Development and Testing of a Tractor-Drawn Sugarcane Billets Planter

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Abstract

Research on mechanization of sugarcane production, however, is very low especially in the area of planting and currently there exists no known mechanical sugarcane planter in Nigeria. As a result, a mechanical planter was designed and fabricated. The main objective of the study is to develop and evaluate the performance of a tractor-drawn sugarcane planter. The planter was designed, fabricated and tested in the Agricultural and Bioresources Department of The Federal University of Technology, Minna. Itconsists of a frame, hopper, cane seed metering device, delivery funnel, furrow opener, furrow covering/press wheel as well as drive wheels which transmits power to the metering device through chain drive arrangement. The performance tests of the fabricated machine were carried out using four levels of cane seed lengths (250mm, 300mm, 350mm and 400mm) at four levels of operational speeds (6km/h, 8km/h 10km/h and 12km/h) and with four levels of cane diameters (16mm, 20mm, 24mm and 28mm). Field capacity, seed rate, cane seed damage, miss index, multiple index and quality of feed index were measured. It was observed that the operational speed of the machine varies directly with machine capacity and miss index. While cane diameter varies directly with miss index, it had no significant effect on machine capacity. The machine was found to perform optimally at 10km/h operational speed, 300mm cane seed length and 28mm cane diameter. At this optimal speed level, the machine had field capacity of 0.53ha/h (4.24ha/day) and miss index of 20.8%. The developed machine could reduce drudgery involved in manual sugarcane planting and save about substantial amount of labour and operating time.

Keywords: Feed index; Multiple index; Mechanical planter; Miss index

Introduction

Sugarcane is an agricultural crop grown primarily for the juice extracted from its stalk and has potential as a renewable energy source ***(Taghinezhad et al., 2013)***. Sugarcane accounts for about 60% of the world sugar requirement **(Gerei and Giroh, 2012).**

Jalaja et al., (2008) revealed that sugar cane is one of the most efficient converters of solar energy into sugars and other renewable form of energy. The plant also produces valuable by-products such as paper, ethanol, alcohol derived chemicals, animal feed, antibiotics, particle board, bio-fertilizer and material for generating electricity.

***Murali and Balakrishnan (2012*)**, sugarcane production is labour intensive as planting alone accounts for about 350 man - hour per hectare of this labour requirement. It is one of the most difficult operations in sugar cane production. It involves opening of the furrow, placement of cane seed and covering of cane seed with soil as well as fertilizer. Accomplishing this tasks using traditional crude tools usually requires about 350 man - hour per hectare or 30-40 bullock pair per hour per hectare. This traditional way of planting sugarcane is tedious, time consuming and cost ineffective which leads to delay in covering large area of land.

The mechanical methods involves the use of planters such as: Tractor operated two row ridges type sugarcane cutter planter, Tractor operated two row multipurpose sugarcane cutter planter, Julien planter, Drum planter, slat type mechanical planter, self propelled two row Billet planter and Bonnel mechanical planter ***(Umesh and Rajesh 2007).***

In spite of the fact that Nigeria has about 500,000 hectares of suitable land for cane cultivation which is capable of producing 3.0 million metric tons of sugarcane ***(Gerei and Giroh 2012.)***, research on mechanization of sugarcane production is very low especially in the area of planting. The traditional way of planting sugarcane is labour intensive, time consuming and cost ineffective. It is therefore necessary to develop an implement for this purpose. The developed implement is expected to improve the timeliness and efficiency of operation as well as reduce drudgery and cost of sugarcane production. The aim of this research work therefore, is to develop a tractor-drawn sugarcane planter.

Design analysis

The following design analysis was carried out to determine and select the various machine parts:

Determination of the minimum width of planter

The minimum width of the planter required to cover 5 hectares per day at operational speed of 10km/h was estimated using equation 1as follows:

$$\mathbf{C_T = v \times w} \qquad \mathbf{1}$$

Where C_T = theoretical capacity, with operational time of 8 hours in a day (m^2/h)

S = speed of operation (m/h)

w = implement working width (m)

Determination of hopper dimensions and capacity

The hopper was designed to feed the metering device in vertical direction. The shape, location and dimensions of the hopper were selected to ensure free flow of the cane seed. To achieve this, static coefficient of friction was determined. The coefficient of friction was found to be 0.42. The dimension of hopper was chosen to avoid frequent loading of the hopper. It has a shape of inverted frustum of rectangular pyramid truncated with rectangular bottom

(100mm×420m and rectangular top (500mm × 420mm) as shown in (Plate 3 and 9) below.

Based on the above stated parameters the volume of hopper was estimated using Equation 2 given by ***Olaoye and Bolufawi (2001)*** as follows:

$$V=\frac{S_R}{n \times BD} \qquad \textbf{2}$$

Where V = volume of the hopper (m^3)

S_R = seeding rate (kg/h)

n = number of refilling per hectare

BD = bulk density kg/m^3

Design of cane seed metering device

Proper design of the metering device by calculating the number of grooves in the cylindrical metering devise is an essential element for satisfactory performance of the planter. It was designed to distribute cane seeds uniformly at the desired application rate and control seed spacing. Hence, the number of grooves on the cylinder was determined as reported by **Khan et al. (2015),** as follows:

$$N_g = \frac{\pi D_W}{i \times x} \qquad \textbf{3}$$

Where: D_w= diameter of the drive wheel

i = drive ratio

x = intra raw spacing (m)

x is equal to the length of the cane seed, since planter is design to achieve an end-to-end planting

Determination of the angular speed of the drive wheels (rpm)

The drive wheels of the planter transmit power to the metering mechanism of the planter through chain drive arrangement. The angular speed of drive wheel which is the same as the angular speed of the smaller sprocket is essential in the design of chain and sprockets as well as estimating power transmission through chain drive.

The angular speed of the drive wheels of the planter was estimated using Equation 4 ***(Macmillan 2002)***

$$\mathbf{S = DN_w} \qquad \mathbf{4}$$

Where S =operational speed (m/min)

D = diameter of drive wheel (0.8m)

N_w= rotational speed of drive wheel (rpm)

Determination of the shear strength of the planters drive wheels

This was determined in other to select materials of appropriate thickness for the wheel thereby avoiding failure by crumbling. The following equation as reported by Thomas and Brown (2005) was used to analyse the shear strength of the drive wheel.

$$\tau = \frac{T}{2A\ t_w} \qquad \mathbf{5}$$

Where: τ = shear strength of the wheel

T = the torque provided by the wheel (196.12)

A = area of the wheel based on the median diameter of the wheel ($A = \pi(r-0.5\ t_w)^2$)

t_w = thickness of the wheel (0.004)

r = the outer radius of the wheel (0.4m)

Determination of the torque of the planter's Wheel

The torque of the planter's wheel is essential in estimating the power that is transmitted to the metering shaft and in determining the minimum size of diameter required for both the wheel shaft and metering device shaft. It was obtained using Equation 6 asreported by ***Khan et al., (2015)***

$$\mathbf{T_w = K_w \times W_w \times R_w} \qquad \mathbf{6}$$

Where: T_w = torque of the wheel

K_w = rolling resistance coefficient of wheel (0.3 for metallic wheel)

W_p = Weight on the drive wheel

R_w = Radius of the wheel

Determination of the diameter of wheel shaft and metering device shaft

The size of the wheel and metering device shafts to transmit power from drive wheel to the metering device is dependent on the twisting moment (torque) and the maximum bending moment on the shafts as well as the allowable stress of the material of make of the shaft. The minimum shaft diameter is obtained from the following relationship reported by ***Gbabo et al. (2013) and Khurmi and Gupta (2007)*** **according to equation 7**

$$\mathbf{d^3} = \frac{16}{S_a \pi}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad \mathbf{7}$$

Where: d = diameter of shaft (m)

S = allowable shear stress (40×10^6 Nm^2 for shaft with key way)

K_b = combined shock and fatigue factor applied to bending moment

K_t = combined shock and fatigue factor applied to twisting moment

M_b = maximum bending moment

M_t = twisting moment (196.12Nm)

Determination of the implement draft

Draft is an important factor in determining implement power requirement. ***According to ASAE (1999)***, average draft requirements can be estimated using Equation 8:

$$\mathbf{D_I = F_i(A+Bv+Cv^2)wd \pm R} \qquad \mathbf{8}$$

Where: D_I = implement draft, N

F_i = dimensionless texture adjustment factor

i = 1 for fine, 2 for medium and 3 for coarse texture soils

A, B and C = implement specific constants

v = travel speed, km/h

w = implement working width, (m)

d = tillage depth, cm (1.0 for minor tillage tools and seeders)

R = range of power requirement due to differences in machine design, machine adjustment and crop conditions.

But w = inter row spacing × number of rows

From ASAE standards, following are the values: (for row crop planter which are drawn type but seeding only)

$F_1 = F_2 = F_3 = 1.0$, A = 900, B = C = 0.0, v = 10.0 km/h, w = 1.0 ×2 =2.0m, d = 1.0 for seeders and R = 25%

Determination of Power requirement of the implement

The power requirement of the planter is a function of implement draft and operational speed of the tractor. Therefore maximum draft requirement of the implement is estimated using Equation 8 as follows.

Maximum draft requirement of the implement = 1800 + 0.25(1800) = 2250N

$$\mathbf{P_{db} = (D_i)\ V} \qquad \mathbf{9}$$

Where: P_{db} =power required by the implement

D = implement draft

V = forward speed of tractor

$$\textbf{Therefore}P_{db} = \frac{D_I \times v}{3.6} \qquad 10$$

Description of the machine

Machine Frame:

This is the skeletal structure of the planter on which all other components are mounted. It was constructed from 40mm x 100mm x 40mm U-channel mild steel and 50.8mm x 50.8mm mild steel angle bar of which are 4mm thick to give the required strength. Provisions are made for the 3-point hitching linkages for tractor connection to the machine. During road transportation and on displacement from one field to another, the whole frame is fully mounted on the tractor but during planting operation the planters frame is supported by drive wheel. The structure of frame is as shown in the plate1

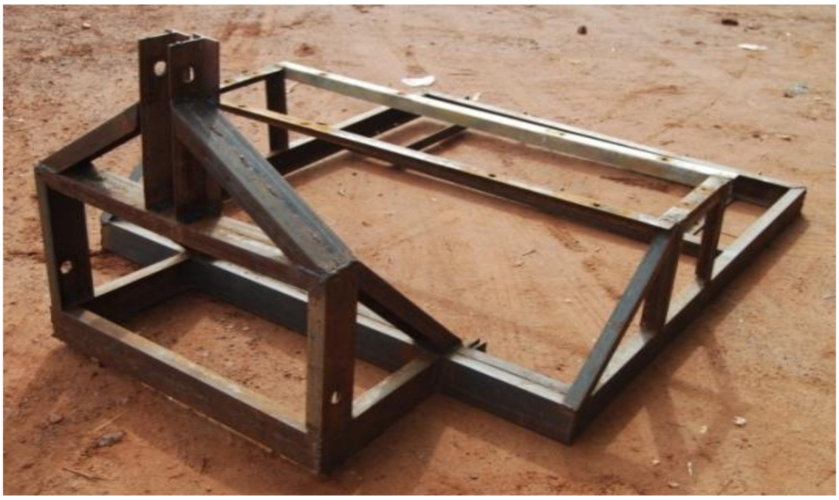

Plate 1: **Machine frame**

Hopper: The cane seed hopper was made from 2mm thick mild steel sheet. The hopper has an inverted frustum of rectangular pyramid truncate with rectangular bottom (420mm x 10mm) and having a height of 350mm and rectangular top of (420mm x 500m x 250m). It has semi - cylindrical base of 320mm diameter and

420mm length with 160mm extension for housing of metering device. It holds cane seed temporarily for planting as the machine is drawn along on the field (Plate 2).

Plate 2: **Hopper**

Metering device:

This is cylindrical in shape and bears grooves at predetermined section on its longitudinal cross-section. The grooves are 40mm wide and 30mm deep. The metering device was made from 2mm thick mild steel sheet. It is 400mm in length and has diameter of 300mm, the opposite This is cylindrical in shape and bears grooves at predetermined section on its longitudinal cross-section. The grooves are 40mm wide and 30mm deep. The metering device was made from sides of the cylinders are closed with 2mm thick circular plate and fastened to the shaft which is suspended in bearings rest on the machine frame. Metering device is to select the cane seed from seed lot and discharges them at predetermined rate and spacing. The metering device is as shown in plate 3.

Plate 3: **Metering Mechanism**

Delivery funnel:

The delivering funnel is as shown in plate 4, it is trapezoidal in shape with upper parallel sides of 330mm x 430mm and lower parallel side of 80m x 80m (spout end) with one of its sides bend inward to change the cane seed from horizontally discharge position to vertical one so as to lay the cane seed along the furrow and not across it. The spout of the delivery funnel is 100mm above the seed bed with the hind side open by 100mm from lower end for successive laying of cane seed into the furrow. It is also made from 2mm thick mild steel sheet.

Plate 4: **Delivery funnel**

Furrow opener:

The furrow opener of this planter is adjustable point tune type. It was made from 8mm thick mild steel flat bar; it has wings to prevent soil from falling into created furrow. It creates furrow before cane seed is discharge from delivery funnel. It is being fastened to the machine frame using size 22 standard bolts and nuts (Plate 5).

Plate 5: **Furrow opener**

Furrow covering/press wheel:

Split packer type covering/press wheel (Plate 6) was constructed to flow back soil into furrow, cover and level the soil over the cane seed. It was made from 2mm thick mild steel sheet; it is attached to the machine frame with bolts and nuts using 50.8mm x 50.8mm mild steel angle bar as toolbar.

Plate 6: **Furrow Coverer**

The drive wheel:

They are circular in shape containing 12mm mild steel rod which serves as spokes (plate 7). These spokes are used to support the centre bushing or hub. The spokes are arranged in such a way that they braced the circular circumference and also give it necessary radial support. Material used is combination of both 12mm mild steel rod and 4mm thick mild steel sheet. The wheels are connected to the two shafts which are suspended in two sets of bearing. Wheels transmit power obtained from being drawn by tractor to the metering device. The logs are fitted to the drive wheels to improve grip ability of wheels with soil surface.

Plate 7: **Drive wheel**

Power Transmission System:

The power transmission system performs the work of reducing the ground speed of the tractor to a permissible level that is suitable for the operation of the cane seed metering system. It is comprised of two sprockets of predetermined sizes. A small sprocket (14 teeth) fitted to the shaft of the drive wheel and a bigger one (42 teeth) connected to the shaft of the cane seed metering device (plate 8). Chain and sprockets are used to transmit power in the drive so as to prevent power loss during transmission.

Plate 8: **Power Transmission System**

Testing of Machine

A 100m x100mfield was ploughed and harrowed. The field was then sub divided into plots of 20m x50m. Cane stalks were obtained from National Cereals Research Institute’s sugarcane field. The cane stalks were cut into 250mm, 300m, 350mm and 400mm cane seed lengths. They were further grouped into 16mm, 20mm, 24mm and 28mm.The machine was loaded with the cane seeds length and planted in a 20m x 50m sub plots at four different operational speeds of 12km/h,10km/h,8km/h and 6km/h for each group.

A three-variable, four level factorial design ($N = 4^3$) provides the frame work for the experiment. The experimental design was a split-plot design according to the principle of factorial experiment. The four levels of speeds were assigned to the sub plot, the four levels of cane seed length were confounded to the main plot and four levels of the cane diameters were assigned to the split-plot.

Miss index

Misses or skips are created when seed grooves fail to pick up and deliver seeds to the delivery funnels. Misses are counted along a randomly selected 15m length of each planted row with the covering devices removed. The missing percentage is presented by an index called the miss index (MI) which is the percentage of spacing greater than 1.5times the theoretical spacing (katchman and smith, 1995).

$$\mathbf{MI} = \frac{n_s}{N} \times 100 \qquad \mathbf{11}$$

Where: ns = number of skips

N = Total number of spacing

Field capacity of Planter: The field capacity of the planter is the total area of land that was covered. It is expressed as the area of field covered in given time and was obtained as equation 12 follows:

$$C_M = \frac{A_f}{T} \qquad \textbf{12}$$

Where C_M = machine capacity (ha/h)

A_f= area of field covered (m^2)

T = time taken (h)

Results and Disussion

Miss index

Table 1 shows the performance of the machine in terms of miss index. Operational speed of the planter was found to affect miss index using varying cane seed lengths and diameters. In general, increase in operational speed tended to increase the miss index of the planter. The highest percent cane seed miss index of 22.1-22.3% were recorded at the highest operational speed of 12 km/h, whereas the lowest percent cane seed miss index of 17.1-17.8% was obtained at the lowest machine operational speed of 6km/h. The result also clearly indicated that operational speed greater than 10km/h would result in percent miss index greater than 20% which by far exceeds the 10% acceptable level of miss index reported by ***Karayel and Ozmerzi (2001).***

Table 1: **Effect of machine speed on miss index for various levels of cane diameter and cane seed length**

Levels	Cane diameter (mm)	Machine speed (km/h)	Miss index at various level of cane seed length (%)			
			250	300	350	400
1	16	6	17.1	16.9	17.2	17.3
		8	18.3	16.9	17.8	18.8
		10	19.3	18.2	19.2	19.4
		12	23.1	23.2	23.2	23.3
2	20	6	18.0	18.3	17.8	18.0
		8	18.0	18.3	20.0	19.8
		10	18.9	19.1	18.9	19.9
		12	23.3	23.3	23.4	23.5
3	24	6	19.0	18.5	19.8	19.8
		8	20.1	19.8	20.0	20.1
		10	20.4	20.1	20.1	20.2
		12	23.3	23.5	23.6	23.5
4	28	6	19.5	19.8	20.8	20.5
		8	20.8	20.0	20.5	20.2
		10	20.8	20.8	20.4	21.1
		12	23.3	23.6	23.5	24.0

Field capacity

Results of test carried out to evaluate the planter's field capacity with respect different operational speeds is shown in Table 2. Increase in machine operational speed resulted in increase in field capacity of the machine for all cane seed lengths. As seen, at cane diameter of 16mm, the lowest field capacity of 0.26-0.29ha/h was obtained for all cane seed lengths at the lowest operational speed of 6km/h, while the highest field capacity of 0.64-0.68ha/h was recorded for the various lengths of the cane seed at the highest machine speed of 12km/h using cane seed of 16mm diameter. Furthermore, at higher cane diameter of 28mm the same trend was followed whereby machine field capacity increased with increase in machine operational speed irrespective of the length of the cane seed.

Table 2: Effect of machine speed on field capacity for various levels of cane diameter and cane seed length.

Levels	Cane diameter (mm)	Machine speed (km/h)	Field capacity at various level of cane seed length (ha/h)			
			250	300	350	400
1	16	6	0.26	0.29	0.28	0.27
		8	0.45	0.44	0.48	0.46
		10	0.52	0.53	0.54	0.53
		12	0.67	0.64	0.65	0.68
2	20	6	0.29	0.28	0.28	0.27
		8	0.46	0.47	0.46	0.45
		10	0.53	0.52	0.53	0.54
		12	0.65	0.66	0.67	0.66
3	24	6	0.28	0.27	0.27	0.26
		8	0.47	0.46	0.45	0.46
		10	0.52	0.53	0.53	0.52
4	28	6	0.27	0.27	0.26	0.26
		8	0.45	0.46	0.45	0.44
		10	0.52	0.54	0.53	0.52
		12	0.66	0.65	0.64	0.65

Conclusion

The machine was successfully constructed and evaluated. The performance evaluation of the machine was carried out to assess the miss index and field capacity of the planter at four levels of operational speed of 6,8,10 and 12 km/h, four levels of cane seed length of 250, 300, 350 and 400m and four levels of cane diameter of 16, 20, 24 and 28mm.

The miss index of the machine was mainly affected by the machine operational speed and cane diameter. The effect of cane seed length was insignificant. The miss index increased with increase in operational speed and cane diameter with the least (17.1%) observed at 6km/h operational speed and 16mm cane diameter but mostly occurred (22.3%) at 12km/h of operational speed and 28mm cane diameter respectively.

Though the performance of the planter was commendable, the following modifications are recommended to still improve its performance efficiency:

The field capacity of the planter mainly depended on operational speed. The size of the cane seeds (diameter and length) did not affect the field capacity of the machine. The highest capacity of 0.68ha/h was recorded at the highest operational speed of 12km/h while the lowest field capacity of 0.26ha/h was recorded at the lowest machine speed of 6km/h.

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الملخص العربي

تطوير واستخدام آلة مقطورة خلف الجرار لزراعة عقل قصب السكر

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البحث عن ميكنة إنتاج قصب السكر منخفض للغاية وخاصة في مجال الزراعة ، ولا يوجد حاليا أي زارع قصب السكر الميكانيكي المعروف في نيجيريا. ونتيجة لذلك ،تم تصميم وتجهيز زارع ميكانيكي. الهدف الرئيسي من الدراسة هو تطوير وتقييم أداء زارع قصب السكر المرسوم بالجرار. صُمم المزارع وصُنع واختبر في قسم العلوم الزراعية والبيولوجية في الجامعة الاتحادية للتكنولوجيا في مينا. أجهزة متطورة من إطار ، قادوس ، جهاز قياس بذور قصب السكر ، قمع التسليم ، فتاحة ثلم ، غطاء ثلم / عجلة الضغط ،بالإضافة إلى عجلات القيادة التي تنقل الطاقة إلى جهاز القياس من خلال ترتيب محرك السلسلة. أجريت اختبارات الأداء للآلة المصنعة باستخدام أربعة مستويات من أطوال بذور القصب (250 مم ، 300 مم ، 350 مم و 400 مم) على أربعة مستويات من سرعات التشغيل (6 كم / ساعة ، 8 كم / ساعة 10 كم / ساعة و 12 كم / ساعة) ومع تم قياس أربعة مستويات من أقطار القصب (16 mm، 20mm، 24mm و28mm) وقد تم قياس قدرة الطاقة ، معدل البذور ، وبذور قصب الضرر ،ومؤشر الخطأ ،ومؤشر متعدد ونوعية مؤشر التغذية. لوحظ أن سرعة التشغيل للآلة تختلف بشكل مباشر مع سعة الماكينة ومؤشر الخطأ. في حين أن قطر القصب يختلف بشكل مباشر مع مؤشر الخطأ ، إلا أنه لم يكن له تأثير كبير على سعة الماكينة. تم العثور على الماكينة على النحو الأمثل بسرعة تشغيل تصل إلى 10 كم / ساعة ،وطول 300 ملم من قصب السكر وقطر 28 مم. في هذا المستوى الأمثل للسرعة ،كان لدى الجهاز سعة حقلية تبلغ 0.53 ha / h) 4.24ha / يوم) ومؤشر ضياع قدره 20.8٪. يمكن للآلة المتقدمة أن تقلل من الكدح الذي ينطوي عليه زرع قصب السكر اليدوي وتوفير كمية كبيرة من العمالة ووقت التشغيل.