



Exploring Optimal Design and Performance Tests of a Two – Row Self-Propelled Seed Planter

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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 was investigated under laboratory and field conditions to optimise the planting process using Response Surface Methodology (RSM). Parameters optimisation of the seed planting process becomes imperative to find parameter values that match predictions with reality and choose the right set of parameters that improve the planter's performance. 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 an 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, a further increase in seed planting moisture content beyond the optimum point caused a decrease in the seedling emergence. Similarly, there was increased planting depth with increasing seed planting speed and moisture content values. Conclusively, soil moisture availability is an important factor affecting seed planting depth in the study area.

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INTRODUCTION

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 (Wankhade and Kotwal, 2014). To complete seed sowing in the narrow time-frame available and ensure successful crop establishment, it is essential to have a reliable planter (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,

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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, 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).

MATERIALS AND METHODS

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 (Hacksaw frame and blade, centre punch, tri-square, metal scriber) 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), a single row IAR animal drawn planter, 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) were evaluated using 20 kg of Quality Protein Maize (QPM) seeds (pre-tested for viability) as test crop.

METHODS

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); ω =

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 (m^2), C = Cohesion , W = Static load on the wheel , Φ = Angle of shearing resistance by the soil. C and Φ vary according to the type and state of soil.

Hopper Design

The Shape chosen was rustrum with rectangular cross section as this is most widely used for cereals (Srivastava, 1993). The parameters that were designed for are: (i) Hopper

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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, m^3 , L_g = run length, m, Q_H = seed rate, kg/ha, B = sowing width, m, η_c = Coefficient of features of the hopper = 0.9, q_H = volume weight, kg/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, m^2 , V_c = Capacity of the hopper, 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, m^3

The standing height of hopper was computed from:

$$H_t = w (n + 1) \quad (9)$$

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

The soil openers are set to the required levels 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 (Fig. 1) 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.

Performance evaluation

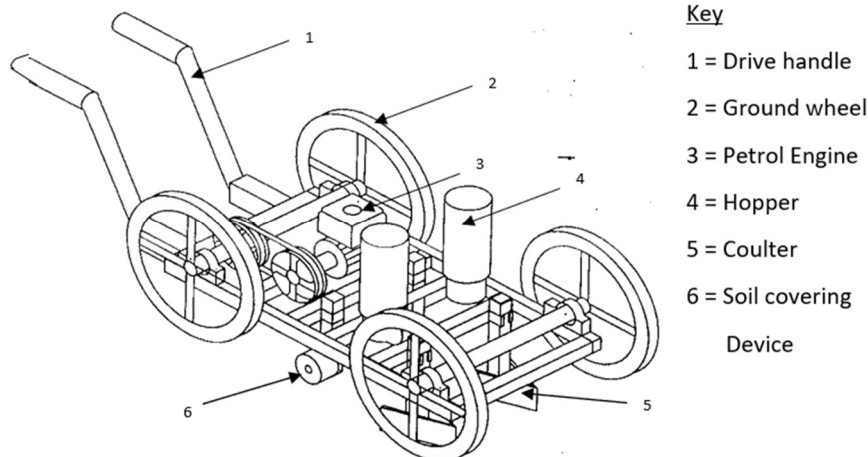


Figure 1: The 2-row self-propelled ridge planter

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Soil moisture content determination

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

$$M_c = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \quad (10)$$

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

Determination of seed delivery rate

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

$$Q = \frac{L * 10,000}{\pi D_e n w} \quad (11)$$

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

Working speed was computed from (FAO, 1994):

$$V = \frac{D_{av}}{t_{av}} \quad (12)$$

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

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:

$$SOE = \frac{(N_1 + N_2 + \dots + N_n)}{(t_1 + t_2 + \dots + t_n)} \quad (13)$$

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

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

$$RE = \frac{(N_1 + N_2 + \dots + N_n)}{NS} \quad (16)$$

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

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).

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.

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 ... 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:

$$y_1 = a_0 + a_1x_1 + a_2x_2 + a_3x_1x_2 + a_4x_1^2 + a_5x_2^2 \quad (17)$$

$$y_2 = b_0 + b_1x_1 + b_2x_2 + b_3x_1x_2 + b_4x_1^2 + b_5x_2^2 \quad (18)$$

$$y_3 = c_0 + c_1x_1 + c_2x_2 + c_3x_1x_2 + c_4x_1^2 + c_5x_2^2 \quad (19)$$

$$y_4 = d_0 + d_1x_1 + d_2x_2 + d_3x_1x_2 + d_4x_1^2 + d_5x_2^2 \quad (20)$$

$$y_5 = e_0 + e_1x_1 + e_2x_2 + e_3x_1x_2 + e_4x_1^2 + e_5x_2^2 \quad (21)$$

$$y_6 = f_0 + f_1x_1 + f_2x_2 + f_3x_1x_2 + f_4x_1^2 + f_5x_2^2 \quad (22)$$

a_0 ... a_5 , b_0 ... b_5 , e_0 ... 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.

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:

$$0.94 \leq x_1 \leq 1.32 \quad (23)$$

$$12.37 \leq x_2 \leq 21.1 \quad (24)$$

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

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

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

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

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

Subject to

$$0.94 \leq x_1 \leq 1.32$$

$$12.37 \leq x_2 \leq 21.1$$

and Minimize

$$y_5 = e_0 + e_1x_1 + e_2x_2 + e_3x_1x_2 + e_4x_1^2 + e_5x_2^2 - \epsilon$$

Subject to

$$0.94 \leq x_1 \leq 1.32$$

$$12.37 \leq x_2 \leq 21.1$$

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

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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: $N = n_f + n_a + n_c$ (25)

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: $N = n_f + n_a + n_c = 4 + 4 + 5 = 13$ (26)

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

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:

$$Y_{RSM} = \gamma_0 + \gamma_1 x_1 + \gamma_2 x_2 + \gamma_3 x_1 x_2 + \gamma_4 x_1^2 + \gamma_5 x_2^2 + \epsilon \quad (27)$$

where, Y_{RSM} = Response Surface matrix output, x_1 = planting speed (m/s), x_2 = moisture content (% db), $x_1 x_2$ = interaction between

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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 γ_i , a matrix model for the process factors was developed from experimental matrix as:

$$x = \begin{bmatrix} 1 & x_{11} & x_{21} \\ 1 & x_{12} & x_{22} \\ \vdots & \vdots & \vdots \\ 1 & x_{113} & x_{213} \end{bmatrix} \quad (28)$$

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:

$$y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_{13} \end{bmatrix} \quad (29)$$

The error term was represented as

$$\epsilon = \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \\ \epsilon_{13} \end{bmatrix} \quad (30)$$

The coefficients in the model were represented as:

$$\gamma = \begin{bmatrix} \gamma_1 \\ \gamma_{12} \\ \vdots \\ \gamma_{113} \end{bmatrix} \quad (31)$$

The general form is represented as:

$$y = x\gamma + \epsilon \quad (32)$$

A vector of the least square estimator is:

$$L = \epsilon^T \epsilon \quad (33)$$

and minimised as:

$$\left(\frac{\partial L}{\partial \gamma} \right) = 0 \quad (34)$$

The coefficients (γ_i) in the model was determined by Design Expert 9.0 software and

$$\gamma_i = (x^T x)^{-1} x^T y \quad (35)$$

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, σ^2 , SSY and SSR were calculated as:

$$SSE = y^T y - \gamma^T x^T y \quad (36)$$

$$\sigma^2 = \frac{SSE}{n-p} \quad (37)$$

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

$$SSY = y^T y - \frac{(\sum_{i=0}^{n-1} y_i)^2}{n} \quad (38)$$

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

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

A Minitab program (Fig. 2) 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( $\varphi, C$ ) :=
  k ← length(b)
  for i ∈ 0..k - 1
    Ri,0 ← bi
    Ri,1 ←  $\sqrt{\frac{b_i}{C_{i,i} - \frac{SSE}{(n-p)}}}$ 
    Ri,2 ← |dt(Ri,1, n - p)|
    Ri,3 ← "yes" if Ri,2 ≤ α
           "no" if Ri,2 > α
  R
  
```

Figure 2: Design Expert 9.0 Program for Computing the Coefficient of the Response Surface Model, t-test value and the p-value.

RESULTS AND DISCUSSION

Seed metering for the three methods investigated

The results of seed metering and ground wheel speed are shown on Tables 3 and 4 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 forward speed.

Table 3: 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 4: 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 |

Seedling emergence for the three methods evaluated for three years

Table 5, 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

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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 5: 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 ^{NS} | 3.06 | 4.75 |
| MTD | 2 | 140.9958848 | 70.4979424 | 38.66 ^{**} | 3.06 | 4.75 |
| SM | 2 | 4.8477366 | 2.4238683 | 1.33 ^{NS} | 3.06 | 4.75 |
| DP | 2 | 3.8106996 | 1.9053498 | 1.04 ^{NS} | 3.06 | 4.75 |
| YEAR | 2 | 95.4650206 | 47.7325103 | 26.18 ^{**} | 3.06 | 4.75 |
| MTD*SM | 4 | 3.7448560 | 0.9362140 | 0.51 ^{NS} | 2.43 | 3.44 |
| MTD*DP | 4 | 8.5596708 | 2.1399177 | 1.17 ^{NS} | 2.43 | 3.44 |
| MTD*YEAR | 4 | 23.5720165 | 5.8930041 | 3.23 [*] | 2.43 | 3.44 |
| SM*DP | 4 | 7.6707819 | 1.9176955 | 1.05 ^{NS} | 2.43 | 3.44 |
| SM*YEAR | 4 | 5.6460905 | 1.4115226 | 0.77 ^{NS} | 2.43 | 3.44 |
| DP*Year | 4 | 4.3868313 | 1.0967078 | 0.60 ^{NS} | 2.43 | 3.44 |
| MTD*SM*DP | 8 | 15.7366255 | 1.9670782 | 1.08 ^{NS} | 2.00 | 2.62 |
| MTD*SM*YEAR | 8 | 43.5390947 | 5.4423868 | 2.98 ^{**} | 2.00 | 2.62 |
| MTD*DP*YEAR | 8 | 9.6872428 | 1.2109053 | 0.66 ^{NS} | 2.00 | 2.62 |
| SML*DP*YEAR | 8 | 10.6502058 | 1.3312757 | 0.73 ^{NS} | 2.00 | 2.62 |
| MTD*SM*DP*YEAR | 16 | 20.1646091 | 1.2602881 | 0.69 ^{NS} | 1.71 | 2.12 |
| ERROR | 160 | 291.7695473 | 1.8235597 | | | |
| TOTAL | 242 | 690.4773663 | | | | |

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

6. 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.

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Table 6: 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 |

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 Table7.

Table 7: 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 ² | -3.2586 | 1 | 1.1654 | -6.0143 | -0.5030 | 1.1698 |
| B ² | -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:

$$R = -191.4646 + 199.41P_s + 11.6671M_c - 4.5216P_sM_c - 60.6553P_s^2 - 0.1674M_c^2 \quad 40$$

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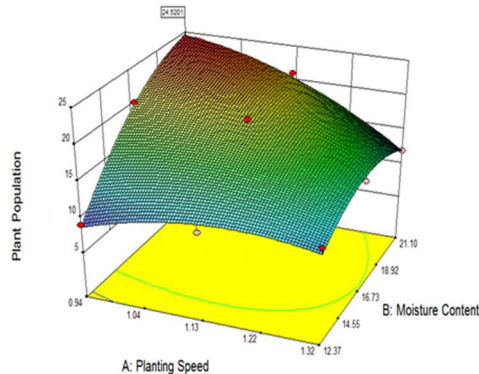
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Effects of the process variables on seedling emergence, depth of planting and the plant spacing using the optimized models are shown in the contour and surface plots

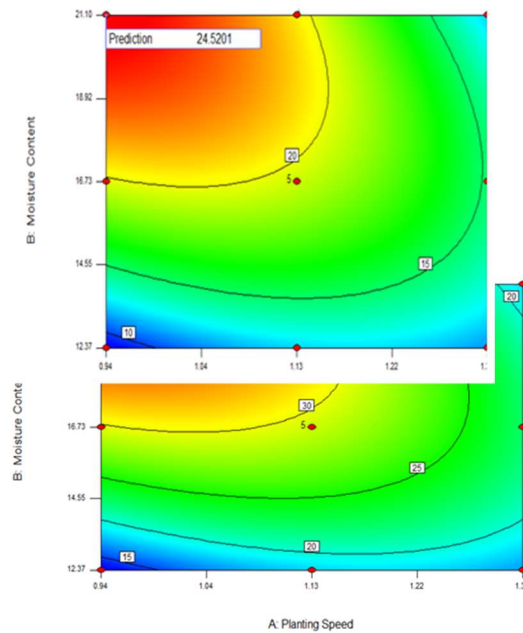
The effects of the process variables on



seedling emergence, depth of planting and the plant spacing using the optimized models are shown in the contour and surface plots shown in Figures 3 to 6. Figures 3 and 4 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 5 and 6 show the contour and response surface plots of the effect of soil moisture content and planting speed on depth of planting, respectively. It was observed that there was increased depth of planting with increasing seed planting speed and soil moisture content. Soil moisture content is an important factor affecting the depth of seed placement. Planting speed

Figure 3: Mean model contour plot showing the effect of soil moisture content and planting speed on seedling emergence for response surface optimization model.

Figure 4: Mean model response surface plot showing the effect of seed planting population, soil



moisture content and planting speed on seedling emergence for response optimization.

Figure 5: Contour plot showing the effect of soil moisture content and planting speed on depth of planting.

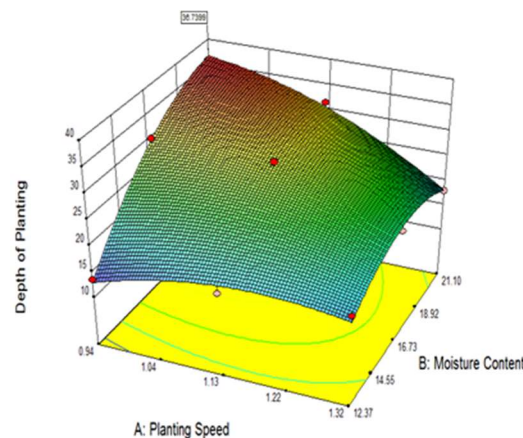


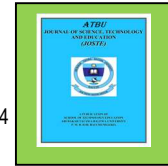
Figure 6: Surface plot showing the effect of soil moisture content and planting speed on depth of planting.

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CONCLUSION

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

1. There was significant difference among the planting methods, and the interactions of planting methods, year and depth of seed placement at 1% confidence level.
2. 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.
3. Soil moisture availability is an important factor affecting the depth of seed planting in the study area.

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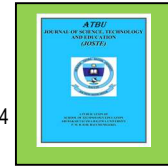
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