PERFORMANCE EVALUATION OF MANUAL MAIZE SEEDING TECHNIQUES UNDER MINIMUM TILLAGE FIELD CONDITIONS

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ABSTRACT

The performance of an auto seeder, jab planter, cutlass and dibbler were comparatively characterized under farmers' field conditions using a Randomized Complete Block Design (RCBD) with four replicates. The goal of this study was to characterize the performance of the auto seeder, jab planter, dibbler, and cutlass under minimum tillage field conditions. In this study, seeding was possible in soils with 7.88%w.b. - 13.92%w.b., 1.50 g/cm^3 - 1.66 g/cm^3, and 0.59 MPa - 2.04 MPa, respectively. The *Abontem* maize seed with length, width, thickness, sphericity, thousand grain mass, and moisture content of 10.35 mm, 8.0 mm, 4.78 mm, 0.72, 289 g, 13.02%w.b. and 86.84%, respectively was used. Seed emergence, depth, inter-hill spacing, consistency, hilling consistency, effective field capacity, and physical power requirement ranged from 45% to 83.7%, 4.3 cm to 6.2 cm, 59% to 69.9%, 75% to 102.7%, 0.05 to 0.13 ha/h, 39 cm to 50.9 cm, and 463 W to 751 W respectively. The auto seeder and jab planter performed significantly ($p \leq 0.05$) worse than the cutlass and dibbler in terms of germination rates, hilling consistency and seeding consistency. For auto seeder, cutlass, dibbler, and jab planter seeding methods, economic feasibility analysis yielded BCRs of 1.04, 1.80, 1.86, and 1.22, respectively. Although the cutlass and dibbler outperformed the mechanized tools in germination rates, hill and seeding consistency, improvements to the metering mechanism and targeted training could enhance auto seeder and jab planter performance. Future studies could explore ergonomic adjustments and testing with crops like cowpea and rice under varying soil moisture conditions to further optimize seeding methods for smallholder contexts.

Keywords: Performance, evaluation, maize, seed emergence, consistency, auto seeder, dibbler.

Introduction

Agriculture is the major backbone of the economy of most African countries. Undoubtedly, the decline in the agricultural productivity of these countries often translates into a decline in the gross domestic product (GDP). In these countries, agricultural productivity and bumper harvest are often attributed to adequate rainfall or some favourable conditions. However, studies have shown that the decline in crop yield particularly in most Sub-Saharan African (SSA) countries is ascribed not only to climatic or agronomic factors but also to unimproved planting technologies (Blanc, 2012). For centuries, Africa has been known for its reliance on traditional agricultural practices of traditional agriculture and the use of primitive tools for general agriculture including land preparation, sowing, harvesting and postharvesting operations. Several studies have revealed that even in this modern era, a large majority of farmers in Sub-Saharan Africa still rely on unimproved technology for sowing of seeds (Blanc, 2012; Addo & Amponsah, 2018; Akolgo *et al*., 2022). The use of cutlass and hoe for the sowing of seeds is still prevalent and popular among many rural farmers in Sub-Saharan Africa. The study indicated that the over-reliance on these primitive tools in Sub-Saharan Africa is hugely associated with financial, technical, educational and socio-cultural factors (Blanc, 2012). Undeniably, the aforementioned factors predominate the reasons for low agricultural productivity in Sub-Saharan Africa. These factors are only part of the broader challenges affecting agricultural productivity in Sub-Saharan Africa region (Bjornlund *et al*., 2020). Binswanger & Pingali (1988) cites poor and unimproved seed sowing technologies as one of the factors for low agricultural productivity in Sub-Saharan Africa.

In Ghana, the sowing of grains, cereals and legumes is largely done using cutlass and dibbler. Generally, improved seed sowing technologies such as the auto seeder and jab planter are not common. According to Kansanga *et al*. (2019), the low utilization of modern seed sowing technologies among farmers in Ghana is attributed to sociocultural factors, conservativeness, poor technical know-how and financial constraints. Rural farmers in Ghana are conserved and reluctant to explore newly introduced implements. Again, the farmers often see the operation of these implements as sophisticated, cumbersome and skill dependent. Kansanga *et al*. (2019) however cites that the jab planter and the auto seeder have been designed to ensure simplicity and ease of operation. The foregoing discussions thus suggests and reiterates that the adoption rate of auto seeder and jab planter for seed sowing is low, especially in Ghana. It also shows that the seed sowing characteristics and benefits of the auto seeder and jab planter compared with conventional tools like cutlass and dibbler have not been widely studied. Furthermore, there is currently no data on the fatigue or drudgery associated with the various seeding methods. In their study on manual maize sowing techniques, López Gómez & Van Loon, (2018) clearly stated this limitation. Mechanizing planting of seeds is key to the establishment and overall performance of crops. In Ghana and other Sub-Saharan African countries, this cultivation method is done manually. However, there is very little report from region on how different manual seeding tools/devices/techniques could affect the technical performance and overall cost of operation. Fortunately, improved farm technologies have been the focus of some recent research. One such area of research is seed sowing technologies. Seed sowing in Sub-Saharan Africa has long been done with traditional tools such as cutlass and hoe. These tools for sowing cereals offer simplicity and ease of operation hence very renowned for peasant farming in Africa (Harris *et al*., 2001). Besides, they are relatively cheaper to develop and better suited to rural African communities where peasant farming is prevalent. However, the continual usage of these tools in this modern era must be supplemented with improved technologies given the rising population and increasing demand for food (Kumar *et al*., 2014; Hemathilake & Gunathilake, 2022). Therefore, the introduction of simple, efficient, cheap and easy-to-use seed sowing implements is paramount for increasing agricultural productivity in Sub-Saharan Africa, particularly Ghana. Hence the need for this research to compare the performance of different manual seeding techniques in a minimum tillage field condition. The main goal of this study was to characterize the performance of the auto seeder, jab planter, dibbler, and cutlass. This study specifically sought to; (i) characterize the soil and seed conditions that favour manual planting of maize; (ii) determine the seeding emergence, depth. Inter-hill spacing, seeding consistency, hilling consistency, effective field capacity and physical power requirement for maize seeding; (iii) calculate the benefit-cost associated with each seeding method; (iv) outline technical suggestions for future improvement of the seeding methods. The findings from this investigation are crucial for guiding policymakers towards a decision on whether or not to adopt the auto seeder and jab planter for seed sowing. It is also relevant to the agricultural mechanization sector as it provides relevant information about the operation and efficiency of the respective seed sowing techniques. The results of this research should provide a firm scientific foundation for future efforts to improve these sowing procedures, making them more efficient and effective.

Experimental

Study area

The study was conducted on the research fields of the CSIR-Crops Research Institute, Fumesua-Kumasi, Ghana in May 2022. The site is located on latitude 6°42'58.59" N and longitude 1°31'56.20" W. Fumesua is located in Kumasi in the transitional forest agroecological zone of Ghana. The region is characterized by bimodal rainfall regimes between May and August and September and November. The mean yearly temperature observed in Kumasi is recorded to be 25.9 °C (78.6 °F). Approximately 1147 mm (45.2 inch) of rainfall occurs on a yearly basis. The climate is mostly humid and warm with variations caused by the shifting of the Intertropical Convergence Zone (ITCZ). The rural inhabitants of this region are mostly farmers due to the relatively high rainfall and fertility of the land (Asare-Nuamah & Botchway, 2019). However, the system of farming is one of small land holdings in which primitive tools are mostly utilized. The elevation of the site is relatively flat with an average elevation of 101m. The study was conducted on a minimally tilled field to represent the field conditions under which farmers usually sow their seeds traditionally. Gramoxone (25.4% Paraquat) weedicide was applied following suggested recommendations by Agrobase, (2023) (i.e., 5.5L of Gramoxone liquid in 500L water per hectare) 7 days after weed slashing to create the minimum tillage conditions.

Research design and data collection

This study employed a randomized complete block design (RCBD) to evaluate the performance of four sowing methods: cutlass, dibbler, auto seeder, and jab planter. The experimental plot measured 80 m × 40 m and was divided into four blocks, each measuring 20 m in width and arranged side by side. Each block was further subdivided into four units, with each unit assigned one of the sowing methods. The random assignment of sowing methods within each block allowed for consistent replication while minimizing the impact of field variability (e.g., differences in soil composition or moisture) on results.

Each sowing method was replicated four times within the setup, and sowing was conducted by trained experts for each respective method to maintain accuracy and consistency. Data collection focused on seeding count, seeding depth, and percentage emergence, which are critical indicators of seeding performance. Within each unit, random sampling was used to select 50% of the total seeding holes (hills) for measurement. This sampling approach ensured a representative analysis of emergence and depth across the plot while maintaining manageable data collection.

Description of seeding methods

The auto seeder Figure 1(b) is a simple, hand-operated implement designed to sow seeds mechanically according to the farmer's settings. The sharp-edged and sharp end of the auto seeder allows it to create holes in the soil and drop seeds simultaneously (Sani *et al*., 2019). The auto seeder is simple, gender-neutral and is operated by one person at a time. It has adjustable seeding rate of 1-5 seeds and can be used to sow medium to large-seeded crops such as cowpea, maize and groundnuts. The seed diameter can range from 3-15 mm. It automatically plants when the planting tip is pushed into the soil and then lifted up from the soil (Kansanga *et al*., 2019). This particular auto seeder is the BP-2 auto seeder manufactured in China by Henan Best Machinery Co. Ltd.

Fig. 1: The seed sowing tools (a) dibbler pole (b) auto seeder (c) jab planter (d) cutlass

The jab planter Figure 1(c), like the auto seeder, also bore and drop seeds concurrently through its pointed tip (Osei-Bonsu *et al*., 2015). However, the main difference between the two is in their mode of operation. The auto seeder is designed to operate first by requiring the user to press on its handle and then released immediately in order to drop seed. The jab planter on the other hand requires the user to close and open its flexible handle in succession in order to drop seed (Chen *et al*., 2019). The jab planter used in this study was manually fabricated at the Department of Agricultural Engineering Workshop, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi. Table 1 summarizes the basic technical characteristics of the seeding tools.

Pulling the handles of the jab planter apart causes the seeds or fertilizers to be delivered from the hopper to settle at the furrow opening for a short time (the beak). This action happens at the same time as piercing/punching the soil. Pulling the handles together is the second motion, which happens immediately after the first. This motion causes the furrow opener (beak) to open, allowing the seed/fertilizer to be delivered into the newly produced planting furrow. The seed/fertilizer metering devices are also closed as a result of this action. In order to reach the desired plant population, these two acts must be done several times and coordinated with the operator's footsteps. The operator must pay close attention to the dropping sounds made at each operation to ensure that the implement is truly planting and that there is no blockage. When the seed/fertilizer hoppers are about to be emptied, the operator will have to utilize his or her weight judgment to re-fill them. Like the auto seeder, the seeding rate for the jab planter can be adjusted (Aikins, 2010; Osei-Bonsu *et al*., 2015).

TABLE 1

Technical characteristics of the seeders

Seeder type	**No-load mass (kg)**	**Dimension (m)**	**Seed hopper present**	**Fertilizer hopper present**	**Seed delivery**
Dibbler pole	2.1	Diameter - 0.03 Height - 1.5	No	No	By hand
Cutlass	0.5	Length - 0.61 Width - 0.03 Thickness - 0.005	No	No	By hand
Jab planter	3.1	Length - 0.18 Width - 0.12 Height - 0.9	Yes	Yes	Gate mechanism
Auto seeder	1.8	Length - 0.19 Width - 0.15 Height - 0.81	Yes	Yes	Roller mechanism

A dibbler (sometimes spelled 'dibber') is a gardening tool used to create holes in the soil for planting seeds, bulbs, tubers, seedlings or small plants. A dibbler comes in many sizes and shapes, including the straight dibbler, T-handled dibbler, trowel dibbler, and L-shaped dibbler. Regardless of the shape, a dibbler must have a tapered end that is pushed to the required depth into the soil (Ma *et al*., 2010). This study used a straight dibbler made from a 1.5m-long tree branch and sharpened at the tip. The dibbler is pushed into the ground to make a hole. The seeds are then dropped into the hole and covered.

In Africa, the cutlass is the most widely used basic farm tool. Simple farm tools like a cutlass are the best that most farmers who lack the funds to purchase mechanised farm equipment can find. The use of cutlass on the farm is very broad ranging from clearing of grass, cutting of trees, planting of seed and so on. It usually comes with a sharp-edged blade and a handle mostly made of wood (D'Avignon, 2018). In this sowing experiment, the sharp edge was used to dig into the soil and the seed (held in the hands) carefully dropped into each hole and covered.

Seed characterization and germination test

The dimensions, sphericity and thousand mass of grain for the *Abontem* maize variety obtained from the Cereals Division of the CSIR-Crops Research Institute, Fumesua, were determined following standard methods adopted by Yenge *et al*. (2018) and Ofori *et al*. (2019). The grain moisture content prior to sowing was determined in-situ using a John Deere moisture meter (model SW08120). A sample of 100 maize seeds was subjected to a standard field germination test to determine the percentage viability of the seeds.

Soil sampling

Prior to seeding trials, three replicates of soil samples were randomly taken for soil moisture content and bulk density determination at depths of 0-10, 10-20, 20-30, and 30-40 cm using a soil auger and a 5 cm diameter soil core sampler with a mallet. For soil moisture, samples were oven-dried at 105°C for 24 h (DeAngelis, 2007). On-site penetrometer tests using the Eijkelkamp penetrologger CBR (model 0615SA), which features a 60° circular steel cone with a base area of 100 mm², were performed at depths of 0-10, 10-20, 20-30, and 30-40 cm to measure soil strength. The penetrologger probe is pressed vertically into the soil while recording the force required for penetration. This measure helps determine soil compaction levels, which directly affect the seeder's performance.

Seeder calibration and setting

Before subjecting the jab planter and auto-seeder to field testing, a laboratory test was performed to evaluate its performance and make any necessary adjustments or modifications. The metering device was properly adjusted to avoid mechanical damage to the seeds.

Evaluation parameters

Performance test parameters including seeding consistency (%), effective field capacity (ha/h), hilling consistency (%), seeding depth (cm), seed emergence (%), inter-hill spacing, and physical energy expenditure (W) were determined for each sowing method using relevant procedures as follows:

Seed emergence

Following 21 days post-planting, observations were conducted to evaluate seed emergence across different seeding methods. The primary focus was on seedlings with at least two shoots, allowing for an assessment of successful establishment rather than initial germination alone. Observations were carried out per seeding method, and the percentage seed emergence was estimated following Equation 1, as proposed by Carlson & Clay (2016) at a recommended seeding rate of 25 kg/ha (APNI and CSIR-SARI, 2022).

$$Seed\ emergence\ (\%) = 100 \times \left[\frac{Plant\ population\ after\ emergence}{Seeding\ rate\ (seeds/ha)}\right] \quad (1)$$

While maize seeds typically germinate within 3-7 days under optimal conditions, the decision to assess emergence after three weeks was intentional. Field emergence can be influenced by environmental factors, including soil moisture levels, temperature fluctuations, and soil compaction, which can all delay uniform emergence. Additionally, the variety of planting methods tested warranted an extended observation period to ensure a representative capture of emergence rates across conditions.

The 21-day window provided a comprehensive view of overall emergence success, enabling a more accurate comparison across the seeding methods applied. By observing at this stage, we ensured that the assessment reflected not only the initial germination but also the establishment of seedlings likely to survive beyond the vulnerable early stages.

Seeding consistency

The seeding consistency was calculated using equation 2. Total seeds per hill was determined by manually digging out the cover soil and counting the number of seeds dropped per seeding method.

$$Seeding\ consistency\ (\%) = \frac{Actual\ number\ of\ seeds\ dropped}{Theoretical\ (expected)\ number\ of\ seeds} \quad (2)$$

Hilling consistency

For each row, the total number of missed hills was tallied separately. These observations were repeated thrice for each method of sowing. The percentage hilling consistency of the seeding technique was determined using equation 3:

$$Hilling\ consistency\ (\%) = \frac{Actual\ number\ of\ hills\ planted}{Theoretical\ (expected)\ number\ of\ hills} \quad (3)$$

Effective field capacity

The time it took to sow three rows of maize seeds per sowing method was recorded using a stopwatch. The effective field capacity (timeliness of operation) for each sowing method (man-hours/ha) was estimated using equation 4 following the methodology adopted by Smith *et al*., (1994) and López Gómez & Van Loon (2018).

$$Effective\ field\ capacity\ (ha/h) = 0.36 \times \left\lfloor \frac{W_e \times D}{t} \right\rfloor \quad (4)$$

Where:

W_e = Effective working width of implement (m)

D – Distance traveled by the implement (m)

t = Total time spent (s)

Seeding depth

A self-constructed, graduated depth probe was used to measure planting depth, similar to the one used by Bobobee *et al*. (2014) was used to assess the depth of seeding as dictated by the depth of penetration of the seeding technique/tool. This probe was constructed from a sturdy stick, with clear depth graduations marked along its length to allow for accurate measurements during the experiment. The seeding depth was determined by vertically pushing the probe with minimal force through the sampled hill for each sowing method until it struck the hard ground.

Inter-hill spacing

The level of concordance with the recommended inter-row spacing of 40 cm for maize seeding was determined by measuring the distance between hills using a carpenter's tape measure for each seeding method.

Drudgery estimation

For each sowing method, a Polar heart rate sensing device (RS 400) was used to obtain the heart rate of each person during the sowing operation. Each person was given 10 minutes of rest before and after any field activity to allow their heart rate to stabilize. Gross energy consumption (Watts) was calculated by tracing the mean heart rate for a field activity on the heart rate-energy conversion chart developed by Jones (1988).

Statistical analysis

Data collected on evaluation parameters were analyzed using SPSS version 22.0 (IBM Corp., 2013) . Simple descriptive statistics such as percentages, means and skewness were used to explore the data. ANOVA was used to compare the significance of the mean differences among the four seeding methods at a 5% significance level.

Economic assessment

Benefit Cost Ratio (BCR) was estimated to measure the cost effectiveness of each sowing technique. BCR was calculated using equation 5 following the method of Shively (2012).

$$BCR = \frac{\text{Total benefit}}{\text{Total cost}} \qquad (5)$$

The fixed (ownership) and variable (operating) expenses were considered to determine the total cost of production per seeding method following relevant cost recommendations by Hunt (1983). Table 2 provides relevant cost assumptions adopted in the estimation of fixed and variable costs per seeding method.

TABLE 2

Relevant cost assumptions

Cost item	Assumption	Reference
Salvage	10% of purchase price	Hanna (2001)
Interest	5% on principal	Hunt (1983)
Insurance	0.5% of purchase price	Hunt (1983)
Tax	0% of purchase price	Hunt (1983)
Shelter	0.5% of purchase Price	Hunt (1983)
Repairs and maintenance	5% of purchase price	Hanna (2001)

Total cost estimation considered the effective field capacity per seeding method, cost of all production activities other than planting such as cost of seed, land preparation, fertilizer application, harvesting, threshing etc. for two production cycles per year. Total benefit (revenue) considered seed emergence (%) per seeding method, actual yield (kg/ha) and cost per kg of maize.

Results and discussion

Seed and soil characteristics

The physical characteristics of sampled *Abontem* maize variety used for the seeding trials are summarized in Table 3. Seed length, seed width, seed thickness, sphericity, thousand grain mass, seed moisture content and germination percentage for *Abontem* seed were 10.35 mm, 8.0 mm, 4.78 mm, 0.72, 289 g, 13.02 %w.b. and 86.84%, respectively.

TABLE 3

Physical characteristics of Abontem maize variety

Parameter	Mean	StDev
Length (mm)	10.35	0.28
Width (mm)	8.00	0.06
Thickness (mm)	4.78	0.08
Sphericity	0.72	0.00
1000-grain mass (g)	289.01	5.13
MC (%w.b.)	13.02	0.86
Germination (%)	86.84	2.83

Figure 2 illustrates the soil conditions under which the study was conducted. Soil moisture content, soil bulk density and soil penetration resistance (cone index) ranged from 7.88 %w.b. to 13.92 %w.b., 1.50 g/cm^3 to 1.66 g/cm^3 and 0.59 MPa to 2.04 MPa, respectively.

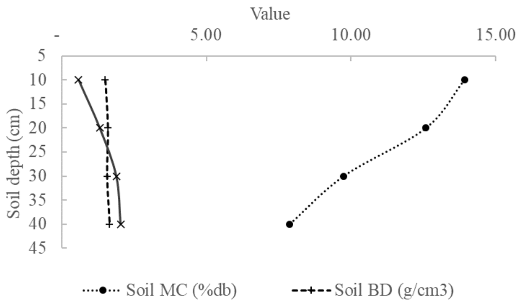

Fig. 2: Soil conditions at 10-40 cm soil depth

With increasing soil depth from 10 cm to 40 cm, soil penetration resistance decreased while soil moisture content and bulk density increased. The observed trend of decreasing soil strength with increasing soil moisture was expected and concurs with studies by Tekeste *et al*. (2008) and Adeniran & Babatunde (2010).

Comparative evaluation of seeding techniques

From the results of the study, the auto seeder recorded the lowest rate of seed germination when compared to the other methods, with seed emergence of 45% (Figure 3). The dibbler recorded the significantly highest seed germination rate at 83.7%. However, none of the seeding methods reached the Table 3's optimum germination rate of 86.8%. This finding suggests that a variety of factors, such as soil condition, tillage method and management practices may influence seed emergence. Unexpectedly, auto seeder and jab planter had lower germination rates than manual methods. This probably could be influenced by the operators' inefficiencies in handling the devices which might have affected the ability of the seeding mechanism to release the correct number of seeds. Secondly, there is the possibility that the seeds being planted were possibly damaged in the course of their release into the soil.

Perhaps the operators of the auto seeder and jab planter were unfamiliar with the tools, or the seeding mechanism failed to release the correct number of seeds. Prior to the seeds being planted, there was also the possibility of seed damage being caused by the auto seeder and the jab planter.

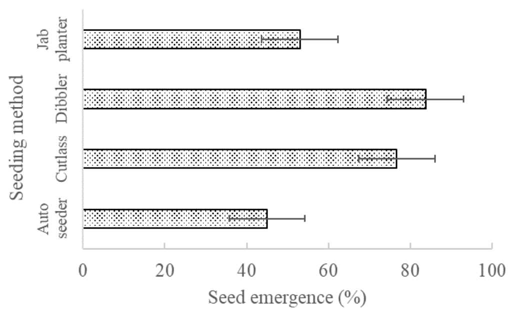

Fig. 3: Percentage seed emergence per seeding method

Figure 4 depicts the results of hilling consistency and seeding consistency per sowing method. For percentage hilling consistency, the use of the dibbler and cutlass exceeded the ideal recommendation (100 hills per 40 m distance) by about 2% and 0.7%, respectively. The auto seeder recorded the least percentage significant hilling consistency (75%), followed by the jab planter at 91%. Conversely, the jab planter recorded the significantly lowest seeding consistency of 59% whereas the cutlass recorded the highest at 90%.

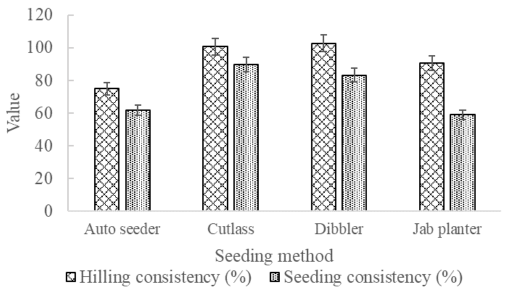

Fig. 4: Hilling and seeding consistency per seeding method

Based on the results for hilling and seeding consistency, it seems that the semi-automated seeding methods are not effective as the traditional cutlass and dibbler methods.

The average seeding depth for the auto seeder, cutlass, dibbler and jab planter is illustrated in Figure 5. The dibbler recorded the significantly highest seeding depth of 6.2 cm whereas the cutlass recorded the least (4.3 cm).

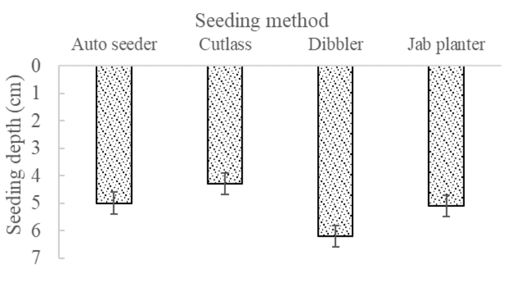

Fig. 5: Seeding depth for each sowing method

Seeding depth variations may have been influenced by factors such as tool weight, operator experience, soil moisture content and ease of use of the tool. Generally, the average seeding depth for the four seeding methods ranged between 4.3 cm and 6.2 cm. However, these values were within the ideal sowing depth recommendation of 3-8 cm for maize (Mbazu, 2021).

The physical energy requirement ranged (drudgery estimation) between 463 W and 751 W for jab planter and dibbler, respectively (Figure 6). Sowing with the dibbler consumed significantly more physical energy than the auto seeder, cutlass, and jab planter. One possible explanation is that the same person was digging and seeding at the same time. This finding may be confirmation of the highest seeding depth recorded for the dibbler in Figure 5.

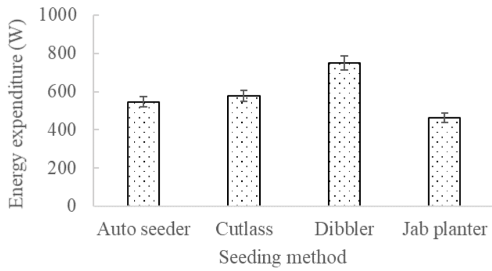

Fig. 6: Physical energy expenditure for each sowing method

Table 4 provides a statistical summary of the evaluation parameters for the seeding methods. Except for effective field capacity and inter-hill spacing, all other parameters showed significant differences.

TABLE 4

Statistical analysis summary

Seeding method	Evaluation parameter						
	Emergence (%)	Field capacity (ha/h)	Hilling consistency (%)	Seeding consistency (%)	Inter-hill spacing (cm)	Seeding depth (cm)	Energy expenditure (W)
Auto seeder	45.0^{b}	0.112	75.0^{b}	62.0^{b}	50.7	5.0^{b}	546^{b}
Cutlass	76.7^{a*}	0.131	100.7^{a}	89.9^{a}	40.8	4.3^{c}	577^{b}
Dibbler	83.7^{a}	0.053	102.7^{a}	83.3^{a}	39.0	6.2^{a}	751^{a}
Jab planter	53.0^{b}	0.104	90.7^{a}	59.0^{b}	45.4	5.1^{b}	463^{b}
LSD	22.84	ns	12.84	11.05	ns	0.56	130.2

* Within each column, means followed by the same letter are not significantly different at $\alpha = 0.05$

Field capacity ranged from 0.05 ha/h to 0.13 ha/h for the dibbler and cutlass respectively. When compared to the other seeding methods, Cutlass was the fastest (approx. 8 man-h/ha), likely due to operator experience and lower implement weight (Table 1). Like the energy expenditure, the dibbler's poor timeliness was caused by the fact that there was only one operator seeding and digging holes simultaneously.

Inter-hill spacing ranged from 39 cm to 51 cm for dibbler and auto seeder seeding methods, respectively. The cutlass and dibbler were closer to the recommended spacing of 40 cm than the auto seeder and jab planter. This further substantiates the significance of operator experience in the successful operation of the seeding tool.

Other issues observed during the field evaluation of seeding methods include:

(i) The presence of weed stubbles on the soil surface hampered the operation of the auto seeder and jab planter, resulting in several stops and consequently low timelines.

(ii) The jab planter handle caused some discomfort, even injuring the operator.

These findings suggest that semi-automated seeding methods, such as the jab planter and auto seeder, may not be appropriate for minimal-tillage conditions. Prior to planting with these semi-automatic seeders, it may be necessary to remove all debris from the field. Secondly, to make working with the jab planter handle more comfortable for long periods of time, the ergonomics of the handle should be improved.

Economic viability

The economic viability of the auto seeder, cutlass, dibbler and jab planter is summarized in Table 5. From results, BCR > 1 makes all four seeding methods economically viable. However, the cutlass and dibbler were more profitable than the auto seeder and jab planter. Effective field capacities and percentage seed emergence of the seeding methods may explain the differences.

TABLE 5

Economic assessment of seeding methods

Cost Item	Seeding Method			
	Auto seeder	**Cutlass**	**Dibbler**	**Jab planter**
Purchase price (GH₵)*	500	50	10	400
Salvage value (GH₵)	50	5	1	40
Economic life (years)	2	2	1	2
TOTAL COST				
Fixed cost				
Depreciation	225	22.5	9	180
Interest	13.75	1.375	0.55	11
Insurance	2.5	0.25	0.05	2
Tax	0	0	0	0
Shelter	2.5	0.25	0.05	2
Total fixed cost (GH₵/y) - (A)	243.75	24.375	9.65	195
Variable cost				
Field capacity (ha/h)	0.112	0.131	0.053	0.104
Labour for planting (GH₵/person)	50	50	50	50
Number of workers (man-h/ha)	9	8	19	10
Cost of planting (GH₵/ha)	446	382	943	481
Other production costs (GH₵/ha)	9,780	9,780	9,780	9,780
Total production cost (GH₵/ha)	10,226	10,162	10,723	10,261
Production cycles per year	2	2	2	2
Annual production cost (GH₵/y)	20,453	20,323	21,447	20,522
Repairs & maintenance (GH₵/y)	25	2.5	0.5	20
Total variable cost (GH₵/y) - (B)	20,478	20,326	21,447	20,542
Total cost (GH₵) - (A + B)	20,722	20,350	21,457	20,737
TOTAL BENEFIT				
Seed emergence (%)	45	76.7	83.7	53
Expected yield (kg/ha)	4,500	4,500	4,500	4,500
Actual yield (kg/ha)	2,025	3,451.5	3,766.5	2,385
Annual yield (kg)	4,050	6,903	7,533	4,770
Price (GH₵/kg)	5.3	5.3	5.3	5.3
Total annual revenue (GH₵)	21,465	36,586	39,925	25,281
Benefit-cost	**1.04**	**1.80**	**1.86**	**1.22**

*GH₵ 11.00 = US$ 1.00 as at May 2022

Conclusion and recommendation

In this study, maize seeding was possible in soils with the range of soil moisture content, soil bulk density, and soil penetration resistance (cone index) at 10 - 40 cm soil depth as follows: 7.88%w.b. - 13.92%w.b., 1.50 g/cm^3 - 1.66 g/cm^3, and 0.59 MPa - 2.04 MPa, respectively. Abontem seed used for this study measured 10.35 mm, 8.0 mm, 4.78 mm, 0.72, 289 g, 13.02%w.b., and 86.84%, respectively, in length, width, thickness, sphericity, thousand grain mass, and moisture content. Across the seeding methods, the ranges for seed emergence, seeding depth, inter-hill spacing, seeding consistency, hilling consistency, effective field capacity, and physical power requirement were respectively 45% - 83.7%, 4.3 cm - 6.2 cm, 59% - 69.9%, 75% - 102.7%, 0.05 - 0.13 ha/h, 39 cm - 50.9 cm, and 463 W - 751 W. Based on results of the economic feasibility study, the BCR for the auto seeder, cutlass, dibbler, and jab planter seeding methods was determined to be 1.04, 1.80, 1.86, and 1.22, respectively.

The following suggestions may improve manual seeding under minimum tillage:

(i) Auto seeder and jab planter design changes should focus on the seed metering mechanism to favour minimal tillage.

(ii) Hands-on training on the operation of auto seeder and jab planter is recommended for users to help improve hilling consistency and seeding consistency.

(iii) The dibbler could be improved in the future by incorporating the ability to set the seeding depth to the desired level.

(iv) The efficiency of dibbler seeding could be improved through a two-person operation.

(v) The ergonomics of the jab planter handle should be improved so that it is more comfortable to use for long periods of time.

Future studies should consider assessing the impact of the jab planter, auto seeder, and other semi- and fully automated planters on seed damage. It would also be interesting to see a replication of this study for crops such as cowpea and rice using mechanised seeders and varying soil moisture conditions.

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