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FIELD PERFORMANCE ANALYSIS OF A TRACTOR-DRAWN TURMERIC RHIZOME PLANTER

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Abstract: A field performance analysis of a developed prototype tractor-drawn turmeric planter is presented. The experiment was randomized in a factorial design of three planter levels of rhizome lengths (30, 45 and 60 mm) and operational speeds of 8, 10, and 12 kmh^{-1}. An average mass of 3 kg of wholesome turmeric rhizomes were introduced into the hopper of the planter and planted in 90 m^2 of experimental plot. During field evaluation of the machine, the effective field capacity, field efficiency, missing index, multiple index and planting depth were considered; whereas laboratory tests were conducted to evaluate the planter's seed rate, percentage rhizome bruise wheel slippage and fuel consumption. Results obtained show that the maximum seed rate was 0.283 th^{-1}. The maximum percent bruised turmeric rhizome was found to be 30.08%. The mean effective field capacity varied between 0.63 - 0.96 hah^{-1}, at operational speeds of 8 and 12 kmh^{-1}, respectively and 45 mm rhizome length. The mean field efficiency was obtained to be 65.8%. The maximum wheel slippage of 4.37% and fuel consumption of 3.8 lha^{-1} were obtained at the machine speeds of 8 kmh^{-1} and 12 kmh^{-1}, respectively; whereas the minimum wheel slippage of 3.14% and fuel consumption of 2.2 lha^{-1} were obtained at the machine speeds of 12 kmh^{-1} and 8 kmh^{-1}, respectively for the range of the studied turmeric rhizome length. The highest and lowest percentage turmeric rhizome miss index of 35% were recorded for turmeric rhizome length of 30 mm at a speed of 10 kmh^{-1} and 8 kmh^{-1}, respectively. An average planting depth of 68 mm was obtained. The numerical optimization approach was adopted to obtain an optimal operational parameters of 12 kmh^{-1} speed and 45 mm turmeric rhizome grading size with an overall desirability index of 0.73. An economic evaluation was calculated using the principle of payback period which was obtained to be very small (1.64 years) compared to the life of the planter of 17 years. Prospects for future works were suggested.

Keywords: *Turmeric rhizome, field evaluation, optimization, performance parameters, planter.*

INTRODUCTION

Turmeric (*Curcuma Longa Linn*) is a stem tuber crop. It belongs to the same family as ginger (Zingiberaceae) and grows in the same hot and humid tropical climate. In Nigeria, turmeric is cultivated mostly on subsistent bases in about 19 states and given different local names depending on the area.

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It is called *atale pupa* in Yoruba; *gangamau* in Hausa; *nwandumo* in Ebonyi; *ohu boboch* in Enugu (Nkanu East); *gigir* in Tiv; *magina* in Kaduna; *turi* in Niger State; *onjonigho* in Cross River (Meo tribe) [1]. It is native to India and Southeast Asia. India is the largest producer, consumer and exporter of turmeric. Indian turmeric has been known to the world since ancient times. It has been used as a dye, medicine and flavoring since 600 BC [2]. To most people in India, from housewives to Himalayan hermits, turmeric is affectionately called the 'Kitchen Queen', the main spice of kitchen [3]. It has many nutritional and medicinal advantages [4 - 6].

In spite of increasing demand for derived products of turmeric in Nigeria which makes its large scale production attractive, it is still cultivated mainly in small plots around homes. In Nigeria, turmeric has not gained the desired attention that will boost its large scale production. From researches carried out, turmeric has little or no mechanization in its production processes from planting to harvesting in Nigeria.

The only mechanization of turmeric production in Nigeria is the land preparation (ploughing and harrowing). Turmeric, if fully mechanized, will ensure timeliness of operation in the farm and reduce cost and drudgery associated with planting, mulching and harvesting. There is a strong research support for cultivation of turmeric on scientific lines, as National Root Crops Research Institute Umudike, Nigeria and its Research Stations located in many states in Nigeria are conducting a multi-locational trial of many turmeric accessions to ensure official release for cultivation by Nigerian farmers.

Planting of turmeric has been a challenge to the farmers in Nigeria due to lack of planting machines. The farmers are left to the traditional method of planting with hoes and cutlasses. This method is time consuming, labour intensive, and associated with human drudgery and human energy intensive. It was noted that farm operations are timely by nature, and whatever help shortens the time required for planting operation will help circumvent the effect of adverse weather conditions [7]. To achieve food security through large scale production of crops with high prospects such as turmeric, there is much need to provide a planting aid to Nigerian farmers to alleviate their suffering and improve the dignity of farm work. However, the recent climatic change which results in delayed early rain and short duration of annual rainfall affects the maturity of the turmeric rhizomes due to the long time taken in manual planting of turmeric. In most cases, turmeric does not attain 7 – 9 months maturity before rainy season elapses due to delay as a result of time spent in the use of manual operation. Bearing in mind the above points, this study was carried out with the objective of analyzing the field performance of a developed tractor-drawn turmeric planter, optimizing its operational parameters as well as the economic evaluation.

MATERIAL AND METHODS

Experimental design and optimization

To evaluate the performance of the planter, three levels of rhizome length (30, 45 and 60 mm) and planter speed variables (8, 10, and 12 kmh^{-1}) were randomized in a general factorial design to carry out the field experiment. The relative contributions of each of the independent variables to response variables (V_r) were determined as shown in Table 1.

Table 1. Levels of experimental independent variables of the randomized factorial design layout.

Independent variables	***Symbols***		***Levels***	
	Actual	***Coded***	***Actual***	***Coded***
			8	*-1*
Speed (kmh^{-1})	*S*	*A*	*10*	*0*
			12	*1*
			30	*-1*
Rhizome grade (mm)	R_g	*B*	*45*	*0*
			60	*1*

The data were subjected to analysis of variance (ANOVA) using design expert software. Optimization of operational parameters of the tractor-drawn turmeric planter was done using the technique of multivariate response of numerical optimization, referred to as desirability index [8, 9] expressed in Eq. (1) as:

$$D_i = [\sum_{i=1}^{n}(V_r)]^{\frac{1}{n}} \quad (1)$$

Where: D_i = desirability index; V_r is the response variable (planted rhizome, missing, bruise, and multiple); n is the total number of responses = 4; $0 \leq D_i \leq 1$; with 0 and 1 representing the minimum and maximum desirable coded levels, respectively.

D_i shows the degree of compatibility or how desirable the response variables are at any given experimental input variable. The goal of numerical optimization is to maximize planted rhizome, minimize missing, bruise, and multiple indices. This study considered the goal for the independent variables (operational speed and grading size) at any process level within the ranges of the design values, whereas the response variables have minimum missing, bruises, and multiple planting as the goal. The optimal solution of the system, which represents the best functions of the planting process is indicated by the high value of D_i. The optimum experimental factor values were obtained from the four response variables that maximize D_i [9, 10].

Experimental Procedure

Calibration

Calibration was necessary to ascertain optimal performance of the planter. The hopper units were loaded with turmeric rhizomes. The ground wheel was jacked up for free turning of the drive wheels. Marks were made on the drive wheels and the body of the planter for easy and convenient counting of the drive wheel complete revolution. The numbers of turmeric rhizomes dropped within five revolutions of the drive wheel were recorded for three different turmeric rhizome lengths. The turmeric rhizomes were also investigated for visible damages.

A 90 x 90 m^2 field located at the Federal University of Technology, Minna farm site, was ploughed and harrowed in readiness for the testing operation. The field was sub divided into smaller plots of 30 x 30 m^2. Cleaned turmeric rhizomes were obtained from National Root Crops Research Institute (NRCRI) Nyanya sub-station, Abuja - Nigeria. The rhizomes were sorted into 30, 45 and 60 mm lengths to determine the required length for optimum performance. The planter was hitched to Eicher 5660 tractor make, loaded with turmeric rhizome and then planted on the 30 x 30 m^2 sub plots at three different operational speeds of 8, 10 and 12 kmh^{-1} (Fig. 1). The different field performance evaluation tests of the tractor-operated turmeric planter involved:

1. Test for seed rate and percent rhizome bruise/damage.
2. Evaluation of the viability of the planter through field performance tests to measure the miss index, multiple index, planting depth, effective field capacity (E_{fc}), field efficiency (E_f), fuel consumption and wheel slippage.

Figure 1. Field test of the turmeric planter.

Rhizome bruise test

The test for percent rhizome was achieved by loading 0.5 kg of turmeric rhizome in the hopper and planting without the furrow closing device for physical observation of the rhizomes. The number of discharged turmeric rhizomes that were damaged mechanically including any significant bruise to the bud or crushing were recorded. The procedure was repeated for three times and their percentage was calculated as the seed bruise percentage using Eq. (2) [11]:

$$R_b\% = \frac{Rb_n}{N_R} \times 100 \tag{2}$$

Where: R_b = turmeric rhizome bruise (%); Rb_n = number of turmeric rhizome bruise; N_R = total number of turmeric rhizomes.

Miss index

The miss index is the ratio of the number of spacing greater than 1½ times the theoretical spacing (set spacing and total number of measured spacing) [11]. Misses were recorded along a randomly selected 10 m length of each planted row with the covering devices removed. Misses or skips were created when seed grooves fail to pick and deliver seeds to the delivery funnels. The missing percentage is expressed in Eq. (3) as [11]:

$$M_I = \frac{n_s}{N} * 100 \tag{3}$$

Where: M_I = Missing index (%); n_s = number of skips; N_t = total number of spacing.

Multiple index

The multiple index (D_I) is the percentage of spacing that are less than or equal to half of theoretical (nominal) spacing and indicates the percentage of multiple rhizome drop. Multiples were created when more than one turmeric rhizome is delivered by the groove. Multiples were also counted along a randomly selected 10 m segment of each planted row. This was measured from 10 m of planted rows and calculated using the Eq. (4) [12]:

$$D_I = \frac{n_d}{N} * 100 \tag{4}$$

Where: D_I (%); n_d = number of multiple dropping at the same spot; N = total number of spacing.

Planting depth

Depth of planting was monitored and measured along the row at a distance of 5m at four randomly selected locations. For good sprouting, planting depth of turmeric rhizome ranges from 5 - 10 cm [13]. However, this was done by adjusting the furrow opener to accommodate depth of 5 to 10 cm and lifting the furrow closer in order for the machine to be operated without the furrow covering mechanisms. The depth at which the rhizomes were placed was estimated vertically upward to the soil surface with the aid of a measuring rule.

Effective field capacity and field efficiency

The time taken to cover the field was recorded and the planter width was measured using a steel measuring tape. The effective field capacity (C_{eff}), theoretical field efficiency (C_{th}) and field efficiency (E_f) were calculated using Eqs. (5) to (7), respectively [11]:

$$C_{eff} = \frac{A_f}{T} \quad (5)$$

$$C_{th} = \frac{S * W_e}{10{,}000} \quad (6)$$

$$E_f = \frac{C_{eff}}{C_{th}} * 100 \quad (7)$$

Where: A_f = area of field covered (m^2); T = total time of operation (hr); C_{eff} = effective field efficiency (hah^{-1}); C_{th} = theoretical field efficiency (hah^{-1}); E_f = field efficiency (%).

Fuel consumption

The fuel tank of Eicher-5660 tractor was filled to the brim prior to field test. After planting, the tractor fuel tank was refilled to the brim using a graduated cylinder to estimate the quantity of diesel required. The quantity of fuel consumed per hectare was calculated using Eq. (8):

$$F_t = \frac{F_c}{A * 1000} \quad (8)$$

Where: F_t = total quantity of fuel consumed (lha^{-1}), Fc = fuel consumed (ml), A = area of field covered (ha).

Wheel slippage

The amount of slippage in the drive wheels of the planter was measured by recording the distance travelled by the drive wheels at five revolutions on no load. Thereafter, three replications of the number of revolutions were recorded when operated under load and the average calculated. The percent wheel slippage was calculated as expressed in Eq. (9):

$$S_w = \frac{L_1 - L_2}{L_1} \quad (9)$$

Where: S_w = wheel slippage (%); L_1 and L_2 = distance travelled under no-load (m) and theoretical distance travelled under load (m), respectively.

RESULTS AND DISCUSSION

Seed rate and percent rhizome damage

The result of the effect of operational speed at varying turmeric rhizome lengths on the mean seed discharge rate is presented in Figure 2. Increase in machine operational speed and turmeric length increased the seed discharged rate. At reduced operational speed and longer rhizome lengths, the rhizomes blocked the hopper discharge chute as there was insufficient vibration due to reduction in speed to cause agitation of the rhizomes in the hopper.

The maximum and minimum seed rate of 0.283 th^{-1} and 0.147 th^{-1}, respectively were obtained at machine speeds and rhizome lengths of 12 and 8 kmh^{-1}, and 60 and 30 mm, respectively.

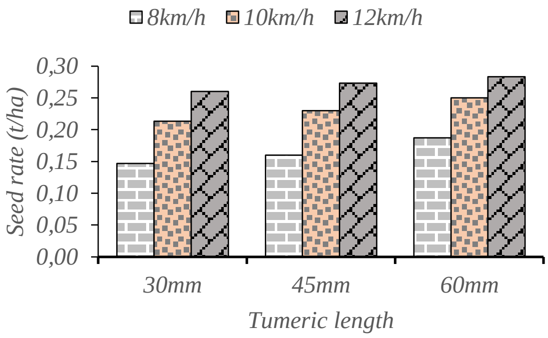

Figure 2. Effect of turmeric lengths at varying speeds on seed discharge rate.

Analysis of variance (ANOVA) conducted indicates that the machine operating speed has significant effect on the seeding rate of the turmeric rhizome planter ($P < 0.05$) as shown in Table 2. Increase in machine speed increases the seed rate as reported by Kalay and Moses [17]. The result further suggests that the interaction between the operating speed of the machine and the turmeric rhizome length has a good significant effect on the seeding rate of the turmeric planter ($P < 0.05$), whereas as rhizome grade was statistically insignificant to seed rate at $P < 0.05$.

Table 2. Analysis of variance for evaluation of seed rate.

Source	Sum of Squares	Df	Mean Square	F-value	P-value (Prob > F)	Remark
A- Speed	21.407	2	10.704	5.255	0.0159	*
B- Rhizome grade	1.407	2	0.704	0.345	0.7125	ns
A*B	33.925	4	8.481	4.164	0.0147	*
Residual	36.667	18	2.037			
Cor. Total	93.407	26				

** and ns denote significant and non-significant effects at P < 0.05, respectively.*

The percent bruised turmeric rhizome was affected by machine operational speed (Figure 3). The percent turmeric damage increases with increase in the operational speed of the machine for the 30 mm rhizome length. At maximum operational speed of 12 kmh^{-1}, the percent rhizome damage decreased to 15%. This is because, at higher speed the machine's metering device tends to pick turmeric rhizomes at a quicker rate, thus reducing sharing force between adjacent rhizomes in the hopper which results in bruises. ANOVA results obtained from field test (Table 3) indicate that machine operating speed and turmeric rhizome lengths as well as their interaction effect did not affect the planting operation at 5% level of probability.

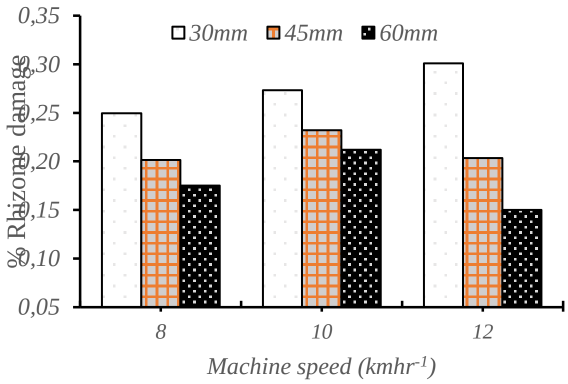

Figure 3. Effect of machine speed on percentage rhizome damage at varying rhizome lengths.

Table 3. ANOVA result for evaluation of percent turmeric rhizome damage.

Source of variation	Sum of Squares	Df	Mean Square	F-value	P-value (Prob > F)	Remark
A - Speed	1.407	2	0.704	0.297	0.7467	ns
B – Rhizome length	12.074	2	6.037	2.547	0.1062	ns
A*B	5.926	4	1.481	0.625	0.6507	ns
Residual	42.667	18	2.370			
Cor. Total	62.074	26				

ns denotes non-significant effects at P < 0.05.

Effect of rhizome length and operational speed on effective field capacity and field efficiency of the turmeric planter

The effective field capacity of planters depends on the operational speed [11, 15]. Field test results (Table 4) show that increase in the machine operational speed resulted in an increase in field capacity of the machine at constant turmeric rhizome length, which agrees with the report of Kalay and Moses [17]. It was observed that the mean effective field capacity of the turmeric planter ranges between 0.63 - 0.96 hah^{-1}. The maximum and minimum field capacities were obtained at 12 kmh^{-1} and 8 kmh^{-1}, respectively at 45 mm rhizome length. This could be as a result of decreased wheel slippage of the planter which increases its operational speed which resulted in increased effective field capacity. Researchers [11, 14]; Mohamed et al. [11] reported that reducing planter's wheel slippage increases its operational speed. Table 3 further illustrates that the best field capacity of the studied turmeric planter was obtained when the rhizome length of 45 mm was planted at the operational speed of 12 kmh^{-1}. ANOVA results show that turmeric rhizome length and its interaction effect with speed were not statistically significant ($P < 0.05$) to the effective field capacity of the planter (Table 5). This was as a result of the close range of mean field capacity values for 45 and 60 mm rhizome lengths at maximum operational speed of 12 kmh^{-1}.

Table 4. Turmeric planter field test for all observed parameters at varying rhizome lengths and operational speeds.

Rhizome length (mm)	Machine speed (kmh^{-1})	Mean field capacity (hah^{-1})	Efficiency (%)	Fuel consumption (lha^{-1})	Wheel slippage (%)
	8	0.65	62.4	2.5	4.19
30	10	0.82	64.6	3.2	3.71
	12	0.92	68.3	3.8	3.26
	8	0.63	60.5	2.3	4.22
45	10	0.68	62.9	2.8	3.86
	12	0.96	69.8	3.4	3.26
	8	0.64	63.4	2.2	4.37
60	10	0.84	64.2	3.0	3.62
	12	0.95	67.3	3.5	3.14

The mean field efficiency was higher at increasing operational speed. It ranges between 60.5 to 69.8%, with the maximum value obtained at operational speed of 12 $kmh^{-1}$for rhizome length of 45 mm. The average field efficiency obtained from the field is 65.8%. This is an indication of a satisfactory performance as it is within the 50 – 75% range of field efficiency of row-crop planters [7]. Analyses of variance (Table 6) indicated no significant difference between operational speeds of the planter at varying rhizome lengths as well as speed-rhizome length interaction effect on the field efficiency. Similar findings were observed by Mohamed et al. [11], Oduma et al. [15] and Raghavendra and Veerangeouda [16].

Table 5. Analysis of variance table for effective field capacity.

Source	*Df*	*Sum of Squares*	*Mean Square*	*F-value*	*P-value (Prob > F)*	*Remark*
Rep	*2*	*9.487*	*4.7435*	-	-	
A - Speed	*2*	*17.452*	*8.6710*	*0.297*	*0.0371*	*
B - Rhizome length	*2*	*3.957*	*1.9735*	*2.547*	*0.1852*	*ns*
*A*B*	*4*	*22.703*	*5.6758*	*0.625*	*0.4962*	*ns*
Residual	*18*	*48.922*	*2.7179*			
Cor. Total	*28*	*102.521*				

** and ns denote significant and non-significant effects at P < 0.05, respectively.*

Table 6. Analysis of variance table for field efficiency.

Source	*Df*	*Sum of Squares*	*Mean Square*	*F-value*	*P-value (Prob > F)*	*Remark*
Rep	*2*	*7.926*	*3.963*	-	-	
A - Speed	*2*	*10.502*	*5.251*	*0.642*	*0.451*	*ns*
B - Rhizome length	*2*	*5.327*	*2.664*	*1.971*	*0.502*	*ns*
*A*B*	*4*	*18.931*	*4.733*	*1.203*	*0.921*	*ns*
Residual	*18*	*38.792*	*2.155*			
Cor. Total	*28*	*81.480*				

ns denotes non-significant effect at P < 0.05.

Effect of rhizome length and operational speed on wheel slippage and fuel consumption of the turmeric planter

Table 4 indicates that wheel slippage varies inversely with fuel consumption and operational speed. The maximum wheel slippage and fuel consumption (4.37% and 3.8 lha^{-1}, respectively) were obtained at the operational speeds of 8 kmh^{-1} and 12 kmh^{-1}, respectively; whereas the minimum wheel slippage and fuel consumption (3.14% and 2.2 lha^{-1}, respectively) were obtained at the operational speeds of 12 kmh^{-1} and 8 kmh^{-1}, respectively for every rhizome length. However, the range of the wheel slippage values obtained from this study is adequately close to the recommended slippage value of 5.7% [11, 16]. Statistical analysis (Table 7) shows that no significant effect exists in the wheel slippage and rhizome lengths, as well as their interaction ($P < 0.05$). Table 8 shows that variation in operation speed and the interaction effect of speed and rhizome lengths were statistically significant ($P < 0.05$) on fuel consumption rate, whereas varying rhizome lengths had no significant effect ($P < 0.05$). It is pertinent to point out that an average of 32.37% of fuel was consumed at varying wheel speeds of the planter at all rhizome lengths.

Table 7. Analysis of variance table for wheel slippage of the turmeric planter.

Source	*Df*	*Sum of Squares*	*Mean Square*	*F-value*	*P-value (Prob > F)*	*Remark*
Rep	*2*	*2.083*	*1.0415*	-	-	
A - Speed	*2*	*0.982*	*0.491*	*1.431*	*0.716*	*ns*
B - Rhizome length	*2*	*1.512*	*0.756*	*1.621*	*0.862*	*ns*
*A*B*	*4*	*11.053*	*2.7633*	*0.225*	*0.287*	*ns*
Residual	*18*	*22.608*	*0.8074*			
Cor. Total	*28*	*38.238*				

ns denotes non-significant effects at P < 0.05.

Table 8. Analysis of variance table for fuel consumption of the turmeric planter.

Source	Df	Sum of Squares	Mean Square	F-value	P-value (Prob > F)	Remark
Rep	2	6.213	3.1065	-	-	
A - Speed	2	3.263	1.6315	13.523	0.0279	*
B - Rhizome length	2	5.042	2.521	7.231	0.0634	ns
A*B	4	16.114	4.029	10.541	0.0311	*
Residual	18	34.108	1.8949			
Cor. Total	28	64.74				

* and ns denote significant and non-significant effects at $P < 0.05$, respectively.

Effect of operational speed on miss index at varying rhizome lengths

Figure 4 shows the variation of missing index with increasing operational speed of the planter. Miss percentage tend to decrease with increase in turmeric rhizome length at constant operational speed except for a speed of 8 kmh^{-1} where an increase in the miss index was observed. Increasing the operational speed to 12 kmh^{-1} at increasing rhizome lengths reduces the percent miss index of the planter. This observation is contrary to the findings of Singh and Gautam [12] for planting of corms. The highest percentage turmeric rhizome miss index of 35% was recorded for turmeric rhizome length of 30 mm at machine operational speed of 10 kmh^{-1}, whereas the lowest percentage turmeric rhizome miss index of 15% was obtained for turmeric rhizome length of 60 mm at the machine operational speed of 12 kmh^{-1}. This is because shorter rhizome lengths tend to fall out much easily than the longer ones, as more than one turmeric rhizome tend to fall from the hopper to the metering system. ANOVA result (Table 9) indicates that the machine operating speed has significant effect on the miss index of the turmeric rhizome ($P < 0.05$), whereas rhizomes lengths were non-significant to miss index (at $P > 0.05$). The results of the analysis also suggest that the interaction between the operating speed of the machine and the turmeric rhizome lengths were significant on the miss index of the turmeric planter ($P < 0.05$).

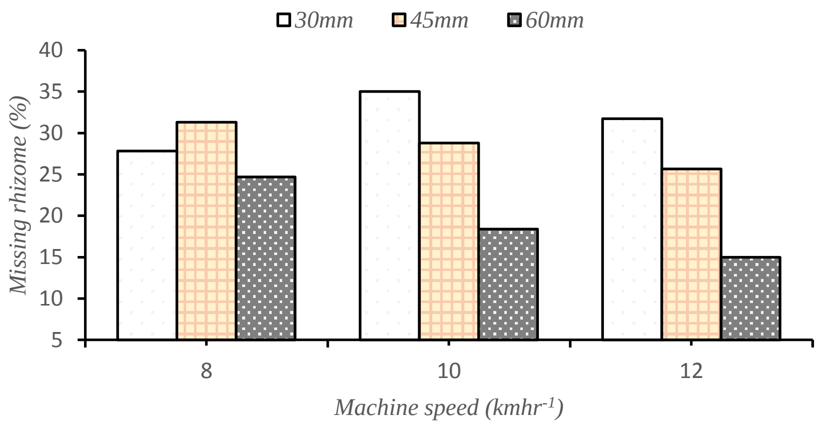

Figure 4. Influence of operational speeds and rhizome lengths (grade) on missing

Table 9. Analysis of variance table for missing index of the turmeric planter.

Source	Df	Sum of Squares	Mean Square	F-value	P-value (Prob > F)	Remark
A - Speed	2	15.630	7.815	3.576	0.0492	*
B - Rhizome length	2	3.630	1.815	0.831	0.4519	ns
A*B	4	32.370	8.093	3.703	0.0228	*
Residual	18	39.333	2.185			
Cor. Total	26	90.963				

* and ns denote significant and non-significant effects at $P < 0.05$, respectively.

Multiple index

The results of the test conducted on the effect of operational speed of the planter on the multiple index for various levels of turmeric rhizome length is shown in Figure 5. The multiple index of the machine decreases with increase in the turmeric rhizome length and operational speed. The highest multiple index of 35% was recorded for turmeric rhizome length of 30 mm at lowest operational speed of 8 kmh^{-1} This implies that as the rhizome length increases, the multiple index reduces. The smaller size of rhizomes tends to metered out faster than the longer lengths due to their short length which enables them to fall out freely. This result is not in accordance with the observations of Kalay and Moses [17], and Singh and Gautam [12] for okra seed and corm planters, respectively. The results of analysis of variance (Table 10) shows that both operational speed and rhizome length as well as the interaction effect of speed and rhizome length were all statistically significant at 5% level of probability.

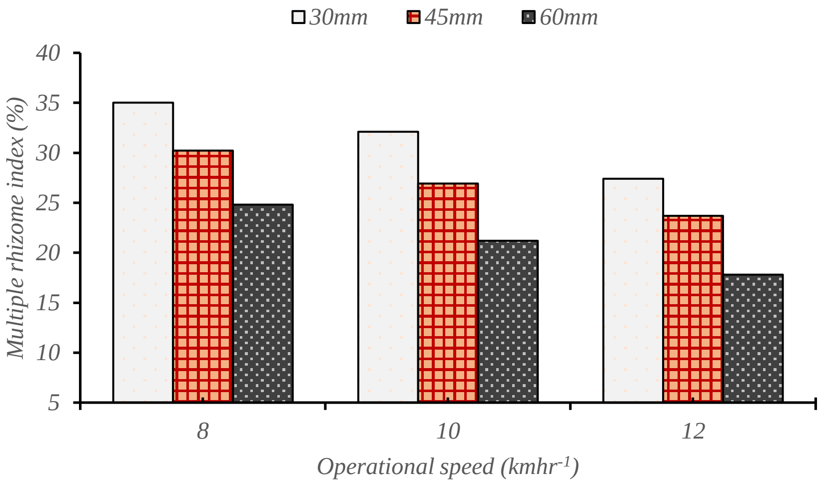

Figure 5. Influence of operational speeds and rhizome lengths (grade) on multiple index.

Table 10. Analysis of variance table for multiple index of the turmeric planter.

Source	Df	Sum of Squares	Mean Square	F-value	P-value (Prob > F)	Remark
A - Speed	2	6.740741	3.37037	8.2727	0.0028	*
B – Rhizome length	2	20.96296	10.48148	25.727	0.0001	*
A*B	4	1.703704	0.425926	1.0454	0.04114	*
Residual	18	7.333333	0.407407			
Cor. Total	26	36.74074				

* denotes significant effect at $P < 0.05$.

Planting depth

The results of planting depth of the machine are as shown in Table 11. The mean depth of planting observed and measured was 68 mm for all operational speeds and rhizome lengths. This depth of planting is within the agronomists' recommended range of 50 -100 mm for turmeric by agronomist [13].

Table 11. Result of planting depth

Replication	Planting Depth (mm)
I	73
II	56
III	82
Total	272
Mean	68

Optimization of Planter Parameters

The result for the optimization of operational parameters of the tractor-drawn turmeric planter is shown in Table 12. Constraints were set before optimizing the planter parameters. These constraints include the optimization goal to obtain the best planting operation across the range of speed of 8 to 12 kmh^{-1}, turmeric grading size between 30 to 60 mm and to minimize missing, bruises and multiple planting. Nine (9) optimize solutions were generated by the Design Expert software for all possible combinations to achieve all goals set for the optimization. The best optimized range of solutions recommended for using the developed turmeric rhizome planter is at machine operational speed of 12 kmh^{-1}and turmeric rhizome grading size of 45 mm with a maximum desirability index of 0.73 at 95% confidence level, represented with a bar chart (Figure 6), which further illustrates the best operating input variables of the planter.

At these optimal input conditions of 12 kmh^{-1} and 45 mm of speed and rhizome length, respectively, the goals of the corresponding response variables (depth of planting, missing, bruised, and multiple) were achieved within the limits with different desirability indexes as shown in Table 13. As the desirability index approaches unity, the better are the treatment combinations for optimizing the operating parameters of the turmeric planter [18]. The desirability index illustrates how desirable the response variables are at any given experimental input variable. It indicates the optimal solution of the turmeric planter, which represents the best functions of the planting process.

Table 12. Conditions for optimal operational parameters of turmeric planter.

Name	*Goal*	*Lower limit*	*Upper limit*	*Lower weight*	*Upper weight*	*importance*
Speed (kmh^{-1})	*In range*	*8*	*12*	*1*	*1*	*3*
Rhizome grading (mm)	*In range*	*30*	*60*	*1*	*1*	*3*
Planted	*Maximize*	*9*	*17*	*1*	*1*	*3*
Missing	*Minimize*	*3*	*11*	*1*	*1*	*3*
Bruised	*Minimize*	*2*	*8*	*1*	*1*	*3*
Multiple	*Minimize*	*2*	*7*	*1*	*1*	*3*

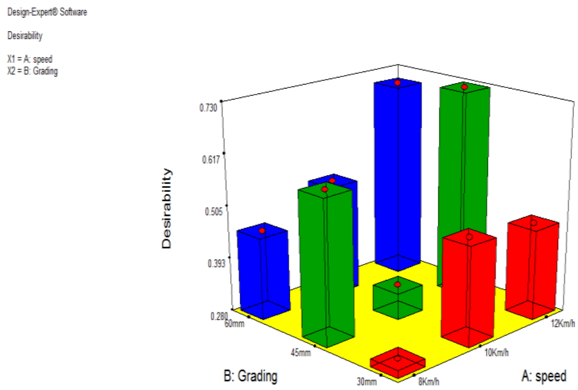

Figure 6. Desirability chart of the optimal operating conditions of turmeric planter.

Table 13. Desirability index at optimum values of the input and response variables of turmeric planter.

Speed (kmh^{-1})	*Rhizome grading (mm)*	*Planted*	*Missing*	*Bruised*	*Multiple*	*Desirability*
12	*45*	*14.66*	*5.33*	*3.00*	*3.66*	*0.73*
12	*60*	*13.67*	*6.33*	*3.00*	*2.67*	*0.70*
8	*45*	*14.00*	*6.00*	*4.00*	*4.67*	*0.59*
10	*60*	*12.00*	*8.00*	*3.67*	*3.33*	*0.52*

Economic Evaluation

Cost analysis

The cost analysis for the tractor drawn turmeric planter is classified into three [20]: cost of material, labour cost, and overhead cost. The overhead cost includes the cost of feeding, transportation and miscellaneous expenses incurred during the construction of the equipment which is taken as 60% of labour cost [19]. The total cost of materials is estimated at N 181,470. The labour cost is taken as 30% of material cost = N 54, 441 [20]; whereas the overhead cost is estimated at 60% of labour cost = N 32, 664.60. The total cost of planter fabrication is the sum of the three costs = N 268,575.60.

Payback analysis

The soil condition of Minna, Niger State, located in the Southern Guinea Savanna of Nigeria allows the use of tractor-drawn turmeric planter for planting of turmeric rhizomes between the months of April and June (78 days). This is the basis for the payback analysis of the turmeric planter. The associated costs of planting turmeric rhizomes in Minna and economic variables based on the current Nigeria's economic situation are presented in Table 14. Applying these data, the payback period was estimated using Eq. (10) expressed as [20, 21]:

$$\text{Payback period} = \frac{\text{Initial investment}}{\text{Annual net undiscounted benefits}} \tag{10}$$

The payback period is calculated as the time needed for the cost of investment to equal the return. In the case of the turmeric planter, a very small payback period of 18 months (1.64 years) was estimated compared to the planter life span of 17 years. This implies that the planter would plant turmeric rhizomes at no cost for almost its entire life time.

Table 14. Payback period of the tractor-drawn turmeric planter.

Cost of planter	*$ 504.08*
Planter hopper capacity (39.22kg x 3)	*117.7kg*
Depreciation	*$ 50.41*
Planter life	*17 years*
Cost of maintenance (for three months)	*$8.33*
Cost of labour (30% of planter cost)	*$ 151.23*
Cost of diesel during planting ($ 4.17 x 78 days)	*$ 325.36*
Cost of raw turmeric rhizome ($0.13 x 117.7kg x 78 days)	*$ 1,285.28*
Total cost	*$ 1, 810.05*
Total income (83 x 117.7 x 78days)	*$ 2, 116.64*
Net income	*$ 306.59*
Note: 1 USD = N 360	

$$payback\ period = \frac{504.08}{306.59} = 1.64\ years$$

CONCLUSION

Field performance analysis of a tractor-drawn turmeric planter was carried out to evaluate its effective field capacity, field efficiency on actual filed conditions, whereas laboratory tests were conducted to evaluate the planter's seed rate, percentage rhizome bruise, wheel slippage and fuel consumption. The seed rate ranges between 0.283 - 0.147 th^{-1}. The maximum percent bruised turmeric rhizome was obtained to be 30.08% at operational speed and rhizome length of 12 kmh^{-1} and 30 mm, respectively. The mean effective field capacity varied between 0.63 - 0.96 hah^{-1}, at operational speeds of 8 and 12 kmh^{-1}, respectively and 45 mm rhizome length. The mean field efficiency was obtained to be 65.8%.

The maximum wheel slippage of 4.37% and fuel consumption of 3.8 lha^{-1} were obtained at the machine speeds of 8 kmh^{-1} and 12 kmh^{-1}, respectively; whereas the minimum wheel slippage of 3.14% and fuel consumption of 2.2 lha^{-1} were obtained at the machine speeds of 12 kmh^{-1} and 8 kmh^{-1}, respectively for the range of the studied turmeric rhizome length.

The highest percentage turmeric rhizome miss index of 35% was recorded for turmeric rhizome length of 30 mm at a speed of 10 kmh^{-1}, whereas the highest multiple index of 35% was recorded for turmeric rhizome length of 30 mm at lowest operational speed of 8 kmh^{-1}. A mean planting depth of 68 mm was obtained. Numerical optimization of operational parameters of the planter was conducted. The optimal operating condition of the planter was obtained at machine operational speed of 12 $kmh^{-1}$and turmeric rhizome grading size of 45 mm, with an overall desirability index of 0.73. Economic evaluation was carried out using the criteria of cost and payback analyses which vary with product and location. A total production cost was estimated at $ 746.04, whereas a very small payback period of 1.64 years compared to the estimated planter's life of 17 years. Further research is required to determine the field performance and optimized operational conditions of a similar planter handling different crops.

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ANALIZA PERFORMANSI AGREGATA TRAKTOR - SADILICA RIZOMA KURKUME

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Sažetak: Rad prikazuje ispitivanja terenski razvijenog prototipa sadilice za kurkumu *(Curcuma Longa Linn)*. Ispitivanja su randomizirana u faktorskom dizajnu sa tri različite dužine rizoma kurkume od 30, 45 i 60 mm, i radnih brzina agregata traktor – sadilica je 8, 10 i 12 kmh^{-1}. U ispitivanju je prosečna masa od 3 kg celih rizoma kurkume ubačena u spremište – levak sadilice i posađena na 90 m^2 eksperimentalne površine. Tokom terenskog ispitivanja mašine-sadilice razmatrani su: efektivni učinak, statistička greška, višestruki indeks i dubina sadnje rizoma kurkume. Laboratorijska ispitivanja su obavljena kako bi se procenila potrebna količina materijala rizoma za sadnju, % proklizavanja točkova traktora i količina potrošenog goriva. Dobijeni rezultati pokazuju da je maksimalna količina utrošenih rizoma kurkume bila 0,283 th^{-1}. Utvrđeno je da maksimalni % modificiranog rizoma kurkume iznosi 30,08 %. Srednji efektivni učinak varirao je između 0,63 - 0,96 hah^{-1}, pri stvarnoj operativnoj brzini rada agregata od od 8 i 12 kmh^{-1}, odnosno dužini rizoma kurkume od 45 mm. Dobijen srednji učinak na polju od 65,8%. Maksimalno proklizavanje točkova traktora bilo je od 4,37%, a potrošnja goriva od 3,8 lha^{-1} dobijeni su pri brzinama agregata od 8 kmh^{-1} odnosno 12 kmh^{-1}. Najmanje proklizavanje točkova traktora je 3,14% i potrošnja goriva 2,2 lha^{-1} dobijeni su pri brzinama agregata od 12 kmh^{-1} i 8 kmh^{-1}. Najviši i najniži % prolaska rizoma kurkume kroz aparat sadilice je 35% , a konstatovan je za dužinu rizoma od 30 mm pri brzini agregata od 10 kmh^{-1} odnosno 8 kmh^{-1}. Dobijena prosečna dubina sadnje rizoma kurkume je od 68 mm. Numerički optimizacijski pristup usvojen je da bi se dobili optimalni operativni parametri rada agregata brzine od 12 kmh^{-1} i veličine dubine sadnje rizoma kurkume od 45 mm sa ukupnim indeksom ostvarljivosti od 0,73. Ekonomska procena isplativosti izračunata je primenom načela povrata investicije, koja je dobijena kao vrlo mala (1,64 godine) u odnosu na mogući vek sadilice od 17 godina. Predloženi su zadaci i mogućnosti za buduće radove.

Ključne riječi: *rizom kurkume, procena polja, optimizacija, parametri izvođenja ogleda, sadilica*

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