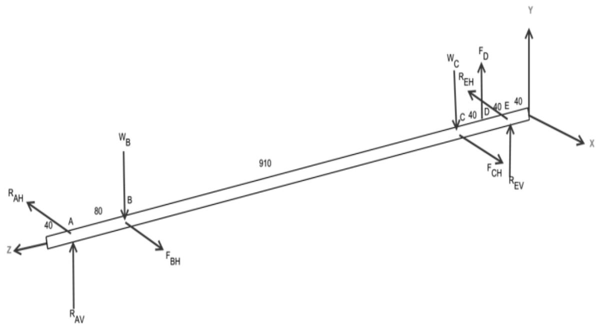

Figure 3. Three dimensional views of the forces acting on the wheel shaft

Where: R_{AV} =Vertical reaction at wheel A

R_{EV}= Vertical reactions at wheel E

W_B = Half of the total weight acting at bearing B (223 N)

W_C = Half of the total weight acting at bearing C (223 N)

R_{AH}= Horizontal reaction atwheelA

R_{EH}= Horizontal reaction at wheel E

F_{BH} = Pulling force of the planter at bearing B

F_{CH} = Pulling force of the planter at bearing C

F_D = Vertical chain force

2.2.10. Test of the planter

According to the design the maize planter was fabricated in Melkassa Agricultural Research Center workshop and tested on a rectangular fallowed farmland of 180 m^2 area having a sandy-loam soil texture with moisture content of 14.20% in wet basis.

Field capacity and efficiency were determined using relevant parameters that included effective operation time, turning time and time losses due to obstructions on the field. A plot of 18 m by 10 m requiring, on average, about fourteen passes with inter-row spacing of 0.7 m was used to assess field capacity and field efficiency. From the data gathered working speed (km/h), effective field capacity (ha/h) and field efficiency (%) were estimated using the expressions below (6);

$V = \frac{D}{t_a}$... (18)

Where: V = Working speed,

D = distance of run (m)

t_a = average time of each pass (second)

$e = 100 * \frac{T_e}{T_t}$.. (19)

Where: e = field efficiency (%).

T_e = effective operating time (sec.)

T_t = total time = (effective operating time +time lost for turning)

$C_e = \frac{W_e * S_{mf} * e}{10}$.. (20)

Where: C_e = effective field capacity (ha/hr)

W_e = implement effective width/inter row spacing (m)

S_{mf} = mean forward speed (km/h)

e = field efficiency (decimal value)

3. RESULTS AND DISCUSSION

The mean field capacity and efficiency of the prototype planter were 0.21 ha/hr and 86 %, respectively. Considering the recommendations by Kepner *et al.* (6) for planters, the field efficiency of the prototype planter is within the acceptable level. The mean depth of seed placement achieved in the field was 4.6±0.3 cm which is within acceptable range.

Table1. Raw material list

A. **No**	*B.* **Type of material**	*C.* **Standard size**
D. 1	*E.* Sheet metal 1.5mm	*F.* 1.5mmx1000mmx2000mm
G. 2	*H.* Sheet metal 2mm	*I.* 2mmx1000mmx2000mm
J. 3	*K.* Sheet metal 3mm	*L.* 3mmx1000mmx2000mm
M. 4	*N.* Sheet metal 6mm	*O.* 6mmx1000mmx2000mm
P. 5	*Q.* Square pipe(hollow)	*R.* 20mmx20mmx3000mm
S. 6	*T.* Galvanized circular pipe (hollow)	*U.* Ø20x3000mm
V. 7	*W.* Square bar	*X.* 15mmx15mmx3000mm
Y. 8	*Z.* Round bar Ø8	*AA.* Ø8x3000mm
BB. 9	*CC.* Round barØ20	*DD.* Ø20x3000mm
EE. 10	*FF.* Bearing	*GG.*

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HH. 11	II. Chain	JJ. 6000mm
KK. 12	LL. Sprocket	MM. 15 teeth
NN. 13	OO. Hinge	PP. 2.5”
QQ. 14	RR. Metal bolt and nut	SS. M-8x30
TT. 15	UU. Metal bolt and nut	VV. M-6x20
WW. 16	XX. Electrode (pack)	YY. Ø 2.5

4. CONCLUSION

A two-row donkey drawn maize row planter has been designed and fabricated with locally available materials to match the need and alleviate the difficulties of rural, small and medium scale farmers. It is simple and does not require any special skill to operate. The evaluation of the prototype planter in terms of depth of planting, optimum plant population, field capacity, field efficiency, labour cost and economics of owning and operating the machine is acceptable. The force required to pull the planter is less than the pull performance of the donkey so it can easily be pulled by the animal. Most importantly, the prototype planter can be efficiently, effectively and economically used by the majority of Ethiopian small holder farmers.

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