



## MULTI-RESPONSE OPTIMIZATION OF PLANTING PROCESS OF A SEED RIDGE PLANTER USING RESPONSE SURFACE METHODOLOGY (RSM)

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### ABSTRACT

The performance of a two- row self-propelled seed planter, Institute for Agricultural Research (IAR) single row animal drawn planter and the manual method of planting were investigated under laboratory and field conditions to optimise the planting process using Response Surface Methodology (RSM). Parameters optimisation of seed planting process becomes imperative in order to find parameter values that match predictions with reality and choose the right set of parameters that improve the performance of planter. Experiments conducted in this study were based on Central Composite Design (CCD), one of the designs in RSM Experimental treatments were three planting methods, three soil moisture levels, and three planting depths randomly assigned in a 3x3 factorial experiment arranged in a Randomized Complete Block Design (RCBD) in three replications. The results show increased plant population with increasing planting speed and moisture content values. Also, increased seedling emergence was observed with increasing moisture content and decreasing planting speed values. However, further increase in seed planting moisture content beyond the optimum point caused a decrease in the seedling emergence. Similarly, there was increased depth of planting with increasing seed planting speed and moisture content values. Further increase in soil moisture content beyond the optimum point caused a decrease in the depth of planting. Conclusively, soil moisture availability is an important factor affecting the depth of seed planting in the study area

### 1.0 Introduction

Planting is a crucial step for successful crop production (Finch-Savage, and Bassel, 2016). Planting is the act of introducing seeds to the ground at predetermined depths in a farming process with the main objective of establishing an optimum plant population, plant-to-plant spacing (intra-row spacing) and appropriate depth of sowing. Planting can be done by any of the following methods: broadcasting, drill seeding, cross sowing, band planting, square nest sowing, furrow sowing and hill sowing (Yusuf, 2010,). Planter performs soil penetration, metering the correct amount of seed to drop at the right location, depositing those seeds in the soil and providing pressure for adequate soil-seed contact (Srivastava et al., 2006, and Wankhade and Kotwal., 2014). It is usually a very time-sensitive operation with only a short period offering the right climatic conditions (Timsina et al., 2011). As factors such as soil temperature and moisture are critical for seed germination (Murray et al., 2006). To complete seed sowing in the narrow time-frame available and ensure successful crop establishment, it is essential to have a reliable planter (Johansen et al., 2012 and He et al., 2014). Nonetheless, for smallholder farmers in developing nations, seed-metering equipment should be simple in operation, affordable, and reliable (Van Loon et al., 2018).

The method adopted for planting depends upon a number of criteria and these include the agronomic requirement for the seed to be planted such as depth of seed placement, required distance between plants (inter and intra row); soil moisture content, and the effectiveness of the method for maximal crop germination (Srivastava *et al.*, 1993). Parameters optimisation (process of choosing the permissible actions by maximizing or minimizing the objective functions subject to the constraints as appropriate with the intent of adding value to the final outcome) becomes imperative. This is to find parameter values that match predictions with reality by choosing the right set of parameters that improve the performance of planter. The goals of this research were to: (1) compare depth of seed placement, planting speed, seed damage, number of seeds per hole and seedling emergence while in operation of the developed planter with an existing IAR single row animal drawn planter and the manual method of planting. (2) optimise the performance of the planter using Response Surface Methodology (RSM).

## 2. Materials and Methods

### 2.1 Materials

The study was conducted at Samaru (Latitude 12° 1'N and Longitude 073°E) in Kaduna State in the northern guinea savanna vegetation zone of West Africa. Materials used in the construction of the planter include tools such as Hacksaw frame and blade, centre punch, tri-square, metal scribe while machines used ( 3.5 kW Gestetner Centre Lathe, 2.75kW Gestetner centre drill, 360 Watts Bosch hand drilling machine, 1.5 kW hand held grinding machine, 750 Watts arc welding machine, and plate cutting machine (maximum 1.5 mm thick). The performance of a 2-row ridge engine-propelled planter (the fabricated planter, Figure 1), a single row IAR animal drawn planter (Figure 2), and manual planting ((dropping seeds into holes made with the heels, covering the seeds with soil and compacting the soil surrounding the seeds with the heels, Figure 3) were evaluated using 20 kg of Quality Protein Maize (QPM) seeds (pre-tested for viability) as test crop.



**Figure 1:** Developed 2-row engine-propelled planter



**Figure 2:** IAR single row animal drawn seed ridge planter



**Figure 3:** Manual method of planting.

## 2.2 Methods

### 2.2.1 Design of planter components

#### 1. Wheel shaft

Angular speed on wheel shaft is given as (Spotts, 1988, and Muvdi and McNabb, 1988):

$$\omega = \frac{2\pi n}{60}, \text{ rad/s} \quad (1)$$

where n = rpm,

No torsional bending is expected along the shaft and no bending is expected on the shaft, diameter of the shaft  $d_s$  was therefore gotten by (Spotts, 1988; Muvdi and McNabb, 1988):

$$d_s^3 = \frac{16}{\pi S_s} \sqrt{(K_t M_t)^2} \quad (2)$$

where,  $S_s$  = Shear stress associated with the shaft = 5.63 mPa,  $K_t$  = Combined shock and fatigue factor applied to torsional moment = 2.0 (for shock loads),  $M_t$  = Torsional moment (Nm). Power required to turn the wheel was computed from Hall et al. (1961):

$$P = T\omega \quad (3)$$

where, P = Power required to turn the wheel (Watts), T = Torque on the shaft (N-m);

$\omega$  = Angular speed of the shaft (rad/s)

Crossley and Kilgour (1983) reported that the applied shearing force on the soil (horizontal force).

$$F = AC + W \tan \Phi \quad (4)$$

where, A = Contact area ( $\text{m}^2$ ), C = Cohesion, W = Static load on the wheel,  $\Phi$  = Angle of shearing resistance by the soil. C and  $\Phi$  vary according to the type and state of soil.

2. Hopper Design: The Shape chosen was frustrum with rectangular cross section as this is most widely used for cereals (Srivastava, 1993). The parameters that were designed for are: (i) Hopper capacity ( $V_c$ ), (ii) Hopper, height (H), (iii) Top neck width (B') and (iv) Bottom neck width (B"). The capacity of the hopper is given as (Bosoi et al., 1988):

$$V_c = \frac{L_g Q_H B}{10^4 \eta_c q_H} \quad (\text{m}^3) \quad (5)$$

where,  $V_c$  = Hopper capacity,  $\text{m}^3$ ,  $L_g$  = run length, m,  $QH$  = seed rate, kg/ha, B = sowing width, m,  $\eta_c$  = Coefficient of features of the hopper = 0.9,  $q_H$  = volume weight,  $\text{kg}/\text{m}^3$ . The hopper length is given as:

$$L_c = a (n_b + 1) \quad (\text{m}^2) \quad (6)$$

where, a = row width, m,  $n_b$  = number of discharge points, The cross sectional area of the hopper is given by:

$$F_c = \frac{V_c}{L_c} \quad (\text{m}) \quad (7)$$

where,  $F_c$  = cross sectional area of the hopper,  $\text{m}^2$ ,  $V_c$  = Capacity of the hopper,  $\text{m}^3$ ,  $L_c$  = effective height of the hopper, m

Total volume of one hopper in the planter is given by:

$$V_b = \frac{V_c}{n} \quad (\text{m}^3) \quad (8)$$

where, n = number of hoppers in the planter,  $V_b$  = volume of one hopper,  $\text{m}^3$

The standing height of hopper was computed from:

$$H_t = w (n + 1) \tag{9}$$

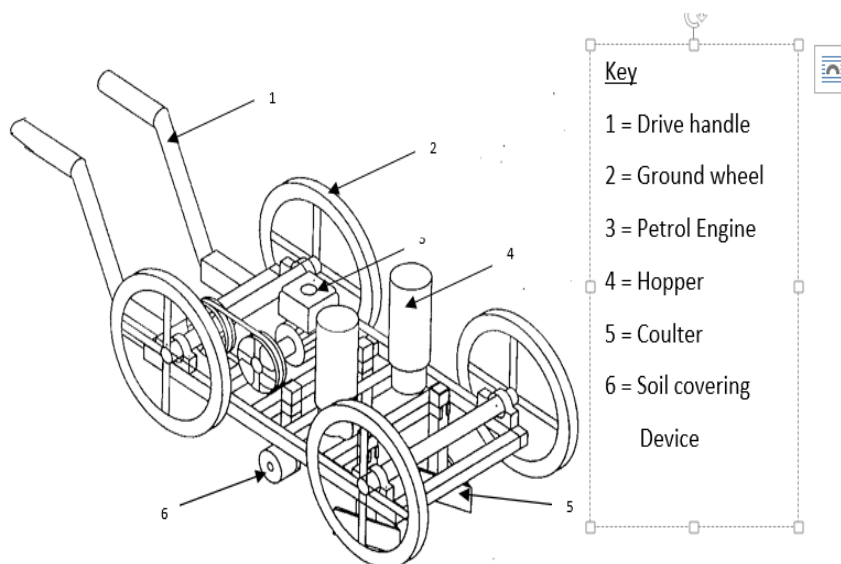
### 2.2.2 Principle of operation of the 2-row engine-propelled seed ridge planter

The soil openers are set to the required level and the delivery chutes are also set to near the point of dropping of seed. The hoppers are filled to the required level. The engine fuel tank is filled to the desired level and the planter (Figure 4) is set in line with the ridges. The clutching arm is raised down to jack the engine up and to put it in idle state and the engine of the planter is cranked on and allowed to run idle for two minutes to allow for the stabilization of the engine. To put the planter in operation, the clutch arm is lowered to engage the drive of the planter which puts it in motion. At the end of a planting row, the clutch is raised to disengage the engine and to allow for turning.

### 2.2.3 Performance evaluation

1. Percent seed damage: The planter was powered on and the broken seeds and whole seeds metered were collected and weighed.

$$\% \text{ seed damage} = \frac{\text{Weight of broken seeds}}{\text{Weight of whole seeds} + \text{Weight of broken seeds}} \tag{10}$$



**Figure 4:** The 2-row self-propelled ridge planter

### 2. Soil moisture content determination

Soil moisture content was calculated as (FAO, 1994):

$$M_c = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \tag{11}$$

where,  $M_c$  = Soil moisture content (dry weight basis), %,  $W_1$  = Weight of container, g,  $W_2$  = Weight of container + wet soil, g,  $W_3$  = Weight of container + oven dried soil, g

### 3. Determination of seed delivery rate

Seed delivery was obtained as (Srivastava et al., 1993):

$$Q = \frac{L * 10,000}{\pi D_e n w} \tag{12}$$

where, Q = delivery rate (kg/ha), L = distance in a given number of revolution (n) of forward wheel, De = effective diameter of ground wheel (m), n = number of revolutions of ground wheel, w = nominal working width (m).

4. Working speed was computed from (FAO, 1994):

$$V = \frac{D_{av}}{t_{av}} \quad (13)$$

Where,  $D_{av}$  = average distance, (m), and  $t_{av}$  = average time, (s).

5. Determination of Seedling emergence ratios:

Seedling emergence is determined from the counts of newly emerged seedlings in each row, three times (morning, afternoon and evening) daily. Speed of Emergence (SOE) (Tressier, 1988), Mean Emergence Data (MED), Emergence Rate Index (ERI) and Relative Emergence (RE) (Bilbro and Wanjura, 1982) were calculated directly from the emergence counts:

$$SOE = \frac{(N_1 + N_2 + \dots + N_n)}{(t_1 + t_2 + \dots + t_n)} \quad (14)$$

$$MED = \frac{(N_1 t_1 + N_2 t_2 + \dots + N_n t_n)}{(t_1 + t_2 + \dots + t_n)} \quad (15)$$

$$ERI = \frac{(N_1 + N_2 + \dots + N_n)}{MED} \quad (16)$$

$$RE = \frac{(N_1 + N_2 + \dots + N_n)}{NS} \quad (17)$$

where:  $N_1, N_2, \dots, N_n$  are numbers of newly emerged seedlings at times  $t_1, t_2, \dots, t_n$ , NS = number of seeds planted in each row = number of germinated seeds + counted un-germinated seeds on the rows as reported by Bilbiro and Wanjura (1982).

### 2.2.4 The experimental design

The treatments considered are three planting methods (engine-propelled planter, animal drawn planter, and manual planting), three soil moisture levels, and three planting depths. The treatments were randomly assigned in a 3x3 factorial experiment arranged in a Randomized Complete Block Design (RCBD) in three replications as described by Gomez and Gomez, (1984). The statistical Analysis Package (SAS) was used for data analysis (SAS Institute Inc, 1989).

#### 2.2.4.1 Response Surface Optimisation

The Response Surface Optimisation (RSO) was implemented using Design Expert 9.0 software. Two models were developed to show how the seed planting process parameters (planting speed and moisture content) can be used to maximize the output responses (seedling emergence, planting depth, plant spacing, number of seeds per hole) and minimize the output responses (number of damaged seeds). The RSM method used for carrying out the experiment is the CCD. The empirical model selection and ANOVA calculation using RSM was carried out in Design Expert 9.0 software.

#### 2.2.4.2 Estimation of decision variables (alternatives).

The variables for evaluating the objective were: planting speed ( $x_1$ ), moisture content of the soil ( $x_2$ ), seedling emergence ( $y_1$ ), Seed depth of planting ( $y_2$ ), plant-to-plant spacing ( $y_3$ ), number of seeds per hill ( $y_4$ ), number of seed damage ( $y_5$ ).

$x_1$  and  $x_2$  are the input variables while  $y_1 \dots y_6$  are the response variables. A set of polynomial equations defined for each of the response variables were used since it is only a polynomial that can give the needed curvature that will define the maximum and minimum points. The objective criteria for evaluating the alternate general polynomial functions is:

$$y_1 = a_0 + a_1x_1 + a_2x_2 + a_3x_1x_2 + a_4x_1^2 + a_5x_2^2 \tag{18}$$

$$y_2 = b_0 + b_1x_1 + b_2x_2 + b_3x_1x_2 + b_4x_1^2 + b_5x_2^2 \tag{19}$$

$$y_3 = c_0 + c_1x_1 + c_2x_2 + c_3x_1x_2 + c_4x_1^2 + c_5x_2^2 \tag{20}$$

$$y_4 = d_0 + d_1x_1 + d_2x_2 + d_3x_1x_2 + d_4x_1^2 + d_5x_2^2 \tag{21}$$

$$y_5 = e_0 + e_1x_1 + e_2x_2 + e_3x_1x_2 + e_4x_1^2 + e_5x_2^2 \tag{22}$$

$$y_6 = f_0 + f_1x_1 + f_2x_2 + f_3x_1x_2 + f_4x_1^2 + f_5x_2^2 \tag{23}$$

$a_0 \dots a_5, b_0 \dots b_5, \dots \dots e_0 \dots e_5$  are the constants of the polynomials which will be determined and upon which the polynomials will be redefined and validated. While  $y_1, y_2, y_3$  and  $y_4$  will be maximized,  $y_5$  will be minimized.

### 2.2.4.3 Constraints

The constraints to the alternatives above are the limits of the input variables. The limits will be categorized into low and high limits for the two input variables. Heckman *et al.* (2002) and Arzu and Adnan (2006) stated that the low and high levels of soil moisture content for planting correspond to the moisture content at wilting point of the soil as low and field capacity of the soil as high. These translate into 12.37% (db) for low and 21.1 % (db) for high. Similarly, FAO (1994) and Grisso *et al.* (1994) stated that the speed limits are fixed for 0.94m/s as low and 1.32m/s as high. Thus, the limits (Table 1) are defined and the constraints can thus be represented as:

$$0.94 \leq x_1 \leq 1.32 \tag{24}$$

$$12.37 \leq x_2 \leq 21.1 \tag{25}$$

**Table 1:** Input variables levels based on research study

Input Factors	Units	Low Level	High Level
planting speed	m/s	0.94	1.32
moisture content	% (db)	12.37	21.1

The problem of optimisation, putting the variables of interest into consideration is of the form (Taha, 2007):

Maximize  $y_1 = a_0 + a_1x_1 + a_2x_2 + a_3x_1x_2 + a_4x_1^2 + a_5x_2^2 - \varepsilon$

$$y_2 = b_0 + b_1x_1 + b_2x_2 + b_3x_1x_2 + b_4x_1^2 + b_5x_2^2 - \varepsilon$$

$$y_3 = c_0 + c_1x_1 + c_2x_2 + c_3x_1x_2 + c_4x_1^2 + c_5x_2^2 - \varepsilon$$

$$y_4 = d_0 + d_1x_1 + d_2x_2 + d_3x_1x_2 + d_4x_1^2 + d_5x_2^2 - \varepsilon$$

Subject to

$$0.94 \leq x_1 \leq 1.32$$

$$12.37 \leq x_2 \leq 21.1$$

and Minimize  $y_5 = e_0 + e_1x_1 + e_2x_2 + e_3x_1x_2 + e_4x_1^2 + e_5x_2^2 - \varepsilon$

Subject to

$$0.94 \leq x_1 \leq 1.32$$

$$12.37 \leq x_2 \leq 21.1$$



### 2.2.5 Response surface experimental matrix design

The input process variables (planting speed and soil moisture content), and the output responses (seedling emergence, seed planting depth, plant-plant spacing, number of seeds per hill, and number of damaged seeds) for modelling and correlation studies were selected as described by Akinoso et al., (2006) and Skwarcz (2006). The relationship between the output responses the input variables were defined using RSM modelling approach. The experimental design was

developed using the Response Surface Matrix (RSM) Central Composite Design (CCD), produced by Design Expert version 9.0 software which uses a suitable matrix/experimental layout based on CCD. The three groups of design points for CCD are:

- i.  $n_f = 2^k$ , Response Surface design or corner points (k is the number of input variables)
  - ii  $n_a = 2k$ ; axial or star points and
  - iii  $n_c$ = center points, repeated several times to obtain a good estimation of experimental pure error.
- Then the total number of experiments would be:  $N = n_f + n_a + n_c$  (26)  
 Response Surface points:  $n_f = 2^k = 2^2 = 4$ , axial points:  $n_a = 2k = 2 \times 2 = 4$  and center points:  $n_c = 5$   
 Total number of experiments would be:  $N = n_f + n_a + n_c = 4+4+5 = 13$  (27)

The developed CCD for the uncoded design is shown in Table 2.

**Table 2:** Response surface methodology experimental run design

Exp Run	Planting Speed (m/s)	Moisture Content (%)	Seedling emergence (in 0.01ha)	Depth of Planting (mm)	Plant Spacing(mm)	Number of Seeds Per Hill
1	1.32	16.74	x	x	x	x
2	1.13	16.74	x	x	x	x
3	0.94	12.37	x	x	x	x
4	1.32	12.37	x	x	x	x
5	1.32	21.10	x	x	x	x
6	1.13	16.74	x	x	x	x
7	1.13	21.10	x	x	x	x
8	1.13	16.74	x	x	x	x
9	0.94	16.74	x	x	x	x
10	1.13	16.74	x	x	x	x
11	1.13	16.74	x	x	x	x
12	1.13	12.37	x	x	x	x
13	0.94	21.10	x	x	x	x

x = values to be measured on field

#### 2.2.5.1 Development of response surface empirical model for output responses

The empirical model correlating output responses (seedling emergence, depth of seed planting, plant spacing, number of seeds per hole, energy consumed and number of damaged seeds - (y)) to the process factors (planting speed, moisture content) and the interaction between them is best explained below as generated by Design Expert 9.0 Software::

$$Y_{RSM} = \gamma_0 + \gamma_1x_1 + \gamma_2x_2 + \gamma_3x_1x_2 + \gamma_4x_1^2 + \gamma_5x_2^2 + \epsilon \quad (28)$$

where,  $Y_{RSM}$  = Response Surface matrix output,  $x_1$  = planting speed (m/s),  $x_2$  = moisture content (% db),  $x_1x_2$  = interaction between planting speed and moisture content,  $x_1^2$  = square of the main effect (planting speed),  $x_2^2$  = square of the main effect (moisture content),  $\gamma_i$  = coefficients of the model parameters and  $\epsilon$  = error value.

$Y_{RSM} = y =$  seedling emergence, depth of seed planting, plant spacing, number of seeds per hill, and number of damaged seeds for response surface model.

In order to determine the constants  $\gamma_i$ , a matrix model for the process factors was developed from experimental matrix as:

$$x = \begin{bmatrix} 1 & x_{11} & x_{21} \\ 1 & x_{12} & x_{22} \\ \vdots & \vdots & \vdots \\ 1 & x_{113} & x_{213} \end{bmatrix} \quad (29)$$

The response factors (seedling emergence, depth of seed planting, plant spacing, number of seeds per hill, energy expended and number of damaged seeds) were represented as:

$$y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_{13} \end{bmatrix} \quad (30)$$

The error term was represented as

$$\epsilon = \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \\ \epsilon_{13} \end{bmatrix} \quad (31)$$

The coefficients in the model were represented as:

$$\gamma = \begin{bmatrix} \gamma_1 \\ \gamma_{12} \\ \vdots \\ \gamma_{113} \end{bmatrix} \quad (32)$$

The general form is represented as:

$$y = x\gamma + \epsilon \quad (33)$$

A vector of the least square estimator is:

$$L = \epsilon^T \epsilon \quad (34)$$

and minimized as:

$$\left(\frac{\partial L}{\partial \gamma}\right)_{\gamma} = 0 \quad (35)$$

The coefficients ( $\gamma_i$ ) in the model was determined by Design Expert 9.0 software and

$$\gamma_i = (x^T x)^{-1} x^T y \quad (36)$$

### 2.2.5.2 Significance testing of the coefficients of the response surface model (Validation)

Following the determination of coefficients in model Equation, the significance of the coefficients was determined by Design Expert 9.0 software as described below. The SSE,  $\sigma^2$ , SSY and SSR were calculated as:

$$SSE = y^T y - \gamma^T x^T y \quad (37)$$

$$\sigma^2 = \frac{SSE}{n-p} \quad (38)$$

where,  $n =$  length ( $y$ ) = length of the output response ( $y$ ),  $p =$  length ( $\varphi$ ) = number of the coefficient to be estimated. The Sum of Square of output responses (SSY) was determined as:

$$SSY = y^T y - \frac{(\sum_{i=0}^{n-1} y_i)^2}{n} \quad (39)$$

The Sum of Square of the Residual Error was determined by Design Expert 9.0 as:

$$SSR = \varphi^T x^T y - \frac{(\sum_{i=0}^{n-1} y_i)^2}{n} \quad (40)$$



A Minitab program (Figure 5) was programmed to create a matrix of three columns. The first column has the response surface coefficient, the lists of the t-values is the second column and the power of the t-test is the third column.

```

result(φ, C) :=
  k ← length(b)
  for i ∈ 0..k-1
    Ri,0 ← bi
    Ri,1 ←  $\left| \frac{b_i}{\sqrt{C_{i,i} \frac{SSE}{(n-p)}}} \right|$ 
    Ri,2 ← |dt(Ri,1, n-p)|
    Ri,3 ←  $\begin{cases} \text{"yes"} & \text{if } R_{i,2} \leq \alpha \\ \text{"no"} & \text{if } R_{i,2} > \alpha \end{cases}$ 
  R
  
```

**Figure 5:** Design Expert 9.0 Program for Computing the Coefficient of the Response Surface Model, t-test value and the p-value.

### 3. Results and Discussion

**3.1 Percent seed damage:** Seed damage by the engine-propelled planter is near zero (Table 1). This implies that the planter is mechanically efficient in the delivery of whole seeds to the soil. Broken seeds reduce the number of seedlings that can emerge on a planted field. The engine-propelled planter thus has the capability of maintaining maximum plant emergence after planting.

**Table 1: Result of percent seed damage**

Sample No.	Right Hopper		Left Hopper	
	Weight of whole seeds (g)	Weight of damaged seeds (g)	Weight of whole seeds (g)	Weight of broken seeds (g)
1	5.2	0.0	5.5	0.0
2	5.8	0.0	6.0	0.0
3	5.6	0.0	5.7	0.0
4	5.1	0.2	5.0	0.0
5	5.0	0.0	6.8	0.0
Total	26.7	0.2	29.0	0.0
Average	5.34	0.04	5.80	0.0
%		0.75		0.00

### 3.2 Seed metering for the three methods investigated

The results of seed metering and ground wheel speed are shown on Tables 2 and 3 respectively. The engine-operated planter will meter between 1 and 2 seeds per hole and having an average travel speed of 1.25m/s. These values are likely to be affected while working on the field as the conditions on the field are not the same as with the laboratory. Bamgboye and Mofolasayo (2006) submitted that planters that are not tractor trailed have not been able to reach the 1 m/s operational speed on the field.

**Table 2: Seed metering test on the 2-row ridge planter**

Trial No.	Spacing between dropped seeds (cm)		Average (cm)	Spacing		No. of seeds dropped per point	
	Hopper 1	Hopper 2		Hopper 1	Hopper 2	Hopper 1	Hopper 2
1	26,23,25.5,25.6	25.3,26.1,26,27.1	25.03	26.13	2+2+1+2=7	1+1+2+2=6	
2	26.7,27.9,26.8,3	25.2,26.1,25,27.1	26.85	25.85	1+2+1+2=6	2+2+2+1=7	
3	28.5,26.1,24,26.6	23,24,25.6,22.3	26.30	23.73	2+1+1+3=7	3+2+1+2=8	
		Total	78.18	75.71	20	21	
		Average	26.06	25.24	1.6	1.8	

**Table 3: Result of ground wheel travel speed**

Trial No.	Distance (m)	Time taken (secs)	Travel speed (m/s)
1	10	11.50	1.15
2	10	12.88	1.29
3	10	13.20	1.32
		Average	1.25

**3.3 Seedling emergence for the three methods evaluated for three years**

Tables 4 shows the pooled ANOVA of the effects of the planting methods, soil moisture and depth of planting on seedling emergence for the years 2012, 2013 and 2014. There are no significant differences between replications within the testing periods. This implies that the values gotten in the

three replications agreed with each other as they close in magnitude. There was significant difference among the planting methods, and the interactions of planting methods, year and depth of seed placement at 1% confidence level. However, the interaction of the planting methods and the years was significant at the 5% probability level. This implies that the methods showed varying capabilities in the number of plants that emerged. Yisa et al. (1994) and Heckman et al. (2002) had similar results and concluded that planting method, depth of seed placement, the state of soil coverage, and the soil moisture affect seedling emergence

**Table 4: ANOVA of the Pooled analysis of the effects of planting methods, soil moisture and depth of planting on seedling emergence in the 2012, 2013 and 2014 testing seasons**

Source of Variation	df	Sum of Squares	Mean Square	Computed F	Tabular F 5%	1%
REP	2	0.2304527	0.1152263	0.06 <sup>NS</sup>	3.06	4.75
MTD	2	140.9958848	70.4979424	38.66 <sup>**</sup>	3.06	4.75
SM	2	4.8477366	2.4238683	1.33 <sup>NS</sup>	3.06	4.75
DP	2	3.8106996	1.9053498	1.04 <sup>NS</sup>	3.06	4.75
YEAR	2	95.4650206	47.7325103	26.18 <sup>**</sup>	3.06	4.75
MTD*SM	4	3.7448560	0.9362140	0.51 <sup>NS</sup>	2.43	3.44
MTD*DP	4	8.5596708	2.1399177	1.17 <sup>NS</sup>	2.43	3.44
MTD*YEAR	4	23.5720165	5.8930041	3.23 <sup>*</sup>	2.43	3.44
SM*DP	4	7.6707819	1.9176955	1.05 <sup>NS</sup>	2.43	3.44
SM*YEAR	4	5.6460905	1.4115226	0.77 <sup>NS</sup>	2.43	3.44
DP*Year	4	4.3868313	1.0967078	0.60 <sup>NS</sup>	2.43	3.44
MTD*SM*DP	8	15.7366255	1.9670782	1.08 <sup>NS</sup>	2.00	2.62
MTD*SM*YEAR	8	43.5390947	5.4423868	2.98 <sup>**</sup>	2.00	2.62
MTD*DP*YEAR	8	9.6872428	1.2109053	0.66 <sup>NS</sup>	2.00	2.62
SML*DP*YEAR	8	10.6502058	1.3312757	0.73 <sup>NS</sup>	2.00	2.62
MTD*SM*DP*YEAR	16	20.1646091	1.2602881	0.69 <sup>NS</sup>	1.71	2.12
ERROR	160	291.7695473	1.8235597			
TOTAL	242	690.4773663				

**NOTE:** NS = Not Significant, \* = Significant at 5% confidence level, \*\* = Significant at 1% confidence level

**3.4 Response surface modelling of seedling emergence with respect to seed planting process parameters:** The results of the model correlating planting speed and seed planting moisture content to seedling emergence are as presented in Table 5. Also presented are the results of model selection and model terms significance. The model developed provide the basis for optimisation to determine the settings of seed planting moisture content and planting speed that will maximize plant population.

**Table 5: RSM experimental run and results of seedling emergence, planting depth, plant spacing, and number of seeds per hole**

Exp Run	Planting Speed (m/s)	Moisture Content (%)	Number of seeds emerging	Depth of Planting (mm)	Plant Spacing (cm)	Number of Seeds Per Hole
1	1.32	16.74	14	21.50	25	2
2	1.13	16.74	20	30.00	36	3
3	0.94	12.37	9	13.50	16	1
4	1.32	12.37	12	18.00	22	2
5	1.32	21.10	12	18.00	22	2
6	1.13	16.74	20	30.00	36	3
7	1.13	21.10	21	31.50	38	3
8	1.13	16.74	19	28.50	34	2
9	0.94	16.74	20	30.00	36	3
10	1.13	16.74	19	28.50	34	2
11	1.13	16.74	20	30.00	36	3
12	1.13	12.37	11	16.50	20	1
13	0.94	21.10	24	36.00	43	3

**3.4.1 Seedling Emergence model:** The experimental data was used to obtain the second order empirical model coefficients of equations. The empirical model equations for the seedling emergence as a function of process variables (planting speed and moisture content) was developed using experimental data. The quadratic equation model terms are shown in Table 6.

**Table 6. Coefficient Table for Seedling Emergence Response Surface Reduced Quadratic Model**

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	19.9310	1	0.8042	18.0295	21.8326	
A-Planting Speed	-0.5000	1	0.7907	-2.3696	1.3696	1
B-Moisture Content	2.8333	1	0.7907	0.9637	4.7029	1
AB	-2.2500	1	0.9684	-4.5398	0.0398	1
A <sup>2</sup>	-3.2586	1	1.1654	-6.0143	-0.5030	1.1698
B <sup>2</sup>	-5.2586	1	1.1654	-8.0143	-2.5030	1.1698
Intercept	19.9310	1	0.8042	18.0295	21.8326	

The actual emergence empirical model is shown as:

$$R = -191.4646 + 199.41P_S + 11.6671M_C - 4.5216P_S M_C - 60.6553P_S^2 - 0.1674M_C^2 \quad 41$$

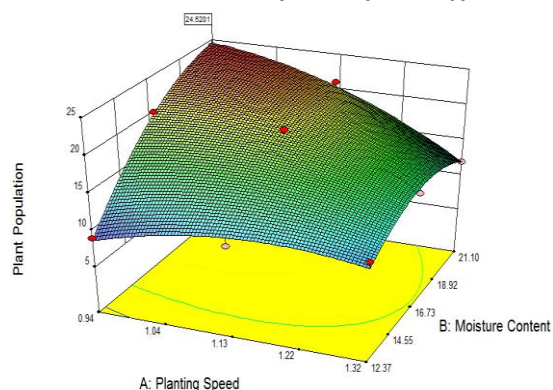
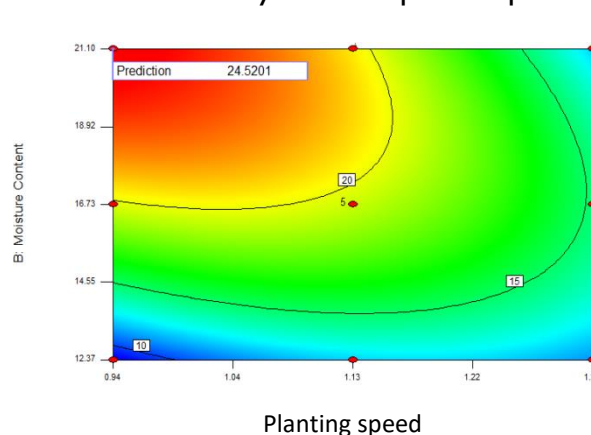
Similarly, the Sequential Model Sum of Squares (SMSS) analysis and the Lack of Fit Model were done for the two response variables for the depth of planting and the plant to plant spacing as shown in equations 42 and 43, respectively.

$$R = -284.858 + 291.732P_S + 17.7127M_C - 6.7824P_S M_C - 87.4009P_S^2 - 0.2575M_C^2 \quad 42$$

$$R = -34.4222 + 36.3813P_S + 2.0577M_C - 0.8139P_S M_C - 11.0803P_S^2 - 0.0289M_C^2 \quad 43$$

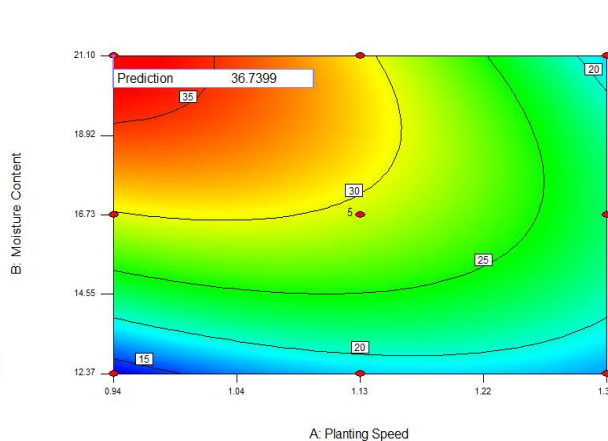
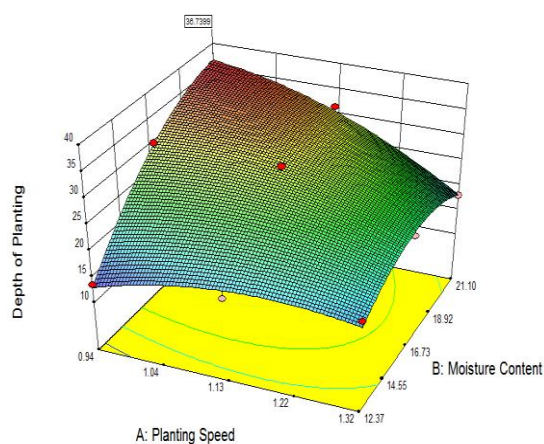
### 3.4.2 Effects of the process variables on seedling emergence, depth of planting and the plant spacing using the optimized models are shown in the contour and surface plots

The effects of the process variables on seedling emergence, depth of planting and the plant spacing using the optimized models are shown in the contour and surface plots shown in Figures 6 to 9. Figures 6 and 7 show that increased plant population was observed with increasing planting speed and moisture content values. Also, increased seedling emergence was observed with increasing moisture content and decreasing planting speed values. However, further increase in seed planting moisture content beyond the optimum point caused a decrease in the seedling emergence. Figures 8 and 9 show the contour and surface plots of the depth of planting model respectively. It was observed that there was increased depth of planting with increasing seed planting speed and moisture content values. Further increase in soil moisture content beyond the optimum point caused a decrease in the depth of planting.



**Figure 6:** Mean model contour plot showing the effect of moisture content and planting speed on seedling emergence for response surface optimization model.

**Figure 7:** Mean Model Response Surface Plot Showing the Effect of Seed Planting Moisture Content and Planting Speed on Seedling Emergence for Response Optimization.



## 4. Conclusions

The following conclusions can be drawn from the experimental results and analysis:

- i. There was significant difference among the planting methods, and the interactions of planting methods, year and depth of seed placement at 1% confidence level.
- ii. The constructed ridge seed planter has comparative advantage over the I.A.R. animal – drawn planter and the manual planting method in terms of percentage seed damage, planting speed, and speed of seedling emergence and the later, being the dominant mode of planting in Nigeria.

iii. Soil moisture availability is an important factor affecting the depth of seed planting in the study area.

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