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Research Paper

Designing, Developing, and Testing the Performance of a Tractor-mounted Seed Tuber Potato Planter

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Abstract

Background: *Potato is the most important vegetable crop in developing countries. However, in Ethiopia, the national average yield of the crop is as low as 13.9 t ha^{-1}. Low level of mechanization is a factor contributing to this low average yield. Hence, mechanizing and modernizing farming systems, including planting tubers, is a major prerequisite for improving the yield of the crop in the country.*

Objective: *The main objective of this study was designing, manufacturing, and testing the performance of a tractor-mounted potato tuber planter.*

Materials and Methods: *Requirements ofmechanical design related to power source, traction, soil property and engineering properties of potato tubers were considered during designing, manufacturing, and selecting appropriate materials. Selection of materials was done using standards based on force and stress analysis of the planter. During field testing, the experiment was laid out as a split-split plot design. Three levels of forward speeds [2.5, 3.6 and 4.8] km hr^{-1} on the main plot, three hopper fill levels [25%, 50% and 75%] on the sub-plot, and three categories of tuber size [25 to 35 mm, 35 to 45 mm and 45 to 55 mm] on the sub-sub plot with three replications were used. The tuber size categories were determined based on the longitudinal diameter of the tubers and considered as small, medium, and large respectively.*

Results*: Effective field capacity and efficiency of the planter were 0.20 ha hr^{-1} and 72.22%, respectively. Mechanically damaged tubers during planting were 0.93%, 1.23% and 1.48% for small, medium and large-sized tubers, respectively. The highest miss index of 18.11% was recorded for the interaction of the tractor speed of 4.80 km hr^{-1} and tuber size range of 45–55 mm.*

Conclusion*: Tuber size of 35 to 45 mm, forward speed of 3.6 km hr^{-1} and hopper fill level of 50% resulted in the optimum planting space of 29.04 cm, 28.93 cm and 29.16 cm spacing uniformity compared with other combinations.*

Keywords*: Effect; Index; Prototype; Spacing; Speed; Size*

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I. Introduction

Potato is the most important vegetable crop in developing countries, and its production is expanding more rapidly than other food crops (Scott *et al.*, 2000). Hundreds of million people in developing countries depend on potatoes for their survival (FAO, 2008). In Ethiopia, the average national tuber yield of potato is 13.9 t ha^{-1} (CSA, 2018).This low productivity can be attributed to many factors, but lack of quality potato seeds, lack of machinery for seedbed preparation, planting, cultivation and harvesting are major constraints (Endale *et al.*, 2008a; Berga *et al.*, 1994).Experiments have shown that the use of improved agricultural implements including planting machinery not only increases production but also reduces manual drudgery and improve man-machine compatibility.

Semi-automatic potato planters were introduced to the potato producing farmers. However, for planting with a semi-automatic potato planting machine, an additional person is required who should sit at the back of the planter and manually pick tubers from the hopper and feed it in to series of rotating cups. The person operating such activities is e subjected to drudgery of work and predisposed to health problems.

Furthermore, the introduction of improved automatic potato planter can significantly reduce drudgery and enhances the potato production (McPhee *et al.*, 1996; Pavek and Thornton, 2003). Improved potato varieties planted with modern planting machines could produce three to four-fold more tuber yield than local varieties established using traditional manual planting practices (Singh, 1977).

Bader (2002) evaluated three potatofeeding systems (semi-automatic chain, semi-automaticray and automatic cup) to determine the optimum operational requirements and to select the most effectivesystem. Automatic cup planter was found to be the best. This prototype potato planter was tractor-mounted type, automatic planter. It has frame, hopper, metering device (chain cup meter), furrow opener, tuber guide, power transmission means and covering device as main component parts. Human labor is still the main source of power used in agricultural work in Ethiopia. In the manual method of planting, the soil is tilled and furrows are made by ox-drawn indigenous plough. As a result, the required depth and spacing uniformity are not maintained at all (Kumar *et al.,* 2015).

This prototype potato planter was able to maintain planting and row space, minimizing labor requirement while being simple, affordable and mounted & operated by 30 horsepower (hp) mini tractor. Therefore, the objectives of the study were to design and manufacture a prototype potato tuber planter and evaluate field capacity and field efficiency of the planter. Tuber spacing uniformity was evaluated in terms of the mean tuber spacing, the coefficient of variation, the multiple index, the miss index and the quality of feed index (Kachman and Smith, 1995).

II. Materials and Methods

2.1. Experimental Site

The automatic tractor mounted potato planter prototype was developed in Menschen für Menschen Foundation (Agro-Technical and Technology College) located in the outskirt of Harar Town. The performance evaluation was carried out on the main campus of Haramaya University in potato research fields. Haramaya University’s main campus is located at about 510 km East of Addis Ababa, between Dire Dawa and Harar towns. Geographically, the campus is located between $9^{o}22'03''$N and $9^{o}27'12''$N latitude and $41^{o}05'26''$Eand$41^{o}58'14''$Elongitude (Figure 1 Map of the study area.)

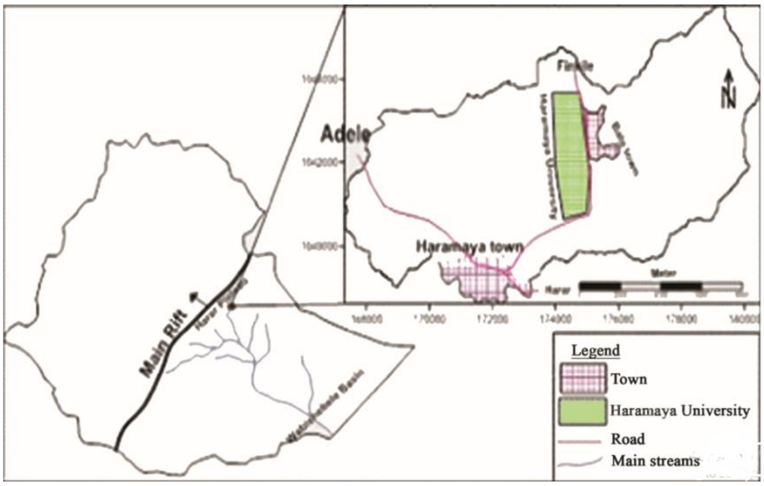

Figure 1 Map of the study area.

2.2. Planting Material

Tubers of the improved Badhasa potato variety, developed and released by Haramaya University, were used as a test crop. The improved potato variety was used because it is widely cultivated by smallholder farmers in the region. The recommended spacing for planting tubers of the potato variety is 30 cm between plants and 75 cm between rows.

2.3. Designing of the component parts of the planter

The selection of materials was done based on design, force and stress analysis. Thus, stress generated in any part of the machine did not exceed the permissible limit for the material used.

2.3.1. Designing the hopper

The slope angle of the bottom surface of the hopper was kept at 42° since, the average angle of repose of potato tuber measured 37°(Figure 2) . The full capacity of the hopper was 36 kg including 2 kg of buffer stock. The hopper material was made from 2 mm thick mild steel sheet metal with a total mass of 20.52 kg.

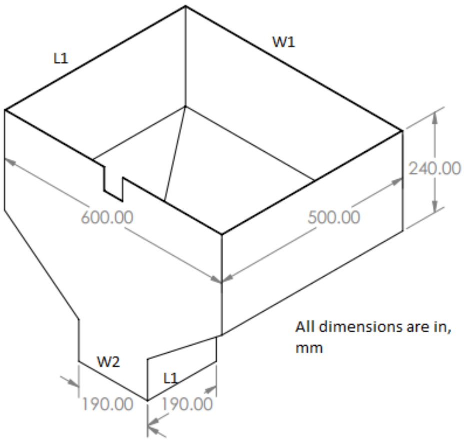

Figure 2. Isometric view of the hopper

Where, H1 and H2 = height of upper rectangle & lower trapezoid, mm; L1 and L2= length of upper and lower rectangle respectively, mm; W1 and W2 = width of upper and lower rectangle respectively, mm.

2.3.2. Designing of the frame

The frame was made from angle iron 50 mm x 50 mm x 4 mm. The total weight of the frame was estimated by taking the density and volume of the frame as shown in Figure 3. Thus, it was found out to be 13.32 kg.

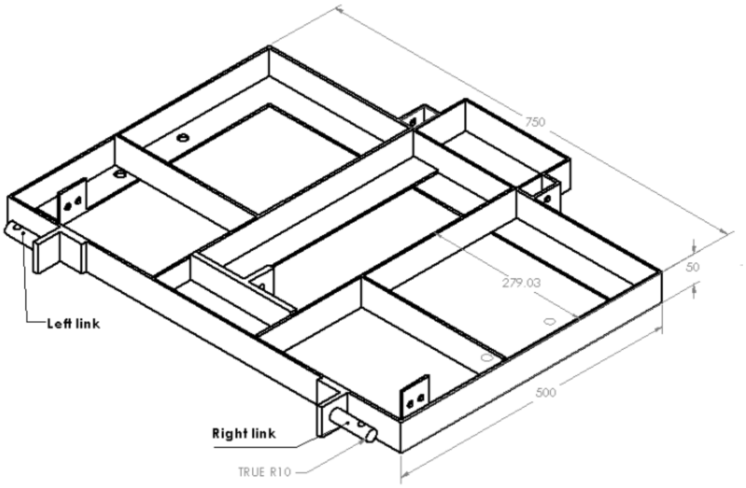

Figure 3. Frame.

2.3.3. Designing furrow opener and shank

The soil force acting on the furrow opener [F_f] was calculated using (Eqn. 1) (Sharma, 2010).

$$F_f = w \times d \times k_o \qquad (1)$$

Where, w = 10 cm; d = 12.50 cm; k_o= 0.20 kgcm^{-2} (for sandy loam soil) (Dubey, 2003)

The horizontal soil resistance (F_o) is assumed to be three to five times higher than specific resistance (Atul and Satyendra, 2011) as shown in the (Figureure 4).

$$F_o = 3 \times F_f = 3 \times 735 \text{ N} = 2250 \text{ N}$$

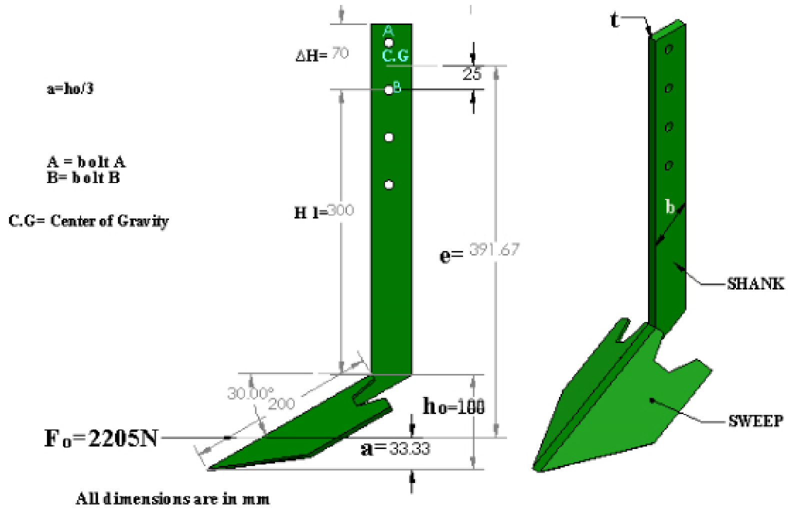

Figure 4. Furrow opener.

The maximum bending moment (M_b) was calculated using (Eqn. 2) (Kurtz *et al.*, 1984).

$$M_b = F_o[H_1 + (h_o - a)] \tag{2}$$

Where, H_1 = 300 mm, h_o = 100 mm; $a = h_o/3$ = 33.33 mm (This force was acting at the one third of sweep height from its tip (Kurtz *et al.*, 1984)); M_b = 808.5 Nm

The most assumed ratio of thickness to width of tine is 1:3 to 4 (Atul and Satyendra, 2011). For this design the thickness [t] to width [b] was taken as 1:4 which means b = 4t.

$$\sigma_b = \frac{6M_b}{t \times b^2} \tag{3}$$

Where, b = 4t; σ_b = allowable bending stress (165 Nmm^{-2}, www.fao.org.)

Thus, $\sigma_b = \frac{6M_b}{16t^3}$; $\quad t = \sqrt[3]{1837.67\ mm^3} = 12\ mm$

Therefore, the width of shank becomes, b = 4 x t = 4 x 12 mm = 48 mm. The weight of the furrow was found out to be 3.05 kg.

2.3.4. Designing the covering device

The discs were manufactured from 3 mm thick mild steel sheet metal by forging as shown in Figure 5.

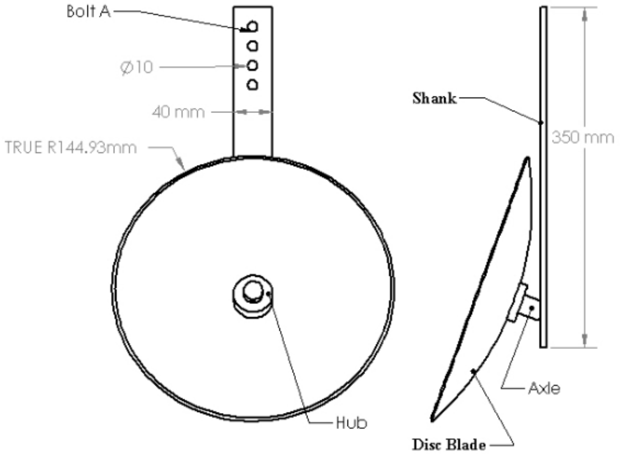

Figure 5. Covering disc.

The diameter of covering and ridging discs [D_d] was calculated using (Eqn. 4) (Sharma, 2010).

$$D_d = \frac{k \times d_p}{\cos\beta} \tag{4}$$

where:- k = a coefficient which varies from 2.50–3.00 for deep tillage (k = 2.5); d_p = 10 cm, β = tilt angle varies from 15° to 25°; It is the angle at which the plane of the cutting edge of the disc is inclined to a vertical line. For a good plough, 25^o of tilt angle was selected,

$$D_d = \frac{k \times d_p}{\cos\beta} = \frac{2.5 \times 10\ cm}{\cos 25^0} \cong 3o\ cm$$

Soil force acting on the discs was calculated using Eqn. 5 (Sharma, 2010).

$$F_d = n[w_c \times d_p \times k_0 \times f.s] \qquad (5)$$

Where, w_c = width of cut, 10 cm; d_p = depth of plow, 10 cm; k_o= specific soil resistance ($k_{o=}$ 5.88 Ncm^{-2}); n = number of discs, 2; f.s = factor of safety, 3.

$$F_d = n\left[w_c \times d_p \times k_o \times f.s\right] = 2[10\ cm \times 10\ cm \times 5.88\ Ncm^{-2} \times 3] = 3528\ N$$

The soil force acting per disc was F_d = 1764 N and the total mass of covering device comprises the masses of shanks, axles, hubs and concave discs, and estimated to be 5.03 kg.

2.3.5. Designing the three - point hitch

In automatic planter, only 25% of the weight of planter is taken by tractor hydraulic system and the remaining 75% is carried by the planter ground wheel (Sharma, 2010). The three-point hitching was made based on the standards for 30 hp tractor (ASAE, 1997). The hitching bars were made of mild steel flat bar 60 mm x 6 mm thick.

2.3.6. Designing the ground wheel

Ground wheels each with 430 mm diameter were manufactured from mild steel flat iron 60 mm x 5 mm. Each wheel had five spokes made from mild steel flat bar 30 mm x 5 mm thick and welded between the rim and hub at 72° intervals (Figure 6).

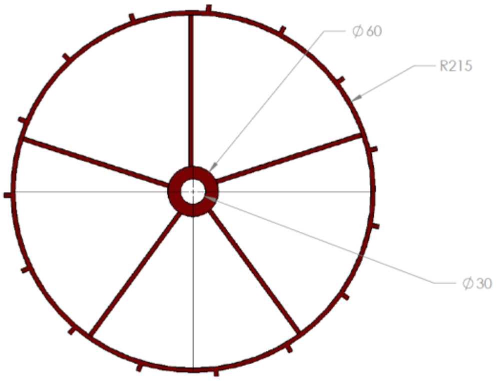

Figure 6. Ground wheel.

2.4. Mass of prototype planter

The total weight of planter was estimated to be 85.93 kg comprising the weight of hopper, frame, metering device, furrow opener, covering devices, three-point hitch and the weight of potato tuber.

2.5. Determining the total draft required by propel planter

The total horizontal draft force [F_D] requirement was calculated using Eqn. 6.

$$F_D = 2F_{RR} + F_0 + F_d \qquad (6)$$

Where, F_{RR} = rolling resistance force, N; F_o = horizontal soil force acting on the furrow opener, N;F_d = horizontal soil force acting on the covering devices, N.

2.5.1. Force of rolling resistance

Torque produced by ground wheel was determined using Eqn.7 (Reece, 2002).

$$F_{RR} = \left(\left(\frac{Z}{D_w}\right)^{0.5} + i\right) \times M_w \qquad (7)$$

$$T = F_{RR} \times r \qquad (8)$$

Where, force of rolling resistance [F_{RR}], Dw= Diameter of wheel, 430 mm; *Z* = wheel sinkage [Z= 0.05 x D_w= 22 mm]; M_w = Weight of the planter on each wheel [0.75 x 843 N]/2= 316.13 N); *i* = gradient of the field,= 5%, where:-T = torque produced on the ground wheel, Nm; r = radius of ground wheel = 215 m

$$F_{RR} = \left(\left(\frac{Z}{D_w}\right)^{0.5} + i\right) \times M_w = \left(\left(\frac{22\ mm}{430\ mm}\right)^{0.5} + 0.05\right) \times 316.13N = 87.31\ N$$

$$T = F_{RR} \times r = 87.13\ N \times 0.215\ m = 18.73\ Nm$$

2.6. Design of Metering Device

A maximum diameter of potato tuber 55 mm was considered and the internal diameter of cup was 1.2 times the maximum major diameter of potato tuber; i.e. 66 mm.

2.6.1. Maximum power available on the metering device

The power transmission was provided from ground wheel through sprockets and chain for seed metering.

No.	Parameters	Measured values	Remark
1	Ground wheel	56 rpm	Calculated value
2	Number of teeth on driving sprocket	38	Standard
3	Number of teeth on driven sprocket	19	Standard
4	Driving sprocket	56 rpm	Calculated value
5	Driven sprocket	115 rpm	Calculated value
6	Velocity ratio	1:2	Assumed
7	Pitch circle diameter P_1	115.35 mm	(Duplex chain-Type B)
8	Operating speed of tractor	4.8 km/hr	Assumed

The power transmitted to metering device was calculated by using (Eqn. 9) (Ryder, 1989).

$$P = \frac{2\times\pi\times N_w\times T}{60} \qquad (9)$$

Where, P = Power transmitted, W, N_w = rpm of ground wheel, assuming 5% wheel slip,
T = Torque on the ground wheel, 18.73 Nm

$$P = \frac{2\times\pi\times N_w\times T}{60} = \frac{2\times 3.14\times 56.\,\text{rpm}\times 18.73\ \text{Nm}}{60} = 110\ \text{W}$$

The design power was calculated using (Eqn. 10) (Khurmi and Gupta, 2005).

$$P_d = P\times K_s \qquad (10)$$

Where, P = rated power, 110 W; P_d = design power, W, K_s = service factor [K_s= K_1 x K_2 x K_3=1.25 x 1.5 x 1=1.88] K_s = service factor [K_s =1.88]

$$P_d = P\times K_s = 110\ \text{W}\times 1.88 = 206.8\ \text{W}$$

Based on the design power [206.8 W] and for 56 rpm the driving sprocket, a 06B-type chain was selected. The total load (or total tension) on the driving side of the chain is the sum of the tangential driving force [F_t], centrifugal force [F_c] and sagging [F_s] whichcan be calculated with (Eqn.12) (Khurmi and Gupta, 2005). Therefore, the total load on the driving side of the chain can be calculated using Eqn.11:

$$F_T = F_t + F_c + F_s \qquad (11)$$

$$F_T = F_t + F_c + F_s = 343.75\ N + 0.076\ N + 4.8\ N = 348.63\ N$$

The spacing between cups (S_c) on the chain was determined using (Eqn.12).

$$S_c = \left(\frac{d_1}{Dw}\right)\times R_s \qquad (12)$$

Where, S_c = spacing between cups, mm; d_1 = diameter of driving sprocket = 115.35 mm;
D_w = diameter of ground wheel = 430 mm; R_s = intra-row spacing = 300 mm

$$S_c = \left(\frac{d_1}{Dw}\right)\times R_s = \left(\frac{115.35\ \text{mm}}{430\ \text{mm}}\right)\times 300\ \text{mm} = 7.62\ \text{cm}$$

Length of chain (L) was calculated using (Eqn.13) (Khurmi and Gupta, 2005).

$$L = \frac{p}{2}(T_1 + T_2) + 2C + \frac{\left[(\frac{p}{2}\cos ec(\frac{180^o}{T_1}) - (\frac{p}{2}\cos ec(\frac{180^o}{T_2})\right]^2}{C} \qquad (13)$$

Where, T_1= number of teeth on the driving sprocket, 38; T_2= number of teeth on the driven sprocket , 19; *C* = center to center distance between sprockets, 0.66m, p = pitch, 9.525 x 10^3 m

$$L = 1.6\ \text{m}$$

The number of cups on the seed metering device was obtained using (Eqn.14).

$$N_c = \frac{L}{S_c} \qquad (14)$$

Where, N_c = number of cups on the metering device; S_c = spacing between cups, m

$$N_c = \frac{L}{S_c} = \frac{1.6\ \text{m}}{0.0762\ \text{m}} = 21\ \text{cups}$$

Thus, 21 equal cups were attached on the chain at interval of 0.0762 m. Since, recommended potato size for ware production was 25 mm up to 55 mm (Lung'aho *et al.*, 2007).

2.6.2. Power Required by Metering Device

The total power required by the metering device during planting operation was calculated using (Eqn. 15, 16 and 17) (Renold, nd).

$$P_c = F_{VCP}\times V_c \qquad (15)$$

$$F_{VCP} = 9.81[(\frac{m_c\times C}{S}) + (m_{ch}\times C) + (\frac{C\times m_t}{S})] + D_f) \qquad (16)$$

$$D_f = \frac{90\times m_t}{S} \qquad (17)$$

Where, -P_c = power required by the metering device, W; F_{vcp}= vertical chain pull load, V_c= 0.32 ms^{-2}, C = 0.66 m, m_c = mass of individual cup (0.13 kg), mass of chain, m_{ch} = 0.74 kgm^{-1}), m_t = mass of tuber on the cup [measured = 0.053 kg], S = 0.0762 m), D_f = dredge factor, N.

$$D_f = \frac{90 \times m_t}{S} = \frac{90 \times 0.05 \text{ kg}}{0.0762 \text{ m}} = 59 \text{ N}$$

$$F_{vcp} = 9.81[(\frac{m_c \times C}{S}) + (m_{ch} \times C) + (\frac{C \times m_t}{S})] + D_f)$$

$$F_{vcp} = 79 \text{ N}$$

This also indicates that the tangential force exceeds the chain pull load, $F_t > F_{vcp}$, indicating that the design was safe. By taking factor of safety [f.s = 3] the total power required by the metering device was,

$$P_c = F_{VCP} \times V_c = 79 \text{ N} \times 0.32 \text{ ms}^{-1} = 25.28 \text{ W}$$

$$P_C = 25.28 \text{ W x } 3(\text{f.s}) = 75.84 \text{ W}$$

2.6.3. Determination of total draft force

The total horizontal draft force [F_D] was calculated using the (Eqn. 18)

$$F_D = 2F_{RR} + F_0 + F_d \quad (18)$$

$$F_D = 2F_{RR} + F_0 + F_d = (2 \times 87.31 \text{ N}) + 2205 \text{ N} + 3528 \text{ N} = 5907.62 \text{ N}$$

2.7. Designing the drive shaft

Forces and bending moment analyzed both in vertical and horizontal plane YX and ZX-plane respectively are as shown in the (Figures 7 and 8).

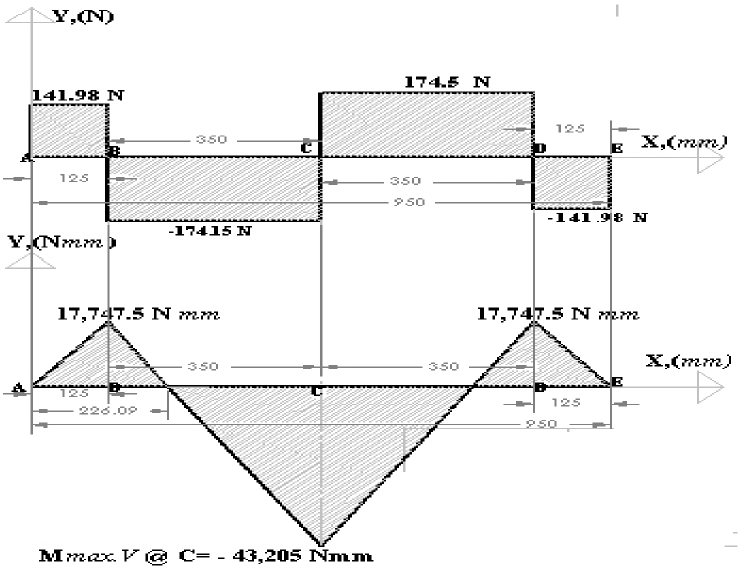

Figure 7. Vertical shear force and bending moment diagram.

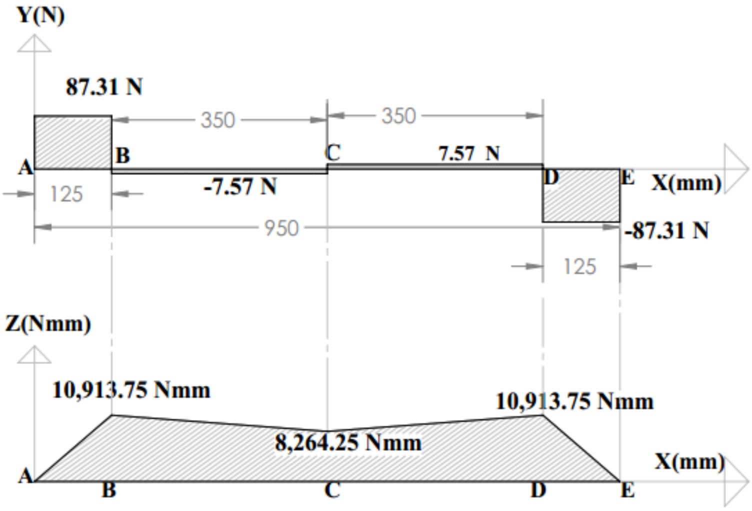

Figure 8. Horizontal shear force and bending moment diagram.

The maximum bending moments on horizontal and vertical planes were found to be 8.264 Nm and 43.20 Nm, respectively and the resultant was 43.99Nm as shown in the (Figure 9).

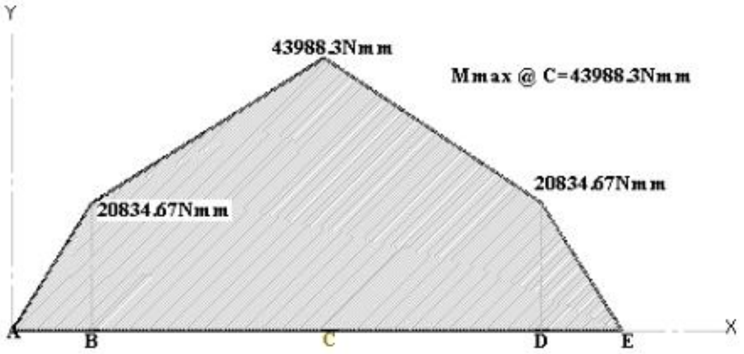

Figure 9. The resultant bending moment.

2.7.1. Determination of the shaft diameter

According to ASME (1995) code, for the shaft with key way the allowable stress should not exceed 40MPa. For this design, allowable shear stress was assumed to be [τ_{all}= 35 MPa] and by taking 25% for keyway consideration [= 0.75 x 35 MPa]. The diameter of the shaft was obtained using the code of ASME (1995) given by the (Eqn. 20);

$$d^3 = \frac{16}{\pi \tau_{allowable}} \sqrt{(K_b M_{max})^2 + (K_t T_{max})^2} \qquad (20)$$

Where, M_{ax} = maximum bending moment, 43.99 Nm; T_{max} = maximum torsional moment, 18.73 Nm; K_b = combined shock applied to bending moment, 2; K_t = combined shock applied to torsion moment, 1.5; $\tau_{allowable}$ = allowable shear stress, 0.75 x 35 MPa= 26 MPa.

From the above calculation, a solid shaft with 30 mm diameter had been selected.

2.8. Power Requirement to Propel the Potato Planter

The assembled prototype potato planter is shown in Figure 10. The total power required to propel the planter was determined using Eqn. 21 (Khurmi and Gupta, 2005).

$$P_T = F_D \times V \qquad 21$$

$$\mathrm{P_T} = \mathrm{F_D} \times \mathrm{V} = 5907.62 \text{ N} \times 1.33 \text{ ms}^{-1} = 7857.13 \text{ W}$$

$$\mathrm{P_T} = \frac{7857.13 \text{ W}}{745.7 \text{ W}} \times 1\text{hp} = 10.54 \text{ hp}$$

Therefore, total power needed to propel prototype potato planter was found to be 10.54 hp.

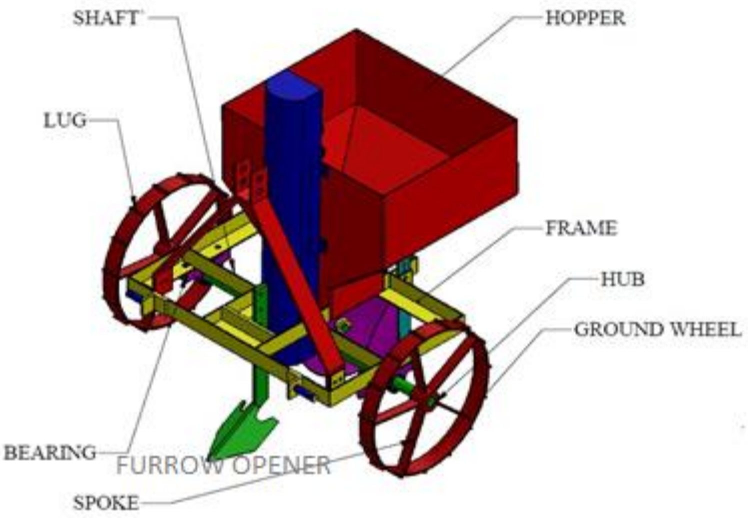

Figure 10: Assembled prototype planter

2.9. Experimental Design

The experiment was laid out as a split-split plot design according to the principle of factorial experiment. The main plot factors were three tuber sizes S_1 [25 to 35 mm], S_2 [35 to 45 mm], and S_3 [45 to 55 mm]. The tuber size categories were determined based on the longitudinal diameter of the tubers and considered as small, medium, and large respectively.

- The sub-plot factors were the three tractor forward speeds V_1 [2.5 kmhr^{-1}], V_2 [3.6 kmhr^{-1}] and V_3 [4.8 kmhr^{-1}]
- The Sub-sub plot factors were three hopper fill levels H_1[25%] , H_2 [50%] and H_3 [75%]

Table 1. Treatment details of the experiment in split-split plot design.

Parameters	Description
Statistical Design	Split-split plot design
Treatment combination	3 x 3 x 3 x 3 = 81
Plot size	3 m x 3 m
Total length of field	42 m
Total width of the field	39 m
Net area	729 m^2
Potato variety	Badhasa
Inter-row spacing	75 cm
Intra-row spacing	30 cm

The size of each experimental plot consisted of five rows accommodating 10 plants per row. The total observation had been 4050 potato tubers.

2.9.1. Statistical Analysis

The data collected were subjected to ANOVA following a procedure appropriate for the design of the experiment using 18th edition Genstat®. Significantly different treatment means were separated using the least significant difference (LSD) test at 5% level of significance.

2.10. Arrangements for testing of the prototype potato planter

A field test was conducted without using the covering device in order to allow measurement between tubers as shown in Figure 11. The prototype potato planter was run over a level track of moist soil surface of 10 m length at the recommended speed of 3.6 km hr^{-1}.

Figure 11 Testing the performance of planter

Percentage external tuber damage was determined using (Eqn. 22) (Kachman and Smith, 1995).

$$\text{Tuber damage } (\%) = \frac{N_d}{N} \times 100 \qquad 22$$

Where, N_d = number of tuber with damage, N = total number of tuber in the observation

The percentage miss index [MISSI %] was calculated using (Eqn. 23) (Kachman and Smith, 1995).

$$\text{MISSI}(\%) = \frac{N_1}{N} \times 100 \qquad 23$$

where:-N_1 = number of spacing's that are greater than 1.5 times the theoretical spacing

Percent multiple index [MULTI %] was calculated using (Eqn. 24) (Kachman and Smith, 1995).

$$\text{MULTI}(\%) = \frac{N_2}{N} \times 100 \qquad 24$$

Where, N_2 = number of spacing's that are less or equal to half the theoretical spacing

The quality of feed index [QFI %] was calculated using (Eqn. 25) (Kachman and Smith, 1995).

$$\mathrm{QFI}(\%) = \frac{\mathrm{N}_3}{\mathrm{N}} \times 100 \qquad 25$$

Where, N_3 = Number of spacing between 0.5 times the theoretical spacing and 1.5 times of the theoretical spacing in the given observations.

Degree of variation [CV %] values was calculated using (Eqn. 26) (Kachman and Smith, 1995).

$$\mathrm{CV}(\%) = \frac{\mathrm{SD}}{\mathrm{M}} \qquad 26$$

Where, SD = standard deviation of the observations, cm; M = mean tuber spacing, cm.
A theoretical field capacity (TFC, hahr^{-1}) was calculated using Eqn. (27) (Kepner *et al.*, 1978).

$$\mathrm{TFC} = \frac{\mathrm{W} \times \mathrm{S}}{10} \qquad 27$$

Where, S = speed of travel, kmhr^{-1}, W= width of the planter, m
The actual or effective field capacity (AFC, hahr^{-1}) was calculated using (Eqn. 28) (Samuel, n.d.)

$$\mathrm{AFC} = \left[\frac{(\mathrm{S} \times \mathrm{W} \times \mathrm{L} \times \mathrm{e})}{((10 \times \mathrm{L}) + (\mathrm{D} \times \mathrm{S} \times \mathrm{W} \times \mathrm{L} \times \mathrm{e}) + (2.778 \times \mathrm{S} \times \mathrm{t}))}\right] \qquad 28$$

Where, L = average length of the field, m;e = effective width of the planter, m*;* D = is the unproductive time, hha^{-1}, t = is the time for a turn at row ends, s.
The field efficiency was calculated using (Eqn. 29) (Kepner *et al.*, 1978).

$$\mathrm{FE}(\%) = \frac{\mathrm{AFC}}{\mathrm{TFC}} \times 100(29)$$

III. Results and Discussions

3.1 Performance of the prototype potato planter

During the field test, the moisture content and the bulk density of the soil were 10.5% and 1.36 mg m^{-3}.The physical properties of the experimental potato seed tubers were measured as shown in Table 2 using a digital vernier caliper and weight balance.

Table 2. Physical properties of potato tubers

Physical properties	Sample	Small size	Medium size	Large size
Major diameter	100	30.00 ± 5.00mm	38.50 ± 5.50mm	50.00 ± 5.00mm
Intermediate diameter	100	24.00 ± 4.00mm	31.00 ± 7.00mm	41.50 ± 6.50mm
Minor diameter	100	22.00 ± 2.00mm	26.00 ± 4.00mm	37.50 ± 7.50mm
Geometric mean	100	24.82 ± 2.99mm	31.62 ± 4.69mm	43.11 ± 5.68mm
Sphercity	100	82.28 ± 12.08%	80.94 ± 8.52%	84.95 ± 4.78%
Av.Tuber weight	1000	20.28gm	30.46gm	51.35gm
Av. Bulk density	1000	360 kg/m^3	440 kg/m^3	590 kg/m^3
Av. repose angle		36.60°	37.50°	37°

3.2 Tuber Damage

Percent tuber damage observed during laboratory tests for tuber size ranges from [25 to 35] mm, [35 to 45] mm and [45 to 55] mm at constant speed was 0.93%, 1.23% and 1.48%, respectively. The highest percent tuber damage was observed at the combination of larger tuber size with full hopper level and tractor speed of 4.8 kmhr^{-1}.

3.3 The Effects of Major Factors on Dependent Variables

ANOVA revealed that tuber size, tractor forward speed and hopper fill level significantly ($P < 0.05$) affected the MISSI [%], MULTI [%], QFI [%] and mean tuber spacing. From (Table 3) it can be seen that the tuber sizes of [45 to 55mm] had the highest MISSI [%] value of 11.72% whereas the least MISSI [%] was observed for small tuber size [25 to 35mm] , which amounted to 4.44%. The highest percent of multiple index of 14.69% was recorded for hopper fill level of 75% and the lowest percent of multiple index was recorded was 5.55% with hopper fill level of 25%. The maximum QFI [%] of 83.83% was recorded for hopper fill level of 25% whereas, the minimum QFI [%] of 80.63% was recorded for hopper fill level of 75%.

Table 3. The effects of main factors on MISSI [%], MULTI [%], QFI [%] and Mean tuber spacing.

Independent Variables		Dependent variables			
	Levels	MISSI [%]^{av}	MULT [%]^{av}	QFI [%]^{av}	Mean Spacing
Tuber Size	S_1 [25– 35] mm	4.44^c	13.58^a	81.98^a	28.24
	S_2 [35– 45] mm	7.90^b	9.88^b	82.22^a	29.04
	S_3 [45 – 55] mm	11.72^a	6.54^c	81.74^a	30.31
LSD (5%)		1.91	1.29	2.63	
Tractor Forward Speed	V_1 [2.5 kmhr^{-1}]	4.81^c	13.45^a	81.73^a	28.21
	V_2 [3.6 kmhr^{-1}]	7.53^b	10.12^b	82.35^a	28.93
	V_3 [4.8 kmhr^{-1}]	11.71^a	6.42^c	81.87^a	30.45
LSD (5%)		1.38	1.11	1.85	
Hopper Fill Level	H_1 [25%]	10.62^a	5.55^c	83.83^a	30.16
	H_2 [50%]	8.76^b	9.75^b	81.48^b	29.16
	H_3 [75%]	4.68^c	14.69^a	80.63^b	28.27
LSD (5%)		1.09	1.12	1.60	

Note: av = average, MISSI= Miss Index, QFI= Quality of Feed Index, MULTI= Multiple Index, LSD [%] = Percent of Least Significant Difference, S1 = small sized tuber, S2 = medium sized tuber, S3 = large sized tuber, V1 = low tractor speed, V2 = medium tractor speed, V3 = high tractor speed, H1 = hopper fill level, 25%, H2= hopper fill level, 50%, H3 = hopper fill level, 75%. *Means followed by the same letter with in the same column are not significantly different at 5% level of significance while, means followed by different letters within each column are statistically different at 5% level of significance.

3.3.1 Mean Tuber Spacing

ANOVA revealed that tuber size, tractor forward speed and hopper fill level significantly ($P < 0.05$) affected the mean tuber spacing. The interaction of tuber size and tractor forward speed; tuber size and hopper fill level, and tuber size, tractor forward speed and hopper fill level had significant ($P < 0.05$) effects on mean tuber spacing. While the interaction of tractor forward speed and hopper fill level had no significant ($P > 0.05$) effect on mean tuber spacing. The average mean tuber spacing recorded during the field test was 29.20 cm (Table 3).

3.3.2 Tuber Miss Index (%)

The results revealed that tuber size, tractor forward speed and hopper fill level significantly ($P < 0.05$) affected the tuber multiple index. The interactions of [Tractor forward speed x Tuber size], [Tractor forward speed x Hopper fill level] had significant effect ($p < 0.05$) on tuber miss index. However, the interactions of [Tuber size x Hoper fill level] and that of [Tuber size x Tractor forward speed x Hopper fill level] had no significant effects ($P > 0.05$) on tuber miss index.

Table 4. The interaction of two factors on the values of MISSI [%].

Parameter	Source of Variation			
		Interaction [V*S] Tuber Size Levels		
	Tractor Speed	S_1 [25-35] mm	S_2 [35-45] mm	S_3 [45-55] mm
MISS (%)	V_1 [2.5 kmhr^{-1}]	1.85^c	5.18^c	7.40^c
	V_2 [3.6 kmhr^{-1}]	5.18^b	7.77^b	9.63^c
	V_3 [4.8 kmhr^{-1}]	6.30^b	10.74^a	18.11^b
	LSD [5%]	2.39		

Note: av = average, MISSI= Miss Index, LSD[%] = Percent of Least Significant Difference, S1 = small sized tuber, S2 = medium sized tuber , S3 = large sized tuber, V1 = low tractor speed, V2 = medium tractor speed, V3 = high tractor speed, *Means followed by the same letter with in the same column are not significantly different at 5% level of significance while; *Means followed by different letters within each column are statistically different at 5% level of significance.

The lowest MISSI [%] was found to be 1.85% for the interactionof tractor speed of2.5 kmhr^{-1} and tuber size range of [25 to 35] mm. However, the highest MISSI [%]was found to be 18.11 % for the interaction of tractor speed of 4.80 km hr^{-1} and tuber size range of [45 to 55] mm (Table 4). From the regression equations as shown in **Error! Not a valid bookmark self-reference.** 5, it can be seen that MISSI (%) increased with increasing tractor forward speed and decreased with increasing level of hopper fill.

Table 5. Multiple linear regression equations for MISSI [%] [Y].

Tuber Size	Regression Equation	R^2 Value
S_1 [25 – 35] mm	Y = 1.55 + 1.92V - 0.08H	0.91
S_2 [35 – 45] mm	Y = 5.42 + 2.43V - 0.13H	0.83
S_3 [45 – 55] mm	Y = 2.11 + 4.70V - 0.15H	0.87

Note:R^2 = coefficient of multiple regression; Y = dependent variable (Miss Index); V = Independent variable [Speed of operation, kmhr-1], H = Hopper fill level [%], S1 = small sized tuber, S2 = medium sized tuber, S3 = large sized tuber.

3.3.3 The tuber multiple index (%)

The ANOVA revealed that tuber size, tractor forward speed and hopper fill level significantly ($P < 0.05$) affected the tuber multiple index. The interactions of tubersize and tractor forward speed; and tractor forward speed and hopper fill level had significant ($P < 0.05$) effect on tuber multiple index. However, the highest MULTI [%] was found to be 18.89 % for the interaction of tractor speed of 2.5 kmhr^{-1} and hopper fill level of 75% (Figure 12).

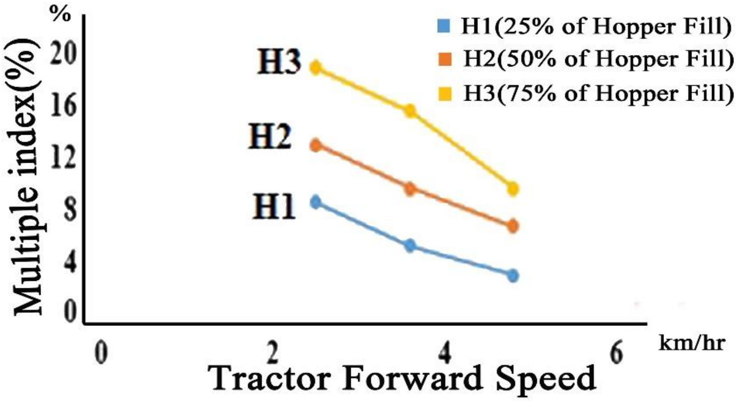

Figure 12. The interaction of V x H on multiple index.

In Table 6, it can be seen that the lowest MULTI [%] was found to be 4.07% for the interaction of tractor speed of 4.8 kmhr^{-1} and tuber size range of 45 to 55 mm.

Table 6. The interaction of two factors on the values of MULTI [%].

Parameter	Source of Variation			
	Interaction(S*V)	Tuber Size Levels		
	Tractor Speed	S_1 [25 – 35] mm	S_2 [35 – 45] mm	S_3 [45 – 55] mm
MULTI (%)	V_1 [2.5 kmhr^{-1}]	18.52^a	13.70^a	8.52^a
	V_2 [3.6 kmhr^{-1}]	12.96^b	10.00^b	6.67^b
	V_3 [4.8 kmhr^{-1}]	8.88^c	6.66^c	4.07^c
	LSD [5%]	1.12		

Note: av = average, MULTI [%]= Multiple Index, LSD [%] = Percent of Least Significant Difference, S1 = small sized tuber, S2 = medium sized tuber , S3 = large sized tuber, V1 = low tractor speed, V2 = medium tractor speed, V3 = high tractor speed, *Means followed by the same letter with in the same column are not significantly different at 5% level of significance while; *Means followed by different letters within each column are statistically different at 5% level of significance.

The results of regression analysis show that tractor forward speed has negative effect on MULTI [%] and MULTI [%] and has a direct relationship with hopper fill level (Table 7).

Table 7. Multiple linear regression equations for MULTI [%] [Y].

Tuber Size	Regression Equation	R^2 Value
S_1 [25 – 35] mm	Y = 18.25 - 4.35V + 0.22H	0.93
S_2 [35 – 45] mm	Y= 10.57 - 2.74V + 0.19H	0.96
S_3 [45 – 55] mm	Y = 7.11 - 2.09V + 0.14H	0.99

Note:R2 = coefficient of multiple regression; Y = dependent variable [Miss Index]; V = Independent variable [Speed of operation, kmhr^{-1}], H = Hopper fill level [%],S1 = small sized tuber , S2 = medium sized tuber , S3 = large sized tuber.

3.3.4 The quality of feed index [%]

ANOVA revealed that hopper fill level, the interaction of [Tuber size x Forward speed], the interaction of [Tuber size and Hopper fill level]; and the interaction of [Tractor forward speed x Hopper fill level] had significant effect ($P < 0.05$) on tuber quality of feed index.

Table 8. The interaction of two factors on the values of QFI [%].

Parameter	Source of Variation			
	Interaction [S*V]	Tuber Size Levels		
	Tractor Speed	S_1 [25 – 35] mm	S_2 [35 – 45] mm	S_3 [45 – 55] mm
	V_1 [2.5 kmhr^{-1}]	79.67^a	81.85^a	83.70^a
	V_2 [3.6 kmhr^{-1}]	81.11^a	82.22^a	83.70^a
	V_3 [4.8 kmhr^{-1}]	85.18^b	83.33^a	77.77^b
	LSD (5%)	3.20		
	Interaction(S*H)		Tuber Size	
	Hopper Fill Level	S_1 [25–35] mm	S_2 [35–45] mm	S_3 [45–55] mm
	H_1 [25%]	85.56^a	84.07^a	81.85^a
	H_2 [50%]	81.85^b	82.22^a	81.11^a
	H_3 [75%]	78.51^c	81.11^a	82.22^a
	LSD [5%]	2.77		

Note: av = average, QFI = Quality of Feed Index, LSD[%] = Percent of Least Significant Difference, S1 = small sized tuber, S2 = medium sized tuber , S3 = large sized tuber, V1 = low tractor speed, V2 = medium tractor speed, V3 = high tractor speed, H1 = hopper fill level, 25% , H2 = hopper fill level, 50%, H3 = hopper fill level, 75%. *Means followed by the same letter with in the same column are not significantly different at 5% level of significance while, means followed by different letters within each column are statistically different at 5% level of significance.

The maximum quality tuber feed index recorded for the interactions of tuber size range of [25 to 35 mm]and hopper fill level of [25%] was 85.56% (Table 8). However, the lowest percent of quality of tuber feed index was recorded for the interactions of tuber size range of [45 to 55mm] and tractor forward speed of 4.8 kmhr^{-1} were 77.77%. The results of regression analysis establish relationships between percent tuber quality of feed index and forward speeds and hopper fill levels (Table 9).

Table 9. Multiple linear regression equations for QFI [%] [Y] over three tuber sizes.

Tuber Size	Regression Equation	R^2 Value
S_1 [25 – 35] mm	Y = 80.18 + 2.43V - 0.14H	0.74
S_2 [35 – 45] mm	Y = 83.078 + 0.65V - 0.06H	0.48
S_3 [45 – 55] mm	Y = 90.85 - 2.61V + 0.01H	0.63

Note: R^2 = coefficient of multiple regression; Y = dependent variable [Miss Index]; V = Independent variable [Speed of operation, kmhr^{-1}], H = Hopper fill level (%), S1 = small sized tuber, S2 = medium sized tuber, S3 = large sized tuber.

3.3.5 Field capacity and field efficiency determination

The highest theoretical field capacity was 0.34 ha hr^{-1} obtained at 4.8 km hr^{-1} forward speed while the lowest value of theoretical field capacity was reported to be 0.18 ha hr^{-1} at 2.5 km hr^{-1}. Field efficiency is the ratio of actual field capacity to the effective filed capacity. The maximum efficiency of prototype observed was 72.22% for 2.5 km hr^{-1} and the minimum value recorded was 56% for 4.8 km hr^{-1} of tractor forward speed.

IV. Conclusions and Recommendations

This study was mainly initiated to design, produce, and test the performance of a prototype tractor-mounted potato tuber planter. The results of ANOVA revealed that the mean planting space recorded was 29.20 cm; this value is close to the recommended planting space of 30 cm. The highest percentage of mechanical tuber damage was found to be 1.48% for the largest tuber size category and high speed. Thus, the prototype planter performed the intended function of planting potato tuber at the required row to row and plant to plant spacing satisfactorily. From the analysis, it can be concluded that the tuber spacing uniformity decreased with varying tuber size, tractor forward speed, and hopper fill. The results obtained from the field tests showed that the planter functioned properly and effectively by metering single tubers with minimum damage and had the planting capacity of 0.19 ha hr^{-1}. The highest actual field capacity was found to be 0.19 ha hr^{-1} at 4.8 km hr^{-1}. The average mean tuber spacing varied with different tuber sizes, tractor forward speed and hopper fill level. However, in this study a tuber size of [35 to 45] mm, forward speed of 3.6 km hr^{-1} and hopper fill level of 50% gave optimum planting space of 29.04 cm, 28.93 cm, and 29.16 cm respectively. To make the planter popular, adaptable and usable among the farmers more efforts must be made. Since this machine is a single row planter, it is better to make multi-row planters in order to increase the efficiency. Graded tuber seeds should be used to meet high efficiency and uniformity in spacing In future research, emphasis should be given to such projects in order to mitigate farmers' drudgery in planting potatoes.

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