

Performance Evaluation of Hand-Operated Seeder for Cotton Planting Under Different Tillage Practices in Benin



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ABSTRACT: Cotton farming faces challenges such as climatic variability, labor shortages and high labor costs, and a lack of suitable equipment, particularly for sowing, which prevent successful sowing within the appropriate timeframe. This study, carried out at the research station of Okpara (Parakou), aimed to evaluate the performance of an adapted hand-operated seeder under different tillage practices. A split-plot design was used to compare three tillage practices: Manual Tillage, Tractor Plough, and Strip Tillage, and two sowing methods: Hand-operated Seeder and Manual Sowing. The key indicators assessed were the sowing time, the effective daily capacity, the clogging frequency and the seedling emergence. Descriptive and two-factor analyses of variance with interaction were performed and validated after checking normality and homogeneity of residuals. Tukey's test was used to separate the means in case of a significant difference at the 5% threshold. Results showed that the hand-operated seeder had significantly lower sowing time of 2.6–3.1 h/ha, compared to 14.4–20.4 h/ha for manual sowing. Strip tillage improved sowing regularity with the hand-operated seeder, by reducing the seed hill opener clogging. Furthermore, the hand-operated seeder ensured optimal plant density (60,735–64,732 plants/ha) and emergence rates closer to the recommended two plants per hill, whereas manual sowing yielded lower. Overall, the use of an adapted hand-operated seeder, combined with the appropriate tillage practices, improves sowing efficiency and crop establishment quality in cotton farming.

KEY WORDS: Benin Republic, Cotton, Mechanization, Seeder, Sowing, Tillage.

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I. INTRODUCTION

Cotton production is a key sector of the national economy, contributing 13.79% of the agricultural gross domestic product in 2021 according to the Ministry of Agriculture, Livestock and Fisheries of Benin (MAEP, 2021). Its economic importance makes cotton a top priority for the country's sustainable agricultural development. However, the current performance of the sector remains limited by some challenges. The progressive degradation of soils in cotton-growing areas (Amonmide et al., 2019), pest pressure and increased climate variability (Afouda et al., 2020) are major factors in declining productivity. In addition to these constraints, some farmers do not follow the recommended technical guidelines and key farming operations, such as land preparation, sowing, and weed control, which are not sufficiently mechanized.

The quality of sowing is a determining factor in crop establishment and productivity. Agricultural seed drills play an essential role in regulating sowing depth, closing the furrow,

and optimizing seed-soil contact. The baseline survey conducted by the Institute of Cotton Research of Benin (IRC, 2024) on the use of seed drills in Benin also confirms the strong predominance of a particular type of hand operated seeded, emphasising the need for a thorough assessment of the performance of these seed drills. It revealed that several models of hand operated seeder are used, but the most common and widely used is the plastic hand operated seeder. This equipment allows farmers to cover small areas and complete sowing in a short time. However, farmers report a number of constraints when using this hand operated seeder, including clogging, low germination rates, and failure to maintain the correct sowing density (IRC, 2024).

Indeed, the performance of hand operated seeder is strongly influenced by soil conditions, which depend directly on the tillage system used, whether conventional ploughing, reduced tillage, or direct seeding, as well as the adjustments and adaptations required for good performance. Numerous studies have highlighted the importance of interaction between the soil and the seed drill. Alwash and Al-Aani (2023, 2025)

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showed that wheel slip, traction force, and emergence rates vary significantly between ploughed and unploughed systems, emphasizing the effect of tillage practices on the operational efficiency of sowing. Similarly, Wang et al. (2025) demonstrated that seedbed quality and seed placement accuracy differ significantly between four tillage methods, indicating that certain practices, such as shallow rotary tillage, can promote a better compromise between soil uniformity and seeding accuracy.

Researchers have focused on seeding dynamics and related mechanical effects. Zhang et al. (2024) showed that vibrations affecting a perforated wheel seeder can reduce distribution uniformity, while Hamid (2024) discussed tolerance thresholds for tire slippage and their impact on performance and soil degradation. Dharmendra et al. (2022) and Faheem et al. (2022) also reported that no-till seeding systems are often associated with increased slip and resistance to forward propulsion, which can alter placement accuracy and increase energy requirements. Furthermore, Gao et al. (2025) and, Al-Miran and Jasim (2025) observed that increasing the forward speed or working depth significantly increases slippage, thereby affecting the uniformity of seeding. Finally, the recent findings of Benkovic et al. (2023) highlighted that tillage systems influence the mechanical and agronomic properties of the soil, which indirectly contributes to variability in seed drill performance.

Although these contributions provide important insights, few studies have specifically analyzed the performance of a hand operated seeder in comparative conditions between several tillage methods, jointly assessing slippage, actual seeding depth, and seed deposit regularity. The technical evaluation of the manual planter equipment is an essential

requirement for improving production systems, as demonstrated by Dayou et al. (2021), which highlights the importance of in-depth analysis to provide guidance for technological choices. The findings of Hinnou et al. (2021), which focus on mechanization needs based on farmers' logic, provide a relevant conceptual framework but need to be supplemented with technical data on equipment performance. Such an evaluation is essential to better understand the interaction between soil characteristics, hand operated seeder dynamics, and final sowing quality. This study aims to evaluate the performance of a hand operated seeder subjected to different tillage systems after adaptation and adjustments based on previously observed shortcomings. This will enable technical recommendations to be made to optimize the seeder operating parameters according to the structural condition of the soil.

II. MATERIALS AND METHOD

A. The Study Area

This study was carried out during the 2025 growing season in the experimental research site of the Institute of Cotton Research Okpara in the municipality of Parakou (Figure 1). The site ($9^{\circ}18' \text{ N}$, $2^{\circ}41' \text{ E}$) is characterized by a Sudanese climate with a unimodal distribution, with a rainy season from May to October and a dry season from November to April. Annual rainfall varies from 900 to 1300 mm and the average daily temperature is around 27.5°C . The soil is classified ferruginous tropical according to the World Reference Base classification (FAO, 2006), with a sandy-loamy texture.

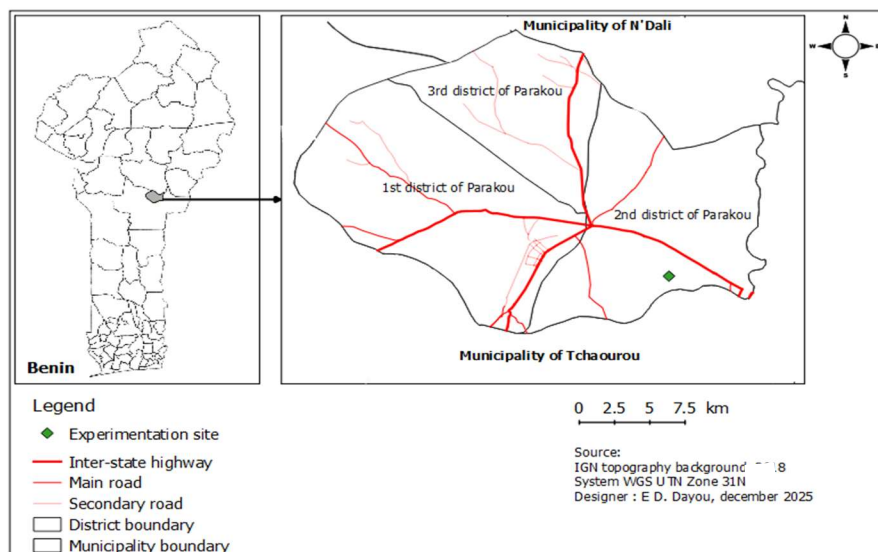


Figure 1 Map showing the experimentation site location

B. Presentation of the hand-operated seeder

The sowing equipment is a plastic hand operated seeder. This manual planter, composed of a hopper, a seed metering system, a press wheel, and a handle, contains eight seed hill openers, with 20 cm spacing between them, and 5 cm as length of the seed hill opener. A depth limiter rubber has been fitted

to the tines to reduce the sowing depth to 3 cm, which is recommended for cotton. It is an adjustable model whose settings have made it possible to isolate the operation of the seed units alternately in order to sow at 40 cm spacing (Table 1). A string line was used to maintain the 80 cm row spacing. This model is mainly manufactured from plastic (Plate 1).

Table 1 Technical characteristics of the hand-operated seeder

Components	Parameters	Unit	Initial values	Adjusted components
Wheel hub	Diameter	cm	40	
	Thickness	cm	10	
Seed hill opener	Quantity	-	8	4 functionals
	Length	cm	5	3
	Distance between 2 seed hill openers	cm	20	40
Seed metering	Disc	-	-	
	Quantity of cell	-	16	
	Theoretical debit	seed	2	

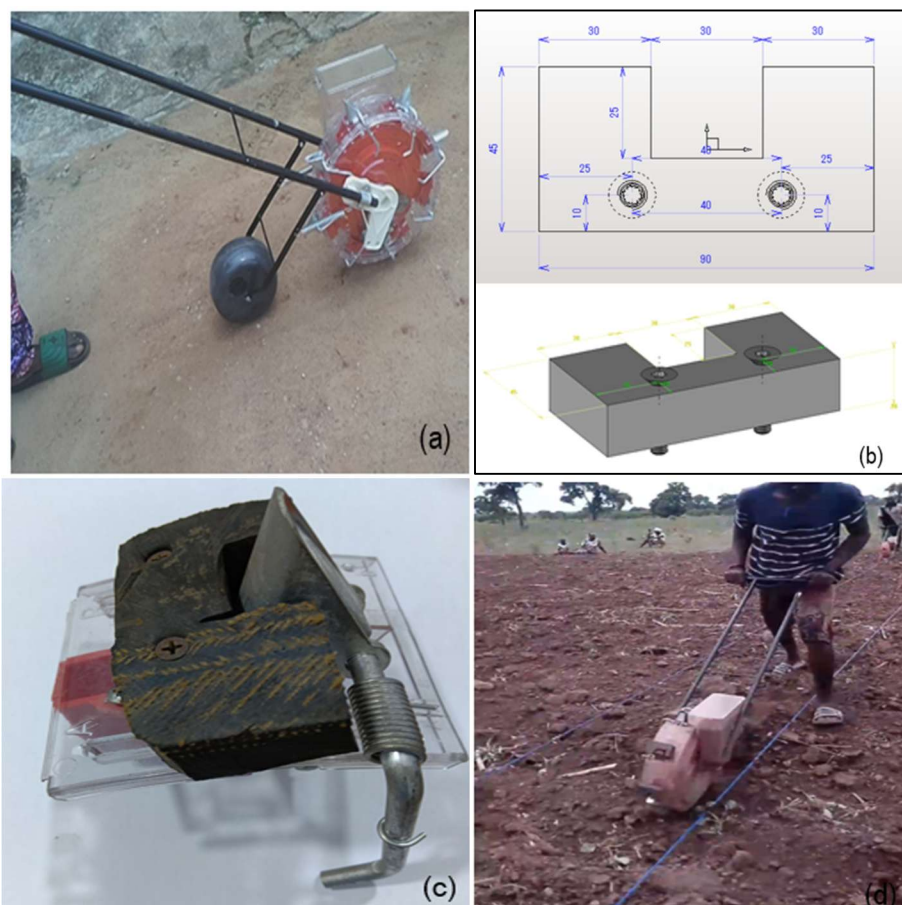


Plate 1 a) Initial model of the hand-operated seeder, b) Schematic computer-aided design of rubber by Dayou E. D., c) Fabricated rubber fixed on seed hill opener, d) Final planter adjusted

C. Experimental design

A split plot with four replication was used. The main factor was the tillage practices, with three modalities: manual tillage (MT), tractor plough (PT) and strip tillage with a tractor and coulters (ST). The sowing method is the secondary factor in subplots with two modalities: sowing with hand operated seeder (MP) and manual sowing (MS) as a control. Each elementary plot consisted of four (4) observation lines 15 m length, on which sowing was carried out with a spacing of 0.80 m between lines and 0.40 m between crops. Altogether, there were 36 elementary plots and 144 observation lines. The experiment was conducted using acid-delinted cotton seeds (*Gossypium hirsutum*) of variety OKP 768 adapted to experimental area.

D. Tillage practices and sowing

Tillage practices were carried out using a hoe for manual tillage (MT) at a depth approximately 5 cm, tractor plough (PT) at 15 cm, and strip tillage with a tractor and coulters (ST) at 15 cm. Sowing was carried out using a plastic hand operated seeder (MP). A preliminary check of the operating condition of the seeder was carried out on flat ground, selecting the best seed metering device and spacing between pockets to ensure proper seed distribution and proper operation of the press wheel. The manual planter was operated by the same operator on all plots to reduce operator bias. Manual sowing was carried out at a rate of 2 seeds per hole at a spacing of 0.8 x 0.4 m, giving a target density of 62,500 plants/ha.

E. Data collection

The sowing time was measured using a stopwatch on the four rows of each elementary plot. The time required for one hectare sowing (TR) was estimated using the relationship (1) following the methodology adopted by Smith et al. (1994) and López-Gómez and Van-Loon (2018) :

$$\text{Time required for sowing (h/ha)} = 0.36 \times \frac{t}{w \times d} \quad (1)$$

where

w = working width of implement (m) ;

d = travelling distance of the implement (m) ;

t = time measured during the travelling distance of the implement (s)

The effective daily field capacity was estimated based on the relationship (2) :

$$\text{Effective daily capacity (ha/day)} = 2.88 \times \frac{w \times d}{t} \quad (2)$$

where:

w = working width of implement (m) ;

d = travelling distance of the implement (m) ;

t = time measured during the travelling distance of the implement (s)

The amount of hill opener clogged were counted during the sowing operation. The number of seed hill opener clogged was counted on each row during sowing. At emergence, the total number of emerged hills and plants were counted in each elementary plot on the 7th and 10th days after sowing, respectively.

F. Data Analysis

Descriptive analyses were performed by determining the mean and standard deviation for each of these quantitative variables. An analysis of variance was performed on data relating to working time, hourly sowing capacity, clogging of the seed hill openers, covered seed holes, number of seed holes raised, number of seedlings raised per seed hole, and density. Two-factor analyses of variance with interaction were performed and validated after checking normality and homogeneity of residuals. Tukey's test was used to separate the means in case of a significant difference at the 5% threshold. When the residuals were not normal and homogeneous, the Kruskal-Wallis test was performed and supplemented by Dunn's test. All statistical analyses were performed with R 4.3.2 (R Core Team, 2023). Differences were considered significant at a 95% confidence level ($p < 0.05$).

III. RESULTS AND DISCUSSION

A. Time required for one hectare sowing and effective daily field capacity

The average sowing time according to sowing method and different tillage practices is shown in Figure 2. Analysis of variance indicated a very significant interaction between sowing method and tillage practice ($p = 0.00593$). Similarly, the main effects of sowing method and tillage practices were highly significant ($p < 0.001$) and very significant ($p = 0.00281$), respectively. The hand operated seeder showed significantly better performance across all tillage practices, by lowering the sowing time, which ranged from 3.1 ± 0.4 h/ha for manual tillage, 2.7 ± 0.5 h/ha for tractor plough, and 2.6 ± 0.5 h/ha for strip tillage, compared to 20.4 ± 6.3 h/ha, 14.4 ± 5.7 h/ha, and 19.5 ± 3.5 h/ha, respectively, for manual sowing. As regarding manual sowing, there is no significant difference of the performance among the three tillage practices. However, tractor plough led to a significant time saving versus manual sowing (Figure 2)

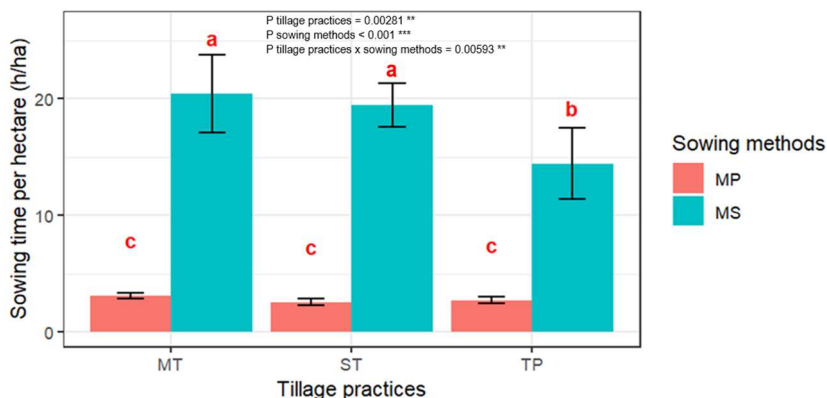


Figure 2 Time required for one hectare sowing

MT: Manual Tillage; TP: Tractor Plough; ST: Strip Tillage; MS: Manual Sowing; MP: Hand-operated Seeder

The effective daily capacity of the hand operated seeder in various tillage practices is presented in Table 2. It appears that the effective daily capacity was significantly influenced by both tillage practices and sowing methods, with a strong interaction between the two factors. Using hand operated seeder substantially increased effective daily capacity

compared to manual sowing across all tillage systems. Under manual sowing, the effective daily capacity remained low and statistically similar among manual tillage, tractor plough and strip tillage. In contrast, when hand operated seeder was used, there were significantly higher efficiencies on strip tillage and tractor plough than manual tillage practice (Table 2).

Table 2 Effective daily field capacity

Tillage practices	Sowing methods	Effective daily capacity (ha/day) ⁺		
		Min	Max	Mean±SD
Manual tillage	MS	0.26	0.70	0.43±0.1 ^c
	MP	2.19	3.13	2.62±0.4 ^b
Tractor Plough	MS	0.29	0.84	0.62±0.2 ^c
	MP	2.24	4.83	3.08±0.7 ^a
Strip Tillage	MS	0.31	0.60	0.43±0.1 ^c
	MP	1.90	3.80	3.19±0.4 ^a
p-tillage practices				0.001 **
p-sowing methods				< 0.001 ***
p-tillage practices x sowing methods				0.01 **

MS: Manual Sowing; MP: Sowing with hand-operated seeder; ⁺Working hours per man-day; *: Significant ($p < 0.05$), **: High significant ($p < 0.01$), ***: Very highly significant ($p < 0.001$); means with different letters are significantly different ($p < 0.05$).

B. Sowing quality and seed hill opener clogging

The number of complete clogging events of the seed wheel furrow openers during sowing per hectare is shown in Figure 3. Kruskal-Wallis test showed that tillage practices had no significant effect on the number of clogging events per hectare ($\chi^2 = 0.06$, $df = 2$, $p = 0.97$). However, tractor plough and manual tillage exhibited higher median values and greater variability, with several observations exceeding 100 clogging events per hectare. In contrast, strip tillage showed

predominantly zero or low values, indicating a significant reduction in clogging occurrence. These results suggested that strip tillage contributed to improve sowing uniformity by reducing clogging incidents. Clogging events were likely to be more severe in heavy soils, particularly under high soil moisture conditions, which in turn negatively affects sowing time and daily field capacity.

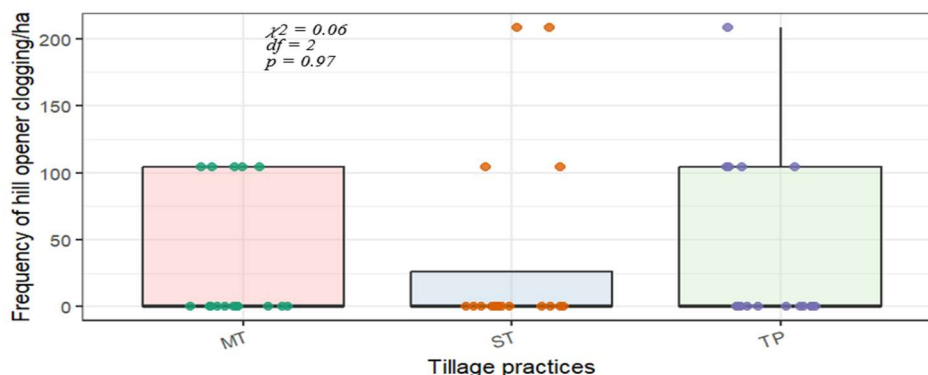


Figure 3 Frequency of hill opener clogging per hectare
MT: manual tillage; TP: tractor plough; ST: strip tillage

C. Seedling emergence per hill and plant density per hectare

The amount of seedlings observed per hill is highlighted in Table 3. It is shown that the number of seedling emergence were significantly affected by sowing method ($p < 0.01$),

whereas tillage practices and the interaction between factors had no significant effect ($p = 0.30434$ and $p = 0.87851$ respectively). Mechanical sowing resulted in a good performance of seedlings per hill, 2 plants per hill as recommended, compared to manual sowing which got less.

Table 3 Seedling emergence

Sowing methods	Tillage practices		
	Manual tillage	Tractor plough	Strip tillage
MP	2.07±0.10 ^a	1.99±0.08 ^a	1.94±0.22 ^a
MS	1.79±0.18 ^b	1.68±0.34 ^b	1.52±0.12 ^b
p-tillage practices			0.304
p-sowing methods			0.007**
p-tillage practices x sowing methods			0.878

MP: hand-operated seeder using manual planter; MS: manual sowing; ^a8 working hours per man-day; p-values: probability of significance; means with different letters in the same column are significantly different ($p < 0.05$). **: high significance ($p < 0.01$)

The variation of plant density per hectare based on different tillage practices and sowing methods is shown in

Figure 4. There is no significant interaction between sowing method and tillage practices ($p > 0.05$). However, the results

reveal a highly significant difference between sowing methods ($p = 0.007$), while the tillage practices had no significant effect on this parameter. Using the hand operated seeder conducted to the highest plant densities at emergence with varies from

60,735 to 64,732 plants/ha. But manual sowing recorded the lowest densities, 47,520 to 55,804 plants/ha, regardless of the tillage practices (Figure 4).

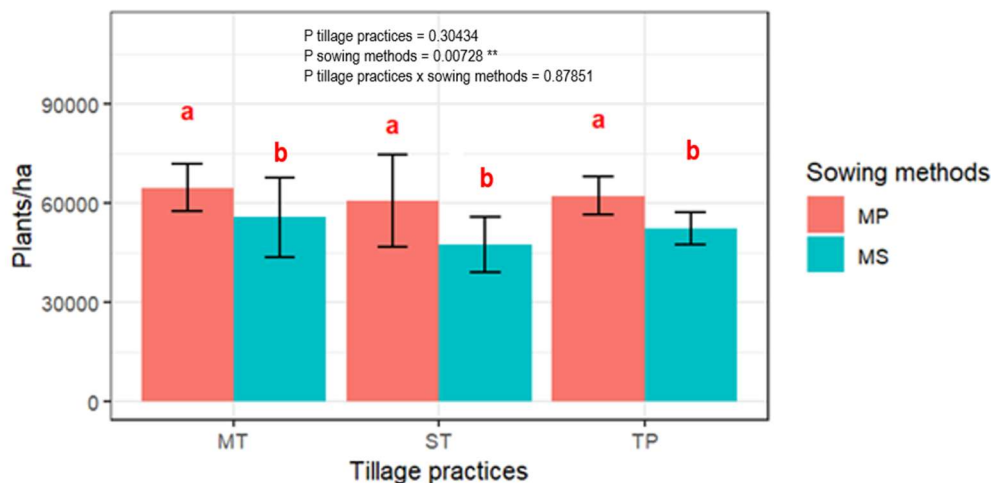


Figure 4 Plant density per hectare depending on tillage practices and sowing methods

MT: manual tillage; TP: tractor plough; ST: strip tillage; MS: manual sowing; MP: hand-operated seeder

IV. DISCUSSION

A. Working time and effective daily capacity

The results clearly indicated that both sowing method and tillage practice significantly affect sowing time and effective daily field capacity. The hand-operated seeder reduced sowing time across all tillage systems, demonstrating the efficiency of mechanized sowing compared to manual methods. Similar observations were reported by Sims and Kienzle (2016), who emphasized that mechanization improves labor efficiency and productivity. The shorter sowing times observed with manual planter compared to manual sowing confirm the observations of Guo *et al.* (2022), who demonstrated that the use of mechanized seeders significantly improves productivity, particularly by reducing working time and improving control over sowing depth.

The hand operated seeder allowed to sow 2 to 3 ha per day, unlike manual sowing, which was limited to less than 0.5 ha. The lower daily capacity under manual sowing across tillage practices aligns with findings of Sims and Kienzle (2017) which highlighted the limitations of manual operations even with improved tillage practices. In the same line, FAO (2019) suggested that adopting appropriate machinery can maximize energy efficiency and operational performance.

The significant interaction between sowing methods and tillage practices indicated that the benefits of improved tillage practices are fully realized only when combined with mechanical sowing. Then, the combination of adequate tillage practices and mechanized sowing provided the best results, significantly reducing sowing time and increasing daily field sowing capacity.

B. Seed hill opener clogging and sowing quality

Clogging of the seed hill opener is a key factor in the efficiency of sowing with hand operated seeder. When clogging is more frequent, it requires more time to clear the clogs, which increases the sowing time. The frequency of

clogging events observed in this study highlighted the influence of tillage practices on sowing quality and operational reliability. Seed hill opener clogging was significantly reduced under strip tillage, suggesting that reduced soil disturbance create cleaner seedbeds that limit obstruction to opener functioning. Similar findings have been found by Aikins *et al.* (2020) showing that soil conditions deeply affect furrow opener performance and blockage risk, ultimately influencing sowing uniformity and seed placement quality. Furrow openers must effectively manage residue and soil interaction to minimize physical barriers; inefficiencies in this process are linked to increased clogging, reduced seed-soil contact, and poorer sowing outcomes, as reported by Zhong *et al.* (2023). Prior studies also emphasize that residue accumulation in conventional tillage systems can obstruct opener operation and delay sowing, especially under moist heavy soils, reducing machine field efficiency (Madhusudan *et al.*, 2024). Thus, integrating improved opener designs and conservation tillage practices offers a practical strategy to enhance sowing quality by reducing clogging and maintaining consistent seed germination conditions. Furthermore, this frequency of clogging is due to high soil moisture conditions during sowing, with a cumulative total of 126 mm in the three days prior to the trial and 93 mm in the three days following. For greater efficiency, hand operated seeder should be used in medium to low humidity conditions to increase their efficacy and time efficiency.

C. Seedling emergence and plant density

The number of seedlings as recommended for cotton is 2-seed per hill, which allows for a density of 62,500 plants/ha for a 40 cm x 80 cm seed bed according to the Centre de Recherche Agricole - Coton et Fibre (CRA-CF, 2021). This recommendation is generally respected when using hand operated seeder, whereas it is not always the case with manual sowing. This is due to the prior adjustments such as the

functional 40 cm inter-hill spacing, the limitation of the sowing depth with the rubber on the hill opener and the choice of appropriate metering that delivers an average of 2 to 3 seeds per hill. Apart from the use of strings, which facilitated the spacing between pockets during manual sowing, complying with the sowing depth and number of seeds per hill is a challenging task. When trying to place 2 seeds per hill, manual sowing wastes a lot of time, but conversely, in some cases, the operators place too many seeds, and even leave some hills unsown. These constraints in manual sowing result in a very large number of plants per hill, which requires thinning, or missing seedlings, which leads to seeding again.

The variability in emergence density depending on the tillage practices confirms the importance of cultivation practices on the uniformity of the crop establishment. Ploughing promotes higher emergence density, but with high variability, while strip-tillage offers more uniform germination but at lower density. These results are similar to those reported by Yemadje *et al.* (2022), who show that strip-tillage better preserves soil moisture and structure, which stabilizes germination under water stress conditions, but can lead to slightly lower yields compared to conventional ploughing in the first early years. In the same context, Dou *et al.* (2024) indicate that strip-tillage systems conserve soil structure and moisture, making them a viable conservation tillage practice in sustainable agricultural systems.

All of these results therefore highlight the need for the rigorous integration of the technical specificities of equipment and tillage practices into local technical itineraries in order to optimize cotton productivity in Benin. Comparison with the findings of other researchers confirms that the choice of seed drills and soil cultivation methods must be adjusted according to soil and climate conditions and available resources in order to reduce the risks associated with uneven sowing and maximize yields.

These findings also confirm the importance of local initiatives to adapt and improve mechanization in line with the realities on the regions and the specific needs of farmers. This study provides valuable insights into sustainable mechanization and its positive impact on cotton farming in West Africa, in relation to current agronomic and socioeconomic challenges.

V. CONCLUSION

This study highlighted the significant benefits of using an adapted hand-operated seeder for cotton sowing under different tillage systems in Benin. Evaluating the seeding wheel is key for identifying technologies that enhance sowing efficiency and adherence to technical protocols. It addressed limitations in inter-hill spacing, sowing depth, and seed number per hill, ensuring target plant density, a crucial determinant of cotton yield. The study demonstrated that mechanical sowing substantially reduced sowing time, increased daily field capacity, and improved seedling emergence and plant density compared to manual sowing. Strip tillage notably reduced furrow opener clogging, enhancing sowing regularity under high soil moisture conditions. Overall, the effective interaction between appropriate tillage practices and locally adapted mechanization improved sowing quality

and operational efficiency. These findings emphasize the importance of integrating equipment adaptation and tillage practices into local technical recommendations to support sustainable and productive cotton farming systems. The research need to assess the impact of different soils and local conditions in different agroecological zones on seed drills performances.

AUTHOR CONTRIBUTIONS

E. D. Dayou: conceptualized the study, developed the methodology and software, performed formal analysis and data curation, and prepared the original draft; **A. Hougni:** contributed to methodology, validation, supervised the work and final review of the paper; **C. Kanlindogbè:** assisted with methodology, software, conducted experimentation, and contributed to the original draft; **G. F. Tiando:** carried out field experimentation and data collection; **E. Sekloka:** provided visualization, supervision, and final review of the paper.

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