

Effects of Travel Speed and Wheel Type on The Field Capacity, Field Efficiency and Wheel Slippage of A Single-Row Self-Propelled Cassava Planter

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ABSTRACT

Travel speed and drive-wheel characteristics are important factors influencing the field performance and planting uniformity of farm machinery. This study was carried out to examine the effects of travel speed and drive-wheel type on the field capacity, field efficiency and wheel slippage of a single-row self-propelled cassava planter. The experiment was conducted at the Teaching and Research Farm of Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria, using rigid and pneumatic drive wheels. Five travel speeds of 1.3, 1.5, 1.7, 2.0 and 2.4 km h⁻¹ were used on well-tilled soil at a furrow depth of 100 mm, with three replications. The results showed that intra-row spacing increased with travel speed, with the pneumatic wheel producing wider spacing (1.08–1.28 m) than the rigid wheel (1.07–1.14 m). Effective field capacity increased with travel speed, ranging from 0.108 to 0.153 ha h⁻¹ for the rigid wheel and 0.104 to 0.133 ha h⁻¹ for the pneumatic wheel. Field efficiency decreased from 88.53 to 72.86% and from 85.35 to 63.94% for rigid and pneumatic wheels, respectively. Wheel slippage increased with travel speed, reaching 20.70% for the rigid wheel and 29.30% for the pneumatic wheel. The rigid wheel exhibited superior field performance due to its lower slippage. A travel speed of 1.3 km h⁻¹ was identified as optimum for the planter under the conditions of the study.

Keywords: Cassava planter, travel speed, drive wheel, field capacity, field efficiency, wheel slippage.

Date of Submission: 09-10-2026

Date of acceptance: 20-10-2026

I. INTRODUCTION

According to Tarawali et al. (2013), mechanical planting is faster and 50% less expensive than hand planting. Cassava production is dependent on a supply of high-quality stem cuttings, as the multiplication rate of planting materials is very low when compared to grain crops that are propagated by seeds (IITA, 2009). The need for improved cassava planting technology has arisen as a result of Nigeria's rural-urban migration and the current trend of increased demand. This eliminates the need for additional work behind the tractor to place the cassava stems for mechanical planting, as well as providing labor for other cassava production processes to meet current and future demand for cassava products. Thus, the development and performance evaluation of a semi-automatic cassava planter are the focus of this research.

Depending on the kind and condition of the soil, one cassava stem cutting (stake) can be planted in each hole in a horizontal, vertical, or slanting posture to a depth of five to ten centimeters (Shadrack, 2011). When the soil is relatively dry, planting is typically done by hand in a slanting position at a 45-degree angle to encourage the formation of compactly arranged roots; when the soil is dry, planting is done horizontally to increase stem production; and when planting is done during the wet season, it is done vertically to produce deeper-lying storage roots for anchorage, ensuring that at least two-thirds of the cutting length is buried or covered with soil (Oyedemi et al. Horizontal cassava planting delivers larger yields than vertical cassava planting while lowering production costs during harvesting (Danao et al., 2015).

Thailand developed a mechanical cassava planter that consists of a main frame, a cutting unit, a planting unit, a fertilizer unit, a ridger, and soil levelers. To operate the planter, two feeders and a tractor driver were necessary. The field performance evaluation, which used three traveling speeds (1.7, 2.0, and 2.4 km/h), yielded a field capacity and efficiency of 0.135 ha/h and 65.3%, respectively (Lungkapin et al, 2009). The imported Cassava Plant Center-Brazil (CPCB) and modified API cassava planters achieved working rates of 0.28 and 0.13 ha/h, respectively (Ale, 2021).

In the investigation of the design and performance evaluation of a cassava planter, Oyedele et al. (2011) used a forward speed ranging from 2.97 to 4.2 km/h. Field efficiency increased with forward speed, with a low coefficient of determination (r^2) of 0.775. Kamal and Bamgboye (2019) used forward speeds ranging from 2.16 to 3.12 km/h to design a metering system for a two-row, single feeder cassava planter. However, the most convenient speed of operation without stem skipping was found to be between 2.16 and 2.64 km/h. Ademosun (1986) suggested forward speeds of 1.5 and 2 km/h for 1- or 2-row picker-pin planters and 1- or 2-row hand-fed planters, respectively. Silveira et al. (2011) investigated the influence of travel speed on maize sowing with a row crop planter equipped with a hoe-type opener and found that higher speeds reduced furrow depth while increasing soil disturbance area. When Bellé et al. (2014) and Gassen et al. (2014) evaluated hoe-type openers for soil scarification, they discovered no correlation between travel speed and planter performance.

Darshana (2019) defines wheel slip as any time a wheel or traction device creates pull, which affects field performance and fuel consumption. Amponsah et al. (2014) and Jebur and Alsayyah (2017) discovered a relationship between tractor wheel slippage and soil moisture content, with increasing soil moisture content from 12% to 22% resulting in slippage from 10% to 20%. The maximum wheel slippage and fuel consumption (4.3 7% and 3.8 L/ha, respectively) were obtained at operational speeds of 8 km/h and 12 km/h, respectively, while the minimum wheel slippage and consumption (3.14% and 2.2 L/ha, respectively) were obtained at operational speeds of 12 km/h and 8 km/h, respectively, for every length (Muogbo et al., 2019). This range of wheel slippage values is comparable to the recommended slippage value of 5.7% (Raghavendra et al., 2013). Mohammed et al. (2017) also found that as the forward speed increased from 5.5 to 8.5 km/h, wheel slippage increased from 3.4 to 2.8% in a Giad planter and from 2.8 to 2.4% in a row planter.

A linear relationship with a coefficient of determination r^2 of 0.9769 in the pneumatic wheel experiment and 0.9951 for the rigid wheel experiment was observed between the tractor forward speed and the intra-row spacing in the evaluation test of a tractor-pulled cassava planter. The intra-row spacing increased with an increase in forward speed of the tractor. The spacing recorded in the evaluation test varied from 0.95 to 1.35 m in the rigid wheel experiment at 1.5 km/h forward speed and 1m to 1.44 m were reported for pneumatic wheels (Ale et al, 2023). The study aimed to determine the effects of travel speeds on the performance of a modified existing self-propelled cassava planter in order to optimize its use and generate a database for reproduction of the planter.

II. MATERIAL AND METHODS

Study Location

The study was carried out at the teaching and research farm of the Department of Agricultural and Bio-Environmental Engineering Technology, Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria (Lat 7°015 ' N, long. 50 35 'E) and an elevation of 210 m. The soil was analyzed as Sandy Clay loam with a mean soil temperature of 29.4°C, pH value of 6.75, bulk density of 1.249 g/cm³, and moisture content of 35.57%.

The Self-Propelled Cassava Planter

The self-propelled planter (Figure 1a) consists of a stem hopper, roller-picker, sweep-type furrow opener, furrow coverer, bevel gear transmission system, belt-and-pulley drive assembly for speed regulation, a 13-horsepower gasoline engine, land wheels, main frame, and an operator's seat. Power is supplied by the gasoline engine, with rotational speed moderated by the belt-and-pulley assembly. Other components of the planter include the instrumentation system and the braking system.



Figure 1a: The Self-Propelled Planter

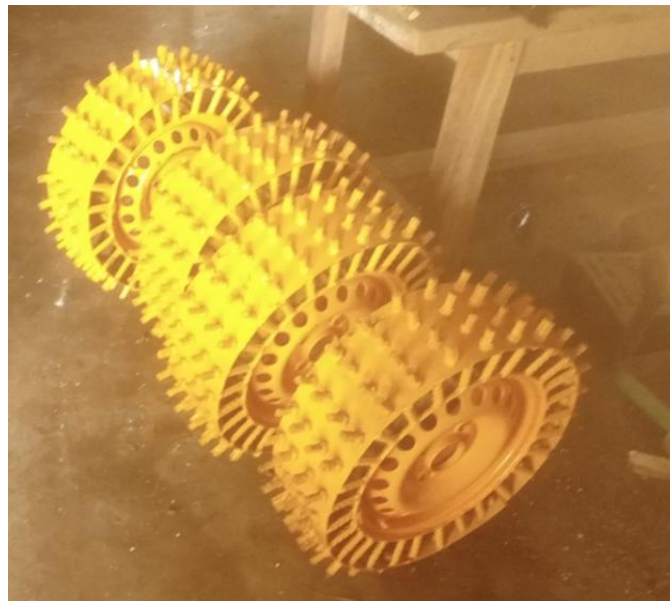


Figure 1b: The Rigid Wheels for the Planter

Laboratory Test of the Planter

The planter was initially tested in the laboratory by suspending the front wheels while the planter is powered. The planter was initially operated under no-load conditions to verify the functionality and synchronization of the planter's components. Subsequently, the hopper was loaded with cassava stakes to confirm the roller-picker mechanism's ability to select and dispense stakes as designed.

Field Experimentation

To determine the effect of the travel speed on the performance of the Planter, five forward speeds of 1.3, 1.5, 1.7, 2.0, and 2.4 km/h were used to drive the planter on tilled soil at the furrow depth of 100 mm for rigid wheel and pneumatic wheel experiments. The planter was operated to plant cassava along a row of 20 m, and the time used to plant the distance was measured using a stopwatch. The field performance of the planter, which includes the Theoretical Field Capacity (TFC), the Effective Field Capacity (EFC), and the Field Efficiency (FE), was determined using Equations 1, 2, and 3 as expressed by Mohamed et al. (2017). The value of wheel slippage was also determined using Equation 4 as expressed by Darshana et al. (2018). The intra-row spacing was measured using a steel measuring tape. This procedure was carried out for each forward speed in three replicates using both the pneumatic and the rigid wheels.

Theoretical field capacity, TFC (ha/h)

$$TFC = \frac{\text{Forward Speed} \times \text{Width of the lanter}}{10} \quad (1)$$

Effective field capacity, EFC (ha/h)

$$EFC = \frac{\text{Area Covered}}{\text{Time}} \quad (2)$$

Field efficiency, FE (%)

$$FE = \frac{EFC}{TFC} \times 100 \quad (3)$$

Wheel slippage, S (%)

$$S = \left(1 - \frac{V_i}{V_a}\right) \times 100 \quad (4)$$

Where; V_i is the forward speed in km/h when the tractor is in operation and V_a is the forward speed in km/h when the tractor is not in operation.

Bulk Density, Moisture Content and Physicochemical Properties of the Soil

Soil samples were taken from seven depths: 0-6, 6-12, 12-18, 18-24, and 24-30, using a 5.8cm diameter and 6cm height core sampler. The samples were collected by driving the core sampler to each depth. To prevent moisture loss, the collected soil was sealed in an airtight polythene bag before being oven-dried and weighed. After oven drying, the soil was allowed to cool for one hour. The soil's bulk density was measured using standard equation 5.

The soil moisture content was determined using a soil moisture meter at the soil depth of 6, 12, 18, 24, and 30 cm. Soil samples were also collected in 3 locations of the study area to determine their physicochemical properties. The experiment was repeated three times to get the mean values of the data collected. The data collected were analyzed using Microsoft Excel 2024

III. RESULTS AND DISCUSSION

Effect of Travel Speed on the Intra-Row Spacing

A linear relationship (Figure 2) was recorded in both the rigid and pneumatic wheels with higher values of spacing (from 1.08 to 1.28 m) and a coefficient of determination (0.93) in the pneumatic wheels. This wider spacing with the pneumatic wheels may be due to slippage from the pneumatic wheels. This result is in conformity with Ale et al. (2023), who reported a linear increase in intra-row spacing with increasing tractor forward speed in the evaluation of a tractor-pulled cassava planter. This result therefore confirms that travel speed and wheel characteristics can influence the uniformity of cassava stem planting.

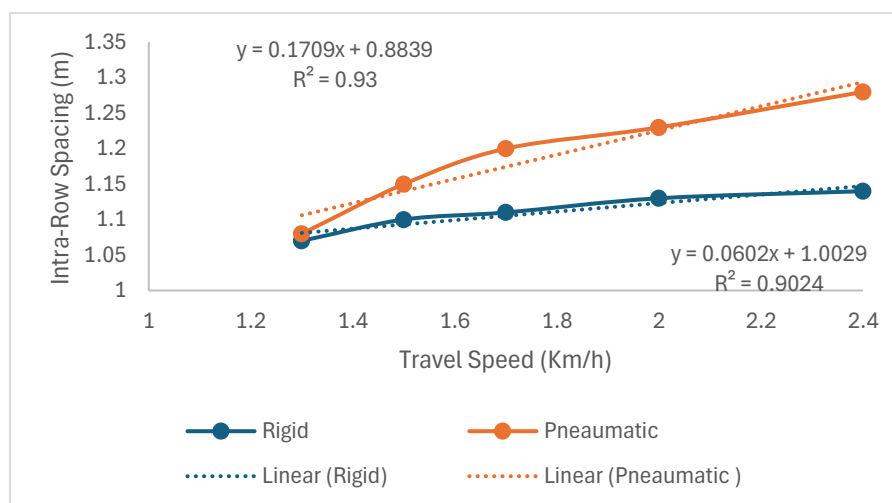


Figure 2: Effect of Travel Speed on the Intra-Row Spacing

Effect of Travel Speed on the Field Capacity of the Planter

Effective field capacity increased with increasing travel speed for both rigid and pneumatic wheels. The rigid wheel recorded values ranging from 0.108 to 0.153 ha/h, while the pneumatic wheel produced values between 0.104 and 0.133 ha/h (Figure 3). The positive relationship between travel speed and field capacity is expected because increasing travel speed allows a greater area to be covered per unit time, provided that excessive wheel slip and interruptions do not offset the gain in speed. The result is consistent with the operating-speed principle reported in previous studies on evaluation of planters (Lungkapin et al 2009). This result therefore shows that the self-propelled planter has a competitive field capacity relative to some existing cassava planters

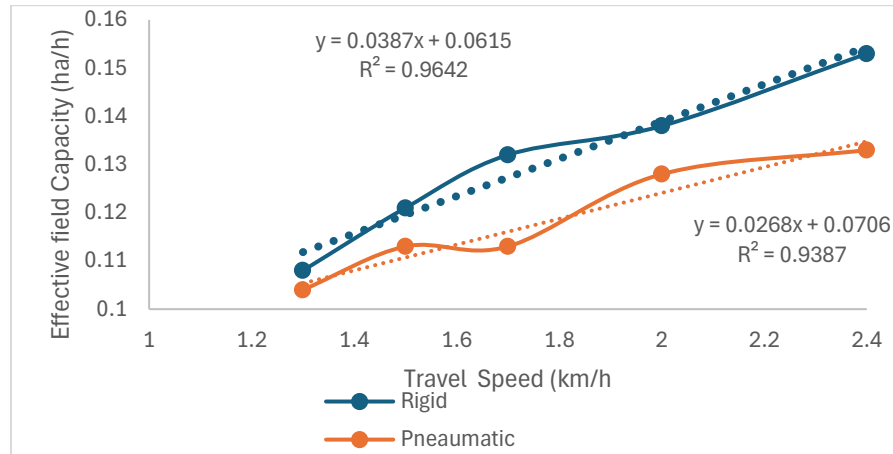


Figure 3: Effect of Travel Speed on the Field Capacity of the Planter

Effect of Travel Speed on the Field Efficiency of the Self-Propelled Planter

The field efficiency decreased as travel speed increased (Figure 4). For the rigid wheel, field efficiency decreased from 88.53% to 72.86%, while the pneumatic wheel decreased from 85.35% to 63.94%. This is different from the field capacity result that increased with the travel speed. This finding is important because it shows that increasing travel speed does not translate into improved field performance. The field efficiency obtained in this study was higher than the 65.3% reported by Lungkapin et al (2009) for a mechanical cassava planter. The declining trend of field efficiency recorded in this study disagrees with the report of Oyedeji et al. (2011), who reported an increase in field efficiency with increasing forward speed. This difference may be associated with differences in planter design, wheel configuration, field conditions, travel speed range, and the degree of wheel slip.

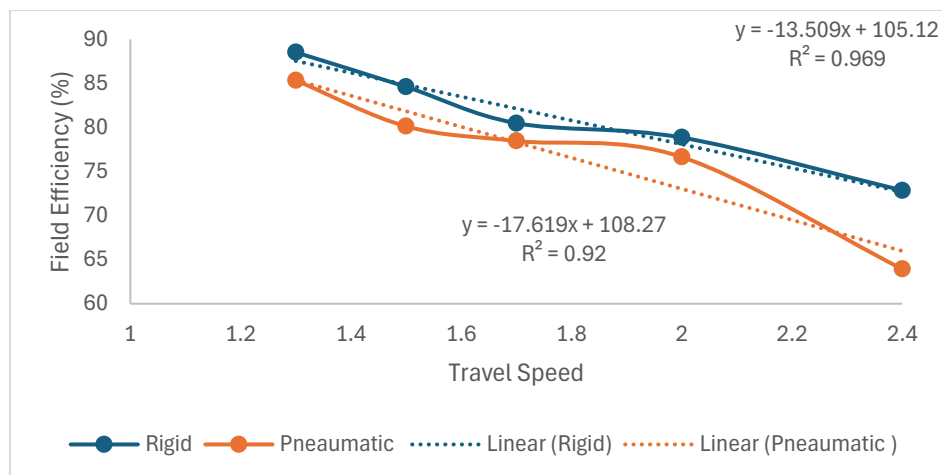


Figure 4: Effect of Travel Speed on the Field Efficiency of the Planter

Effect of Travel Speed on the Wheel Slippage of the Self-Propelled Planter

A linear relationship (Figure 5) was recorded between the travel speed of the planter and the wheel slippage with higher values (from 6.4 to 29.3 %) and a coefficient of determination r^2 of 0.9797 recorded in the pneumatic wheels. The rigid wheel recorded slippage values from 2.32% to 20.70%. The values of wheel slippage increased with an increase in the values of the travel speed. The higher slippage associated with the

pneumatic wheel partly explains its wider intra-row spacing and lower field capacity at higher travel speeds. This observation agrees with the findings of previous studies that wheel slippage is influenced by operating and soil conditions (Amponsah et al. 2014; Jebur and Alsayyah 2017; Muogbo et al., 2019; Ale et al. 2023). However, the maximum slippage of 29.30% recorded for the pneumatic wheel in the present study is substantially higher than the values reported in the earlier studies. This difference indicates that wheel type, planter configuration, travel speed, and field conditions may have exerted considerable influence on traction performance. The very high slippage at 2.4 km/h also suggests that operating the planter at the highest speed may compromise planting uniformity and overall field performance.

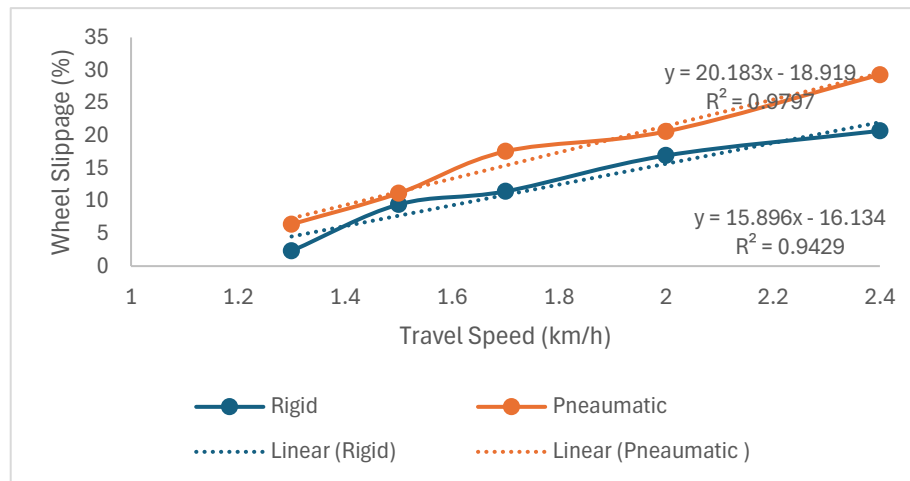


Figure 5: Effect of Travel Speed on the Wheel Slippage

IV. CONCLUSION

The following conclusions have been drawn from this study:

1. Pneumatic wheels were characterized with higher values of intra-row spacing and wheel slippage. It is therefore concluded that higher row spacing was caused by wheel slippage.
2. Rigid wheels were characterized by higher values of effective field capacity and field efficiency. It is therefore concluded that the higher values of the field capacity and the field efficiency are the result of the resistance of rigid wheels to slippage.
3. There is a good correlation between the field capacity, the field efficiency, and the travel speed of the self-propelled planter.
4. The travel speed to achieve the optimum field performance of the planter is 1.3 km/h.

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