Development of Tractor Drawn Single Row Irish Potato Planter with Fertilizer Applicator

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ABSTRACT

Irish potato planting in Nigeria has been accomplished by traditional method of planting potato tubers on the field, which is labor intensive, time consuming and produce low yields of potato per hectare. This is due to lack of suitable row planting machine. In order to solve the above problem, this study aimed to develop a prototype of Irish potato planter with fertilizer applicator which is capable of planting potato tubers in rows at desired depth and spacing and applying fertilizer simultaneously. The developed tractor drawn single row Irish potato planter with fertilizer applicator consists of main frame, tuber hopper, fertilizer hopper, cup feed seed metering mechanism, shovel type furrow opener, ground wheel, seed tube and spring loaded furrow cover. This machine has an edge over existing irish potato planting machine with additional of spring loaded furrow opener, rubber coated metering cup to avoid injuring of the tubers and incorporation of fertilizer applicator which saves the farmer additional cost of applying fertilizer after planting. The performances of tractor drawn single row Irish potato planter with fertilizer applicator was evaluated in the laboratory and field at a tractor walking speed of 3.5 km/hr and moisture content of 13.41%. At the tractor speed of 3.5 km/hr when the moisture content was 13.41%; the average depth of planting was 133.3 mm, the average intra row spacing of the planted potato seedling was 291.2 mm, the average number of potato per drop of the planted potato seedling was 1, quantity of fertilizer per drop was 10.6 g, the average percentage of missing was 2.46%, the average height of ridge was 285.7 mm, the average depth of fertilizer dropping was 133.3 mm, the average fuel consumption was 10.3 l/ha and the average field efficiency was 75.04%. The implement is recommended for small scale and medium scale farmers.

Keywords: Metering device, Fertilizer applicator, Irish potato, furrow opener, furrow coverer

INTRODUCTION

The agricultural sector plays a pivotal role in ensuring global food security and sustaining livelihoods. The shortage of food production in Nigeria and increasing demand for efficient and sustainable farming practices, there is a growing need to innovate agricultural machinery to enhance productivity while minimizing resource consumption and environmental impact (Muhammad, 2018). Potato cultivation stands as one of the significant contributors to the world's food supply, with potatoes being a staple crop in many regions. Traditional methods of potato planting and fertilizer application often involve manual labour, leading to inefficiencies, increase labour costs, and inconsistent results (Anderson, 2008)

The advent of mechanized farming has revolutionized agricultural practices, offering opportunities to streamline operations, increase yields, and optimize resource utilization. The development of tractor drawn single row Irish potato planter with fertilizer applicator has emerged as a key technological innovation, enabling farmers to achieve precision planting and fertilizer application with minimal manual intervention (Okunade and Ibrahim, 2011). However, existing potato planters lack the sophistication needed to optimize planting depth, spacing, and fertilizer distribution for maximum yield potential. Furthermore, the integration of fertilizer application functionality into potato planters presents additional advantage in terms of potato production (Iritani et al., 2002).

In many countries today, the potato is an important commercial crop. A brief examination of potato output in several African countries finds Egypt as Africa's leading producer, followed by Malawi. Despite Nigeria being the fourth largest producer of potatoes in Sub-Saharan Africa and also seventh largest producer of potatoes in Africa (Ugonna et al., 2013). Nigeria being Africa most populous country and pride of Africa, there is need for Nigeria to take number one position in potato production in Africa and this can be achieved through mechanization of potato production.

The manual planting of Irish potatoes is labor-intensive, time-consuming, and inefficient, especially when it comes to large-scale farming. Traditional methods involve significant human effort for digging, placing seeds, and covering the soil, all of which can result in inconsistent seed spacing, uneven planting depths, and reduced yields. Furthermore, the simultaneous application of fertilizers manually is imprecise and difficult to synchronize with the planting process. These inefficiencies lead to low productivity, wastage of inputs, and increased labor costs, which significantly affect the profitability of potato farming. In Nigeria, small-scale farmers and medium-scale farmers often lack access to Irish potato planter designed for precision agriculture.

The existing Irish potato planter are imported. Many are either too expensive or not available for Nigeria Irish potato farmers. They lack the technology to adapt different topography of Nigeria farm. Most of the existing one are not integrated with the fertilizer applicator which requires separate operations, which increases time and cost. Additionally, current Irish potato planter metering mechanism are made of iron and mild steel material which always causes injury to the planted tuber resulting to low germination.

This research seeks to introduce a cheap, fast and convenient method of potato planting for farmers. The designed planter would result in high accuracy of crop spacing and correct estimations for plants population per hectare of land.

The aim of this study is to develop a tractor drawn single row Irish potato planter with fertilizer applicator

MATERIALS AND METHODS

Design Considerations/criteria of Potato Planter with Fertilizer Applicator

The development of a tractor drawn single row potato planter with fertilizer applicator required the study of different parameters of the machine component and their inter relationship. The planter was designed to fit the standard three-point hitch system, making it compatible with tractors commonly used by small- and medium-scale farmers. The machine's weight was evenly distributed to prevent undue strain on the tractor, and a balance between machine load and tractor stability was considered. The metering mechanism was designed to handle varying tuber sizes of Irish potatoes, ensuring damage-free delivery. Adjustable controls was included to set the spacing (commonly 25 cm - 30 cm) between planted tubers to suit different field conditions and crop management practices. The mechanism must prevent jamming and allow smooth flow even with irregular-shaped tubers.

The furrow opener was designed to ensure precise planting depth (typically 10cm - 15 cm), adjustable to different soil textures and moisture levels. It was designed to ensure it is capable of working in tilled or semi-tilled soils. The furrow coverer was designed to cover the seeds adequately with soil and capable of working at different topography because of its spring loaded design, avoiding compaction but ensuring good seed-soil contact for optimal germination. The integrated fertilizer applicator was designed to deliver the correct amount of fertilizer at the time of planting, ensuring both seeds and fertilizer are placed at optimum proximity to promote early growth and minimize nutrient loss. The machine was designed to have a simple control system that requires minimal training for the operator. The overall design was cost-effective, ensuring that it is affordable for small- and medium-scale farmers. The machine was constructed using locally available materials and manufacturing processes where possible to reduce costs. The planter and operator safety was considered in the design.

Materials Selection

According to Sagni (2019), the selection of materials was based on durability, cost and availability, strength and rigidity, weight and friction as shown in Table 2.1.

Table 2.1 Materials needed for the fabrication of tractor drawn single row potato planter with fertilizer applicator.

S/N	Components	Material /specifications
1	Main frame	2” × 2” × 3 mm mild steel square pipe
2	Tuber hopper	2.5 mm mild steel sheet metal
3	Fertilizer hopper	Plastic material
4	Tuber tube	mild steel sheet metal
5	Chain and sprocket	Steel
6	Ground wheel	1” × 3 mm mild steel flat bar
7	Cups	Plastic
8	Fertilizer fluted roller	Teflon material
9	Three point hitch system	2” × 10 mm mild steel flat bar
10	Furrow opener	3 mm mild steel sheet metal
11	Furrow coverer	3 mm mild steel sheet metal
12	Seed tube	Rubber tube/ plastic

Source: Sagni, (2019)

Machine Description

The designed tractor drawn single row potato planter with fertilizer applicator as shown in Figures 3.9 consists of main frame, tubers metering mechanism, fertilizer metering mechanism, tubers hopper, fertilizer hopper, tuber tube, ground wheels, furrow openers and furrow coverer. The single-row potato planter has a general specifications with overall dimension of (1100 mm×1015 mm×800 mm), space between plants 20 cm-30 cm, space between furrow tops 50 cm-80 cm, connecting of 3 point linkage of category one. The tubers metering device of the tractor drawn single row potato planter with fertilizer applicator is a spoon type vertical drive which, consists of 12 spoons and chain with equivalent spoon distance of 12 cm. Tuber packing is greatly affected by the relationship between the cell size and thickness of the tuber (Yogesh and Shambhu, 2022). So, the chain-feed of the potato planter was developed to plant tuber pieces by modified spoons size. These spoons diameters range were 25-45 mm to suit the cut tubers, according to the measured physical properties by (El-Ghobashy et al., 2014). The spoons with chain is passed from the hopper bottom to top and driven by ground wheels. The tubers hopper having a capacity of 140kg was designed to easily feed the cut tubers and conveys it from the hopper-through the metering device to the furrow opener by tuber tube. The dropping of tuber-stakes was as a result of gravitational force. The transmission system was designed to control the number

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of spoons per revolution using different chain-sprocket transmission to prevent slipping and also to transmit the motion from the planter wheel (D = 450 mm) to the feeding device. Furrow opener (shoe shape type) is fixed in the front beam to adjust and control the depth of the furrow. The furrow coverer consists of two disc units located at the back end.

Design-Related Physical and Engineering Properties of Irish Potato

The physical properties of tubers are important factors for the design of potato planter. Most of the potato varieties selected for the study were classified as small, medium and large variety based on the physical properties of tubers namely; geometric diameter, bulk density and angle of repose etc. (Sagni, 2019). Saleh and Awolola (2022), reported some design-related properties of Irish potatoes commonly grown in Nigeria which was useful in designing of the Irish potato planter and is tabulated in Table 2.2 and 2.3

Table 2.2: Design-related properties of Nicola Irish potato variety

VARIABLE	UNITS	NUMBER OF SAMPLE (N)	MEAN	STANDARD DEVIATION (SD)	COEFFICIENT OF VARIATION (CV) (%)
Length	mm	100	66.5	10.2	15.3
Width	mm	100	37.3	3.3	8.9
Thickness	mm	100	32.4	3.8	11.7
Arithmetic mean diameter	mm	100	45.4	4.4	9.7
Geometric mean diameter	mm	100	43.0	3.8	8.8
Sphericity	∅	100	0.7	0.1	14.3
Roundness		100	0.6	0.1	16.7
Surface area	mm^2	100	5854.8	1022.5	17.5
Volume	mm^3	100	42606.8	11204.4	26.3
Bulk density	kg/m^3	3	0.51	0.02	3.9
Solid density	kg/m^3	3	1.0	0.12	12
Porosity	%	3	48.8	4.8	9.8
Thousand kernel weight	G	5	55872.02	1746.075	3.13
Moisture content	%	3	76.3	8.5	11.14
Hardness	HV	5	1.52	0.11	7.2
Angle of repose	°	3	27.2	1.72	6.3
Coeffiecient of friction	μ	5	0.27	0.02	7.4

Source: Saleh and Awolola, (2022).

Table 2.3: Design-Related Properties of Diamant Irish Potato Variety

VARIABLE	UNITS	NUMBER OF SAMPLE (N)	MEAN	STANDARD DEVIATION (SD)	COEFFICIENT OF VARIATION (CV) (%)
Length	Mm	100	57.4	9.5	16.6
Width	Mm	100	35.2	4.8	13.6
Thickness	Mm	100	31.7	3.8	11.9
Arithmetic mean diameter	Mm	100	41.4	4.5	10.9
Geometric mean diameter	Mm	100	39.8	4.1	10.3
Sphericity	∅	100	0.7	0.1	14.3
Roundness		100	0.7	0.1	14.3
Surface area	mm^2	100	5031.1	1030.5	20.5
Volume	mm^3	100	34081.9	10501.9	30.
Bulk density	kg/m^3	3	0.55	0.03	5.5
Solid density	kg/m^3	3	0.99	0.05	5.1
Porosity	%	3	44.6	5.5	12.3
Thousand kernel weight	G	5	40233.9	1339.5	3.3
Moisture content	%	3	85.9	3.01	3.5
Hardness	HV	5	1.7	0.14	8.2
Angle of repose	O	5	26.4	1.2	4.6
Coefficient of friction	μ	5	0.26	0.012	4.6

Source: Saleh and Awolola, (2022).

Design Calculations

Main frame design and selection

To give the necessary strength and rigidity, withstand all forces and types of loads acting on it during operation, a mild steel square section frame measuring 50 mm × 50 mm × 3 mm thick (L×W×T) was utilized as shown in Figure 2.1. Axel, which also held the wheel, chain, sprockets, and two discs (ridger), supported the entire weight of the seed and fertilizer hoppers.

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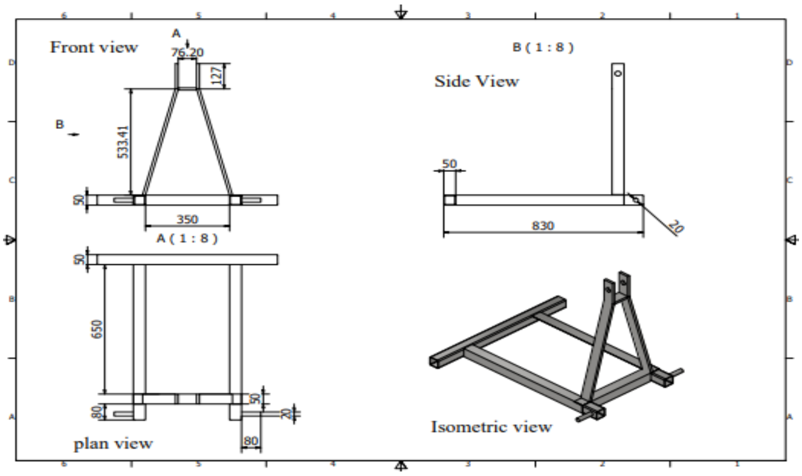

Figure 2.1: Main frame design (All dimensions in mm)

Tuber hopper design, selection, and fabrication

Mild steel cut sheets were used to make the hopper because of their ability to support heavier loads. The physical characteristics of tubers have been noted to be round, oblong, and long-oblong in size. The average bulk density of the seed was used to calculate the hopper's volume. All of the tuber shapes—round, oblong, and long oblong seeds—had angles of repose of 27.6, 33.2, and 42.6 degrees. As a result, the machine's hopper was designed to make it simple for potatoes to slide from the hopper to the metering cups.

Volume and capacity of tuber hopper

The tubers hopper has the combination of rectangular box and trapezium shape as shown in Figure. 2.2. According to Yogesh and Shambhu (2022), to work out the volume of the entire hopper, the volume of both rectangular shape box and trapezium shape box as shown in Equation 2.1 and 2.2 were taken into consideration.

$V = a \times b \times h$ ` 2.1

Where,

V = Volume of upper rectangular box (cm^3).

a = length (cm)

b = width (cm)

h = height of the rectangle (cm)

$70 \times 50 \times 25 = 96250\ cm^3$

Volume of trapezoidal box (m3) = $\frac{(Xt+Xb)}{2} \times Y \times Z$ 2.2

Where

Xt = dimension’s top width (cm)

Xb = dimension’s bottom width (cm)

Y = Vertical dimension (up-down) (cm)

Z = Back side lower width of the hopper (cm)

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Volume of lower trapezoidal box = (70+10)/2×46.6×22 = 40 × 46.6 × 22 = 41008 cm^3

Entire volume of hopper (m^3) = 96250 + 41008 = 137258 cm^3 or 0. 137258 m^3

According to Gachanja, (2019) the volume of full-scale equipment as shown in equation 2.3 was adopted.

Volume of full-scale equipment = $V_t \times 10$ 2.3

Where

V_t = Entire volume of hopper

The volume of full-scale equipment = 0. 137258× 10 = 1.373 m^3

Gachanja, (2019) reported that potato occupation space is 3/4 of total volume as shown in Equation 2.4.

Volume of potato space (Vpc) = 3/4 V_t 2.4

= 3/4 × 0. 137258 = 0.103 m^3

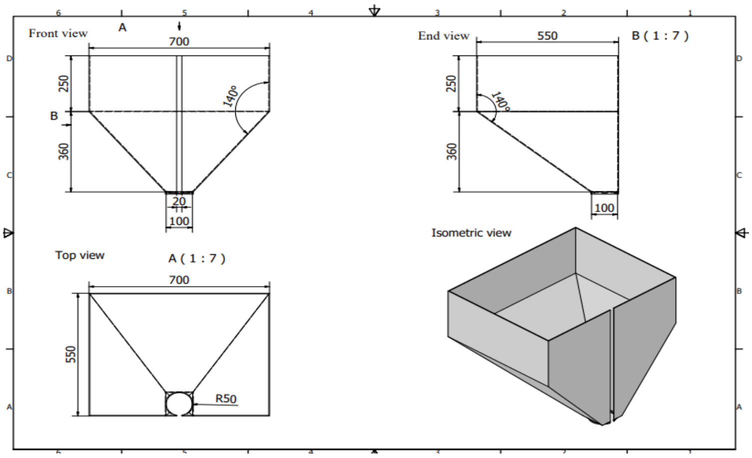

Figure 2.2 Tuber hopper design (All dimensions in mm)

Weight of Potatoes

According to Gachanja, (2019) the radius of potatoes is about 3 cm while the weight of one potato seedling ranges from 15 gram upwards. Stroud, (2003) reported that the volume per potato (V_p) is given by Equation 2.5;

$V_p = 4/3\ \pi R^3$ 2.5

Where V_p = volume per potato

R = radius of the potato

$V = 4/3 \times \pi \times 3^3 = 113.1\ cm^3$

Since, 1 m^3 = 1 × 10^6 cm^3

Volume of potato (V_p) = $1.131\times10^{-4}\ m^3$

Gachanja, (2019) reported that number of potatoes to fit in the tuber hopper is given using Equation 2.6

$(Np) = \frac{Vpc}{Vp}$ 2.6

Where

Vpc = Volume of potato space

Vp = Volume of potato

Np = 0.103 m^3/1.131×10^{-4} = 911potatoes

Gachanja, (2019) reported that total weight of potato in the tuber hopper (Tw) is given in equation 2.7

Tw = weight of 1 potato × Np 2.7

= 15 g × 911 =13665 g

Since, 1000g =1 kg

So, Tw = 14 kg

Total weight in the full-scale equipment = 14 kg × 10

=140 kg

Thickness of hopper

According Malik et al., (2017), the thickness of seed box is given by using the expression in Equation 2.8

$$ts = \frac{\sqrt[3]{3\times\rho\times a2\times h2}}{4\times a\times bs} \quad 2.8$$

Where

ts = thickness of seed hopper, cm;

ρ = bulk density of potato seeds, (930 kg/m^3)

a = bottom width of seed box, cm (10 cm);

h = height of seed box, cm (68 cm); and

bs = bending stress, kg/cm^2 (let, 1000 kg/cm^2)

$$\text{So, } ts = \frac{\sqrt[3]{3 \times 930 \times 102 \times 682}}{4 \times 10 \times 100}$$

= 0.272 cm ≈ 2.7 mm

3 mm adopted base on availability in the market.

Design of fertilizer system

It has three components i.e., fertilizer hopper, adjustment lever and fluted roller.

Fertilizer hopper

The primary fertilizer hopper was rectangular in shape whereas the secondary fertilizer hopper was frustum of a pyramid as shown in Figure 2.3. According to Yogesh and Shambhu (2022), the volume of rectangular box and the frustum of a pyramid is express in Equation 2.1 and 2.9 respectively as.

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$30 \times 20 \times 30 = 18000$ cm^3

Volume of frustum of a pyramid = $(1/3) \times h\ (A + \sqrt{(A \ x \ B)} + B)$ 2.9

Where,

A = Area of top base (cm^2)

B = Area of the bottom base (cm^2)

h = is height of the frustum (cm)

Volume of frustum of a pyramid = $(1/3) \times 20(600 + \sqrt{(600 \ x \ 325)} + 325) = 9110.586955$cm^3

Complete volume of box = 18000 + 9110.586955 = 27110.58696 cm^3

Now,

According to Yogesh and Shambhu (2022), bulk density of a fertilizer (DAP) in kg/m^3 is given in Equation 3.10

(DAP) in kg/m3 = M/V 2.10

1150 kg/m3 = M/.012936m3 or M = 1150×0.0271 = 31.177 ≈ 31 kg

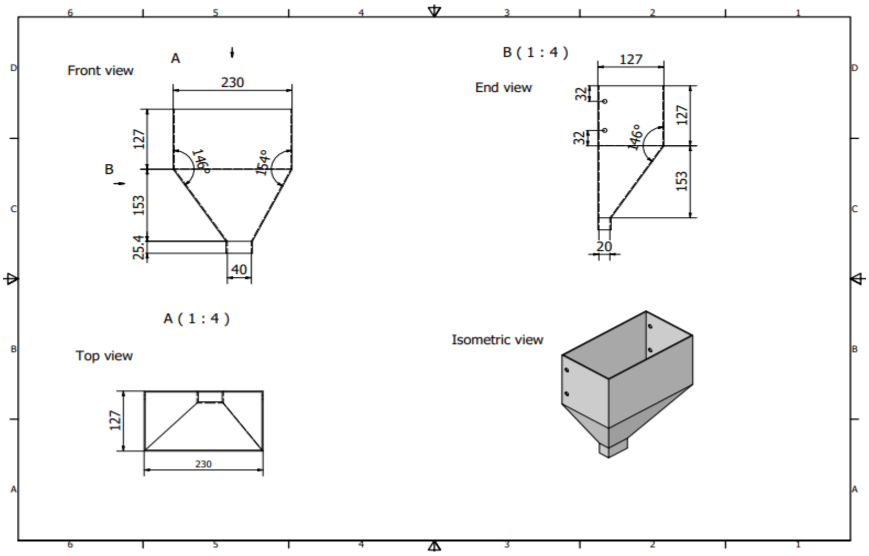

Figure 2.3: Fertilizer hopper design (All dimensions in mm)

Fertilizer adjustment lever and fluted roller

Beneath the secondary fertilizer box, a fluted roller was welded. The fluted roller cylindrical gear's pitch length measured 10.8 mm. A threaded type nut is attached, and it may be rotated in two directions: clockwise to tighten the grooves for a lower fertilizer percentage, and counterclockwise to release the grooves for a bigger fertilizer application.

Design and fabrication of power transmission wheel (drive wheel)

Yogesh and Shambhu (2022) reported that diameter of power transmission wheels as 22.5 cm to 40 cm for bullock driven planter and 40 cm to 60 cm for tractor driven planter. In order to get the desired number of cups and plant spacing, 450 mm diameter of power transmission wheel as shown in Figure 2.4 was taken in the design. The dimension of rim, hub and number of pegs were decided as follows:

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Rim design

Yogesh and Shambhu (2022) reported that the recommended values of 50 mm to 100 mm rim width of ground wheel is for planter application. Rim width of ground wheel was chosen as 100 mm for the design. Thickness of the peg (lugs) and rim was designed on similar ratio. The thickness of rim (T) was calculated using the expression in equation 2.11 as provided by Yogesh and Shambhu (2022).

$$T\ (mm) = (D\ (mm)/200) + 3.175 \qquad 2.11$$

$$(450/200) + 3.175 = 5.425 \approx 5\ mm$$

Hub design

The inner diameter of hub of the drive wheel was taken equal to the diameter of the shaft i.e., 20 mm. Two pillow type bearing hubs were provided and fitted on the main frame to support both the end of the shaft.

Peg (lugs) design

On the periphery of ground wheel 13 pegs of length 22 mm, width of 100 mm were provided to improve lugging ability and to avoid slippage of ground wheel during operation. Thickness of the pegs was 3 mm.

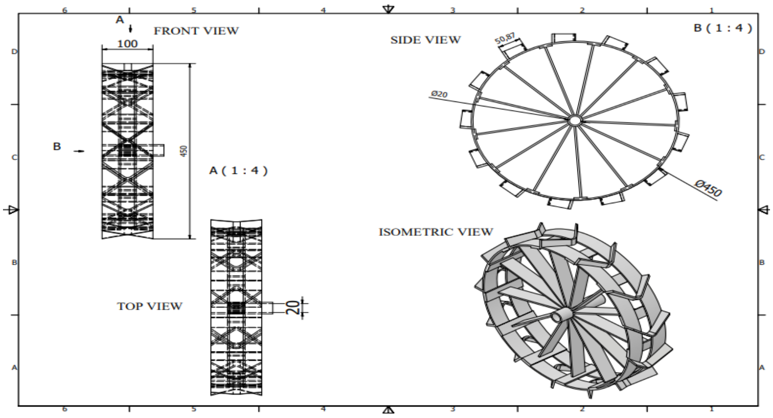

Figure 2.4: Power transmission wheel (All dimensions in mm)

Fabrication of furrow opener

According to Yogesh and Shambhu (2022), the shoe type furrow opener as shown in Figure 2.5 provided wider furrow and offers low draught, this type was selected and used in the present machine, the mild steel shoe type furrow opener was fabricated to penetrates the soil and for making furrow. Nut and bolt were used to fasten the device to the front side of the machine frame. Shoe angles of the furrow opener adopted was 120°.

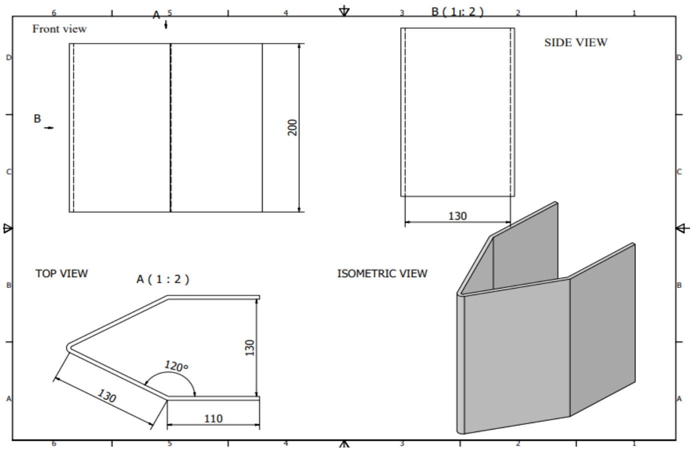

Figure 2.5: Shoe type furrow opener (All dimensions in mm)

Furrow coverer selection and fabrication

Two discs, preferably made of mild steel sheet, were joined to the back side of the main frame to form the furrow coverer as shown in Figure 2.6. The diameter, thickness, and concavity of the discs were 280 mm, 300 mm, and 3 mm, respectively. It is easily changeable.

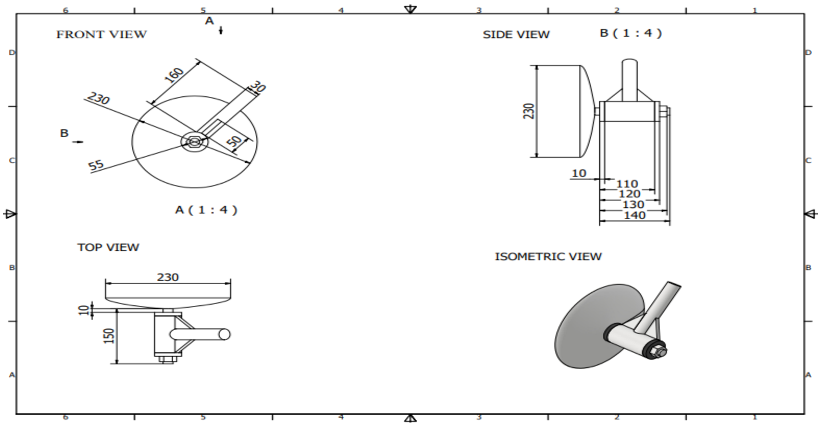

Figure 2.6: Furrow coverer (All dimension in mm)

Bearing selection

For the metering mechanism, four steel ball bearings were utilized. The metering system's upper shaft is fastened to a ball bearing on one side and a bushing on the other. They enable the transportation of a compressive load with less friction and wear and tear. The fluted roller shaft structure is fastened with two pillow type bearings. High-speed steel is the substance used for the bearing.

Design of metering mechanism

The elevator cup-chain is rotated by rotary motion of the ground wheel through two vertically fixed gears with similar teeth and diameters. The circular conical cup as shown in Figure 2.7 had a diameter of 60 mm made of rubber coated metal. The length of the chain was estimated as follows: Potato brackets, or cups, were fastened to the chain at regular intervals using bolt and nut on a K-1 attachment type chain (which is constructed of hardened steel) for the elevator use. According to Yogesh and Shambhu (2022) Equation 2.12 determined the number of chain links, m

$$m = \frac{2C}{P} + \frac{Z1+Z2}{2} + \frac{P(Z2-Z1)2}{4\pi 2C} \qquad 2.12$$

Where,

m = number of chain links;

C = centre to centre distance of gears Z1 and Z2; 66 cm or 660 mm

Z1 = number of teeth on smaller sprocket; 32

Z2 = number of teeth on larger sprocket; 32

P = pitch length in mm; 14

$$m = \frac{2\times 660}{14} + \frac{32+32}{2} + \frac{14(32-32)2}{4\pi 2\times 660} = 94.3 + 32 + 0 = 126 \text{ links.}$$

According to Yogesh and Shambhu (2022), length of the chain was determined using Equation 2.13

$$L = Ln \times P \qquad 2.13$$

Where

Ln = Number of chain links;

P = Pitch of chain, mm

L= 126 × 14 = 1764 mm or 176.4 cm length

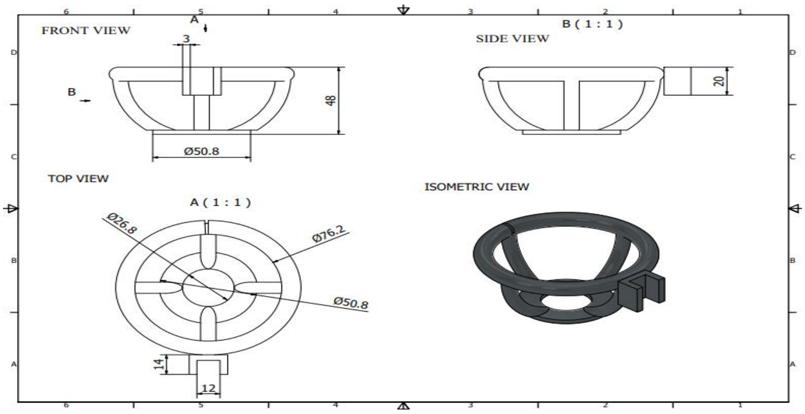

Figure 2.7: Circular conical cup (All dimensions in mm)

Design of length of the chain

According to Yogesh and Shambhu (2022), length of the potato planter chain on designed basis was calculated using Equation 3.14

$$L = 2C + 1.57\,(D1 + D2) + \frac{(D2-D12)^2}{4C} \qquad 2.14$$

$$L = 2 \times 660 + 1.57\,(143 + 143) + \frac{(143-143)^2}{4 \times 660} = 1320 + 449.02 + 0 = 1769.02 \approx 1800 \text{ mm}$$

According to Yogesh and Shambhu (2022), Pitch of the elevator K-1 attachment chain was determined using Equation 3.15

$$\text{Pitch, } P = D\sin\left(\frac{180}{Z1}\right) \qquad 2.15$$

P = 143 sin (180/32) = 14.02

And the Pitch angle on the sprocket (gear) was determined using equation 2.16

$\alpha = 360/Z1$ 2.16

360/32 = 11.25^{o}

Design of shaft

The diameter of the shaft used for both mechanism (Seed + fertilizer) was same and length of the shaft for seed metering mechanism and fertilizer metering mechanism was 690 mm and 595 mm (with adjustment mechanism). According to Khan et al. (2015), the equation of drive mechanism is

$HP = (2\pi \times Nw \times Tw)/4500$ 2.17

Where

Nw is speed of ground wheel in RPM

Tw is the torque on the wheel.

Since the speed of the machine is 2.5 km/h. However, According to Yogesh and Shambhu (2022), in practice the animals are operated at about 2.0 km/h average speed, but the machine was made for 2.5 km/h to allow some margin than maximum speed.

Nw = (speed of machine in m/s × 100)/π × 60 2.18

(0.7 × 100)/3.14 × 60 = 0.3713 ≈ 0.4

According to Yogesh and Shambhu (2022), the torque on each wheel is shown in equation 2.19

Tw = Kw ×Wt ×Rw 2.19

Where,

Kw is the coefficient of rolling resistance (0.3 for the metal wheel) and Wt is the active weight of the machine (70 kg approximately) and Rw is the radius of ground wheel (22.5 cm).

Tw = 0.3 × 70 × 22.5 =472.5 kgf

Hence,

Hp = (2π×0.4× 399)/4500 = 0.264 hp

Determination of maximum bending moment on the shaft

According to Yogesh and Shambhu (2022), the power is transferred to the machine by the drive wheel and chain drive system. For the measurement of bending moment of a shaft or machine is measured by the theorem of chain drive system. So, load on the chain or chain load (Q) is shown in Equation 2.20

Q = Kl × Pt(kgf) 2.20

Where,

Kl = coefficient of chain (1.15 for the mild steel) and

Pt = push force of the chain;

So, Q = 1.15×45kgf = 51.75 kgf

According to Yogesh and Shambhu (2022), chain drive is working at an angle θ (90^o) for seed metering and (30^o) for fertilizer metering shaft with the horizontal. Therefore, equivalent chain load on the machine is shown in Equation 2.21

Qv = Q sin (θ) 2.21

Qv = 51.75 × sin (90) = 51.75 kgf

According to Yogesh and Shambhu (2022), maximum bending moment on the shaft given by the chain drive system is shown by using the expression given in Equation 2.22

Mb= (Weight on wheel × Overhang) + (Qv × Overhang) 2.22

Mb = (45×15) + (51.75×5) = 933.75kgf or 9156.86N.m (∵1kgf = 9.81Nm)

Assume the overhang of wheel = 15 cm and so that the overhang of sprocket = 5 cm (Yogesh and Shambhu, 2022).

Hence, equivalent bending moment = $\sqrt{(Mt2 \quad + \quad Mb2)}$ = $\sqrt{399 \quad + \quad 933.7}$ = 1014.73 kgf

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Where, Mt = Tw

According to Yogesh and Shambhu (2022), the equation for diameter of the shaft is shown in Equation 2.23

$$M_{eq} = \frac{\pi}{16} \times d^3 \times \tau_s \qquad 2.23$$

According to Yogesh and Shambhu (2022), allowable shear stress, τ_s in shaft is 600 kg/cm^2

So, from Equation 3.23, the diameter of the shaft is shown in equation 2.24

$$d^3 = \frac{16}{\pi\tau s} M_{eq} \qquad 2.24$$

$$d^3 = \frac{16}{\pi 600} \times 1014.73 = \sqrt{8.61}\ 3 = 20\text{mm (Approximately)}$$

Design of fertilizer delivery metering chain

A fluted roller shaft with a diameter of 20 mm and length of 595 mm was driven by a ground wheel shaft and elevator chain transmission as shown in Figure 3.8. The fertilizer metering unit's chain drive and shaft were connected using gears, with similar sprocket parameters. According to Yogesh and Shambhu (2022), the length of chain attached between drive wheel shaft and fluted roller shaft was calculated using Equation 2.25

$$L = 2C + 1.57\,(D1 + D2) + \frac{(D2\ -\ D1)2}{4C} \qquad 2.25$$

Where

C is centre to centre distance of two sprockets (gears) in mm

$$= 2\times380 + 1.57\,(19+19) + \frac{(19-\ 19)2}{(4\times380)}$$

= 760 + 59.66 + 0 = 819.66 ≈ 820 mm chain length

During continuous operation of machine on undulated field condition, the length of chain increased from 10 mm to 20 mm due to the tensile force acting on them (Yogesh and Shambhu, 2022). So, the new length of the chain;

= 820 + 20 = 840 mm

According to Yogesh and Shambhu (2022), number of links on fluted roller metering chain

$$m = \frac{2\times380}{15} + \frac{19+19}{2} + \frac{15(19-19)2}{4\pi2\times\ 630} = \frac{760}{15} + 19 + 0 = 69.66 \approx 70 \text{ links}$$

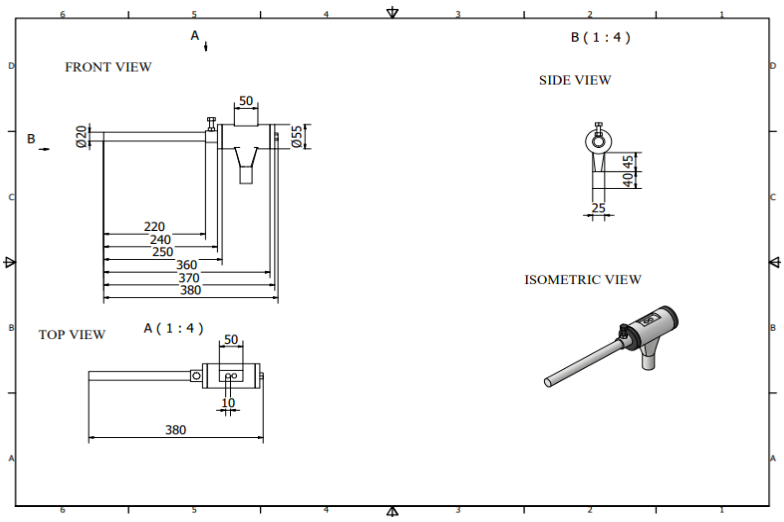

Figure 2.8: Fertilizer metering device (All dimensions in mm)

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Design of cup-to-cup distance on the chain

According to Yogesh and Shambhu (2022) the recommended plant to plant distance for potato tuber is 20 cm - 30 cm

Diameter (d) of ground wheel for the analysis is 45 cm.

Required bracket cups for 20 cm - 30 cm plant to plant spacing = 12

Length of the chain = 1800 mm

So, recommended spacing between two adjacent cups was

$= \frac{1800}{15} = 120 \text{ mm} \approx 12 \text{ cm}$

Now as per designed basis;

According to Yogesh and Shambhu (2022) No. of cups on metering chain can be calculated using equation 3.26

$$i = \frac{c \times t}{a} \qquad 2.26$$

i= Number of cups;

c = circumference of ground wheel, 1414.3 mm = 141.43 cm

t = speed ratio (drive wheel shaft to metering shaft)

a = spacing between two adjacent cups

Speed ratio of ground wheel to metering shaft = $\frac{\text{No.of teeth on metering shaft (TM)}}{\text{No.of teeth on driven shaft (TD)}}$

$$= \frac{Ng}{Nm} = \frac{Tm}{Tg} \qquad 2.27$$

Where

Ng = rpm of ground wheel;

Nm= rpm of metering shaft

Tm = Number of teeth on sprocket of metering shaft;

Tg = Number of teeth on driven shaft

Speed ratio Sr = $\frac{Ng}{Nm} = \frac{32}{32} = 1$

Let selected drive wheel size be 450 mm = 45.0 cm

So, circumference of ground wheel = πd = 3.14 × 45 = 1414.3 mm = 141.43 cm

Number of cups, i = $\frac{c \times t}{a} = \frac{141.43 \times 1}{12} = 11.8$

Therefore, no. of cups was taken as 12

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$$\text{Peripheral distance between cups} = \frac{\text{Cirwithference of ground wheel}}{\text{No.of cups}} \qquad 2.28$$

$$= \frac{141.43}{12} = 11.79 \text{ cm} \approx 12 \text{ cm}$$

Designed tractor drawn single row potato planter with fertilizer applicator

Figure 2.9, 2.10 and 2.11 present the Designed isometric, orthographic and exploded view of the tractor drawn single row potato planter with fertilizer applicator

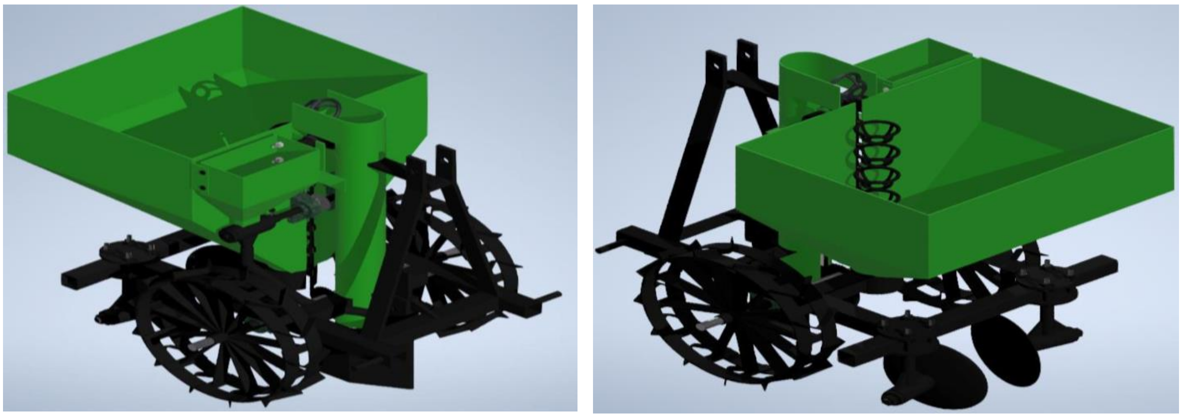

Figure 2.9: Designed tractor drawn single row potato planter with fertilizer applicator

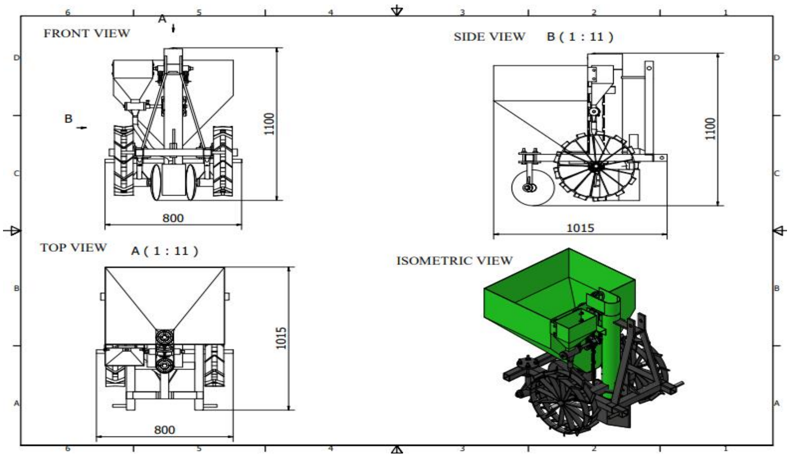

Figure 2.10: Orthographic and isometric view of tractor drawn single row potato planter with fertilizer applicator (All dimensions in mm).

PART LIST			
ITEM	QTY	COMPONENT PART	DESCRIPTION
1	1	Tuber hopper	2.5mm MS sheet metal
2	1	Fertilizer hopper	2.5mm MS sheet metal
3	12	Tuber cups	plastic
4	1	Fertilizer metering device	Teflon material
5	2	Ground wheel	1" x 3mm MS flat bar
6	1	Tuber tube	3mm MS sheet metal
7	1	Ground wheel shaft	20mm MS rod
8	1	Base frame	2" x 2" x 3mm MS square pipe
9	1	Furrow opener	3mm MS sheet metal
10	1	Delivery chute	3mm MS sheet metal
11	2	Furrow coverer	3mm MS sheet metal
12	1	Three point hitches	3mm MS sheet metal
13	3	Chain and sprocket	Steel

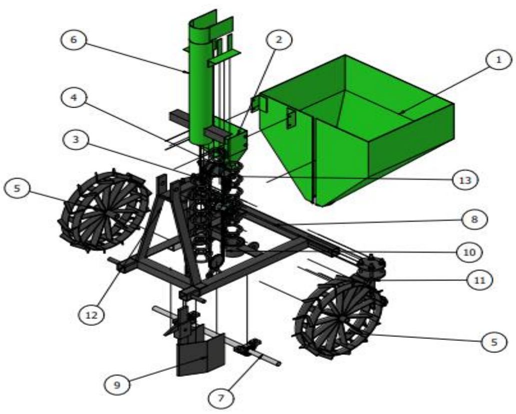

Figure 2.11: Exploded view with part list of the tractor drawn single row Irish potato planter with fertilizer applicator.

Mode of operation of the designed planter

During operation, the planter moves forward by the tractor, then the chain and spoon assembly start moving anchored from the bottom to the top through the cut tubers hopper. As the chain moves up, each spoon carries one piece of cut tubers and the chain moves further up and the spoon gets inverted inside a tuber tube which drops the tuber piece to the ground at desired spacing and depth. At the same time, the furrow opener opens up a furrow in which the cut tubers are planted. As the planter moves further, the furrow coverer attachment then covers the cut tubers and makes a ridge. The fertilizer mechanism convey the appropriate designed quantity of fertilizer to the fertilizer delivering chute, which then places the fertilizer at the desired spacing and depth.

Performance evaluation

According to Sagni (2019), it was essential to assess tractor drawn single row Irish potato planter with fertilizer applicator performance in terms of seed rate, seed distribution, seed placement, and field efficiency. The following tests were conducted in the field and in the laboratory in order to evaluate it for the aforementioned parameter.

Field Description

According to Sagni (2019) the field condition has an impact on the yield of tubers and seed germination. As a result, this field conditions affect the sowing process. Prior to seeding, the following parameters were established.

i. Soil type

ii. Soil moisture content (percent)

iii. Seed bed depth

iv. Plot size

v. Bulk density

vi. Technique for planting

Determination of theoretical field capacity, field capacity and field efficiency

According to Sagni (2019) theoretical field capacity, effective field capacity were computed using equation 3.29 and 3.30.

Theoretical field capacity (ha/h) = $\frac{W \ x \ S}{10}$ 3.29

Where: W= Width of planter, (m)

S = Speed of operation, (km/h)

10 = factor calculated as = 10000/1000 = 10

Effective field capacity (ha/h) = $\frac{Area \ of \ plot \ (ha)}{Time \ taken \ (hr)}$ 3.30

According to Sagni (2019) field efficiency was the ratio of the effective field capacity to the theoretical field capacity and was calculated using equation 3.32

Ef = $\frac{FCe}{FCt} \times 100$ 3.31

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Where: Ef = field efficiency, (%)

FCe = effective field capacity, (ha/h)

FCt = theoretical field capacity, (ha/h)

RESULTS AND DISCUSSION

design and fabrication of Tractor Drawn Single Row Irish Potato Planter with Fertilizer Applicator

The design and fabrication of Tractor Drawn Single Row Irish Potato Planter with Fertilizer Applicator was done as shown in plate 3.1.

Plate 3.1: Pictorial view of the developed tractor-drawn single row Irish potato planter with fertilizer applicator.

Table 3.1 shows the result obtained from the design calculation of selected part of the Tractor Drawn Single Row Irish Potato Planter with Fertilizer Applicator, table 3.2 shows the specifications of Tractor Drawn Single Row Irish Potato Planter with Fertilizer Applicator

Table 3.1: Design calculation values of selected parts of tractor drawn single row Irish potato planter with fertilizer applicator

S/N	Component part	Measurement	Values
1	Tuber hopper	Top width	600 mm
		Bottom width	100 mm
		Top length	500 mm

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		Total height	570 mm
		Angle of repose	30º
2	Fertilizer hopper	Top width	200 mm
		Bottom width	40 mm
		Top length	310 mm
		Total height	320 mm
		Angle of repose	30º
3	Main frame	Total weight	690 mm
		Total length	830 mm
		Total height	760 mm
4	Ground wheel	Diameter of drum	400 mm
		Circumference of drum	1257.14 mm
		Thickness of drum	3 mm
		Diameter of shaft	25 mm
		Number of spikes on the drum	13
		Diameter of pulley	150 mm
5	Metering cup	Diameter of cups	60 mm
		Cup height	60 mm
		Cup thickness	2 mm
		Number of cups	12
		Cup to cup distance	120 mm
		Cup sprocket diameter	150 mm
6	Seed tube	Seed tube diameter	80 mm
		Seed tube height	710 mm
		Seed tube thickness	32 mm

Table 3.2: Specifications of tractor drawn single row Irish potato planter with fertilizer applicator

1	Power source	Minimum of 30 hp tractor
2	Overall dimension	
	a. Length	1060 mm
	b. Width	820 mm
	c. Height	1040 mm

	d. Weight	80 kg
3	Furrow opener a. Type b. Size i. Length ii. Width iii. Height	 Shoe type 260 mm 150 mm 400 mm
4	Furrow coverer a. Type b. Size iv. Length v. Width vi. Height	 Spring loaded disc 350 mm 120 mm 260 mm
5	Metering mechanism a. Potato tuber i. Type ii. Conveyor sprocket ration iii. Size of conveyor sprockets/ no of teeth iv. Size of sprocket idler v. Spacing between two cups b. Fertilizer i. Type ii. Diameter of roller iii. Length of roller iv. No of rollers v. Size and no of cells on the roller vi. Drive system vii. Transmission ration	 Elevator cup chain 1:1 150 mm / 30 75 mm 120 mm Cell feed roller type 50 mm 85 mm 1 28 mm / 2 Chain and sprocket 1:2
6	Hopper a. Potato box i. Capacity	 131.5 kg

	ii. Type of hopper b. Fertilizer box i. Capacity ii. Type of hopper	Rectangular with trapezium box 27.6 kg Rectangular with frustum pyramid box
7	Ground wheel drive a. Number of ground wheel drive b. Type of ground wheel drive c. No of spike d. Effective diameter	 Two Spiked type 13 475 mm
8	Type of hitch	Three point linkage
9	Number of row	One
10	Intra-row spacing at 5% slippage of ground wheel	300 mm

Result of field performance evaluation of potato planter

The soil characterizations used for the field evaluation as shown in table 3.3 and field calibration of the developed Tractor-Drawn Single Row Irish Potato Planter cum Fertilizer Applicator was carried out at the department of food and Agricultural Engineering, Kwara State University experimental field, Ilorin, Kwara State. The field was well prepared (ploughed and harrowed) with 20 cm depth of cut and 60 cm width of cut and free of surface trash and obstructions. The experimental field for the equipment testing was divided into 3 experimental plots of 40 m × 10 m, respectively.

Table 3.3: The soil characterizations used for the field evaluation

S/No.	**Parameters**	**Result**
1	Type of soil	sandy loam
2	Soil moisture content	13.41%
3	Soil bulk density	1.285 gm/cm3
4	Depth of seed bed	22cm
5	Method of sowing	centre to centre
6	Size of each plot	40 m × 10 m
7	Number of plot	3

Field evaluation of developed tractor drawn single row Irish potato planter with fertilizer applicator result discussion

The result of the performance evaluation of the Tractor Drawn Single Row Irish Potato Planter with Fertilizer Applicator, particularly Depth of planting, Intra row spacing of seed, Number of potato per drop, Quantity of fertilizer per drop, Percentage of missing, Percentage of double picking, Height of ridge, Depth of fertilizer, Fuel consumption, Theoretical field capacity, Effective field capacity, is paramount to understanding its efficiency and effectiveness in agricultural operation.

Table 3.4: Performance evaluation of the developed planter at 3.5km/hr tractor speed

S/N	TESTING PARAMETER	3.5km/hr
1	Effective working width	765 mm
2	Depth of planting	133.3 mm
3	Average intra row spacing of the planted potato seedling	291.2 mm
4	Number of potato per drop	1
5	Quantity of fertilizer per drop	10.6 g
6	Percentage of missing	2.46%
7	Percentage of double picking	4.12%
8	Height of ridge	285.7 mm
9	Depth of fertilizer	133.3 mm
10	Fuel consumption	10.3 l/ha
11	Theoretical field capacity	0.26 ha/hr
12	Effective field capacity	0.1951 ha/hr
13	Total time	0.21 hr
14	Area of land	0.04 ha(400 m^2)
15	Efficiency of the planter	75.04%

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

The ultimate goal of this research was to design and fabricate a simple but highly efficient Tractor Drawn Single Row Irish Potato Planter with Fertilizer Applicator suitable for small and medium scale farmers which can be used to sow Irish potato and apply fertilizer simultaneously thereby addressing the challenges of low production in terms of Irish potato production in Nigeria and as well as drudgery involve in Irish potato cultivation. Based on various methodologies involved in designing of farm machinery, the Irish potato planter with fertilizer applicator was developed successfully.

Recommendations

Based on the results obtained from designing and fabrication of Tractor Drawn Single Row Irish Potato Planter with Fertilizer Applicator, the machine is recommended that a performance evaluation should be carried out on it. Additionally, integrating modern technology such as GPS systems or smart sensors could enhance the planter’s precision and efficiency, making it even more user-friendly and adaptable to varying field conditions.

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