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Original Research

Optimal Seed Rate and Planting Technique Determination for High Productivity in Rice (*Oryza sativa* L.) Varieties in the Southern Guinea Savannah of Nigeria

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ABSTRACT: Lack of an established planting techniques and continuous usage of high seed rates have contributed to major challenges of achieving food security and high productivity in rice seed production in Nigeria. There are obvious variations in these two factors being currently used by different farmers, seed companies and research institutions. In this paper, field trials were conducted during the 2019, 2020 and 2021 rainy seasons at the research field of the National Agricultural Seeds Council, Sheda, Abuja, Federal Capital Territory, Southern Guinea savannah zone, Nigeria. A split-split plot design in three randomized blocks (replicates) was employed to determine the optimum combination of planting techniques and seed rates aimed at achieving high yield for rice seed production in Nigeria. The four (4) varieties used (FARO 44, FARO 59, FARO 66 and FARO 67) were laid out as main plot; Planting techniques at three (3) different planting techniques: dibbling, broadcasting and transplanting) as sub-plot; and seed rate at three (3) levels (25, 50 and 75kg/ha) as sub-subplot. A multi-dimensional scale analysis was explored to look at different dimensions of the result for 2019, 2020, 2021 and combined-years analysis. From the result, Interactions between planting technique and seed rate for optimum seed yield per hectare revealed that in combined-year, broadcast, dibbling and transplant planting techniques with seed rate of 50 kg/ha (3.37 t/ha), 50 kg/ha (3.58 t/ha) and 25 kg/ha (3.43 t/ha) respectively were significant. Response surface regression shown that the transplant planting technique with seed rate of 44 kg/ha sprung up unexpected increase in seed yield when subjected to total weed count (from 4.065 t/ha to 6.625 t/ha) which otherwise shows the suppressing effect of the independent variable (transplant planting technique) on weed. Transplant and dibbling planting techniques with seed rates of 42 and 40 kg/ha respectively produced optimum seed yield between 4.96 t/ha and 5.60 t/ha. It is therefore concluded from the response surface regression analysis that dibbling planting technique + 40 kg/ha seed rate and transplant planting technique + 42 kg/ha seed rate were the most productive and optimal combination for planting a hectare of rice field with enhanced productivity. But result from the ANOVA interactions of planting technique and seed rate established that the combination of (broadcast + 50 kg/ha), (dibbling + 50 kg/ha) and (transplant + 25 kg/ha) were optimal for high productivity per hectare in rice field establishment. Considering the effect of weed, it is concluded that transplant planting technique with an increased seed rate of 44 kg/ha could be recommended as the best planting technique and seed rate with suppressing effect on weed.

Keywords: Seeds, NASC, FARO, ANOVA, Seed rate

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INTRODUCTION

It is a significant task to address the problem of global food security in the twenty-first century. However, seed is a crucial, vital and essential input for attaining sustained growth in agricultural production and productivity. A sustained increase in agricultural production and productivity depends on the development of improved varieties, methods of planting adopted, optimum seed rates as well as timely and adequate supply of quality seeds to the farmers.

In Nigeria, there are 711 varieties from 42 crop species which have been released till date and out of which there are 229 varieties from 10 crop species which have also been enlisted in the ECOWAS crop catalogue. From these, so many improved rice varieties have been released for cultivation with adaptation to various ecologies prevalent in Nigeria. Part of the requirements for their release however is usually based on the outstanding characteristics or potential yields of the released materials. Improved varieties account for about 40% increase in crop yield and productivity (Anonymous, 2022). Crop establishment is one of the key factors that affect the success of seed crop in terms of productivity and the rate of establishment has a great impact on plant density and the competitiveness of the crop, tillering, maturity and yield (Oghalo, 2011; Harris and Vijayaragavan, 2015). Therefore, high establishment rates improve yield, better competition against weeds, uniform growth and maturity. Additionally, optimum crop establishment reduces seeding rates needed for field planting (Baloch *et al*., 2002; Harris and Vijayaragavan, 2015). In Nigeria today, majority of the rice farmers sow their seeds through broadcasting because it is cheap and faster while few consider transplanting or line seeding techniques as their choice of planting method.

Most productive planting techniques and seed rates for higher productivity, weed management, pests and disease control are very necessary to investigate and recommend to Nigerian rice farmers to minimize the many problems being faced during the production like high cost of quality seed, inappropriate establishment techniques, pests and disease incidence, reduction in seed quality and lodging.

Consequently, lack of an established planting techniques and continuous usage of high seed rates have contributed to major challenges of achieving food security and high productivity in rice seed production in Nigeria. There are obvious variations in these two factors being currently used by different farmers, seed companies and research institutions, hence, this research activity was conducted to determine and establish:

(a) the most productive planting technique and optimum seed rate required for planting a hectare of rice seeds.
(b) the best planting technique and seed rate that suppress weed to minimum standstill.

MATERIALS AND METHODS

Location of study

Field experiment was conducted during the rainy season for three consecutive years from 2019 to 2021 in the Southern Guinea Savannah of Nigeria. The study was located at the research field of National Agricultural Seeds Council (NASC), Corporate Headquarters, Sheda, Abuja (08°53'7.56 N, 007°03' 58 E. 104; 212m above the sea level).

Materials used

Materials used for the experiment were rice seed varieties (FARO 44, FARO 59, FARO 66 and FARO 67) sourced from Ebonyi State University Seeds, Ebonyi State, National Cereals Research Institute, Badeggi, Niger State and National Agricultural Seeds Council through seeds produced from its seed increase establishment. Other materials were tractor, tray, NPK 15:15:15 fertilizer, Urea (46%), herbicides, tag, peg, cutlass, hoe, meter rule, net, seed laboratory equipment (drying oven, sensitive weighing balance, moisture content meter, etc.), book and pen (for data collection).

Rice varieties used and their descriptors

FARO 44

Origin: Taiwan through IRTP
Ecology: Rainfed Irrigated Swamp
Tillering capacity: 15 – 20 tillers/plant stand
Plant Height: 110 – 120cm
Stem base colouration: Green
Leaf sheet colour: Green
Leaf length: Long
Leaf blade: Long, semi-broad and lax
Ligule type/length: Short
Flag leaf: Erect
Photoperiod sensitivity: Insensitive
Stigma colour: Colourless
Panicle exertion: Very well exerted
Grain type: Narrow and long (A)
Grain yield potential: 4.8 t/ha
Maturity date: 110 – 120 days
Husk colour at maturity: Straw
Awns: Rare small partial awns
Tolerant to Major diseases: Susceptible to AfRGM and Blast

FARO 59

Origin: Africa Rice
Ecology: Upland
Tillering capacity: Medium
Plant Height: 100 – 120 cm
Stem base colouration: Light purple
Leaf sheet colour: Light purple
Leaf length: Long

Ligule type/length: Intermediate
Flag leaf: Erect
Photoperiod sensitivity: Insensitive
Stigma colour: Cream
Panicle exertion: Well exerted
Grain type: B (Medium bold)
Grain yield: 4-6 t/ha
Maturity date: 90 days
Husk colour at maturity: Golden
Awns: Awnless
Amylose content: Intermediate
Domancy: Weak

FARO 66

Origin: International Institute of Tropical Agriculture/AfricaRice
Ecology: Lowland Rainfed/ Irrigated Swamp
Tillering capacity: 15 – 20 tillers per plant stand
Plant Height: 115 – 120cm
Flood tolerant: Yes
Stem base colouration: Green
Leaf sheet colour: Green
Leaf blade: Long, semi-broad and lax
Ligule type/length: Long and pointed
Flag leaf: Erect
Photoperiod sensitivity: Insensitive
Stigma colour: Colourless
Panicle exertion: Very well exerted
Grain type: Narrow and Long (A)
Grain yield: 6.7 t/Ha
Maturity date: 120 – 130 days
Husk colour at maturity: Straw
Awns: Awnless
Tolerant to Major diseases: Susceptible to AfRGM and Blast

FARO 67

Origin: International Institute of Tropical Agriculture/AfricaRice
Ecology: Rainfed Lowland
Tillering capacity: 15 – 20
Plant Height: 115 – 120cm
Flood tolerant: Yes
Stem base colouration: Straw
Leaf sheet colour: Straw
Leaf length: Long
Ligule type/length: Long and pointed
Flag leaf: Erect
Photoperiod sensitivity: Insensitive
Stigma colour: Cream
Panicle exertion: Well exerted
Grain type: Long (A-)
Grain yield: 6.6 t/Ha
Maturity date: 120 – 130 days
Husk colour at maturity: Straw
Awns: Awnless
Amylose content: Intermediate
Domancy: Weak

Experimental treatments and design

Experimental area was marked into plots in a split-split plot design in three replicates. The layout is as follows: Main-plot factor: Four (4) rice varieties – FARO 44, FARO 59, FARO 66 and FARO 67 – Subplot factor: Three (3) planting techniques dibbling, broadcasting and transplanting (this was done at seedling age of 4 weeks after nursery establishment); and sub-subplot factor Three (3) seed rates – 25, 50 and 75 kg/ha. Each plot within main plot measuring 7.4 m x 6.4 m (47.36 m2) was separated with 1.5m distance while each sub-plot within the main plot measuring 1.8 m x 1.8 m (3.24 m2) was separated by 1m bound and sub-sub plot measuring 1.8 m x 1.8 m (3.24 m2was separated 0.5m bound. Gap of about 1.5 m separated each main-plot in the block and between each block (replicate). Therefore, the total number of sub-plots in a main plot were three (3) with each split into three (3) sub-sub plots totaling nine (9) plots in in each of the four (4) main-plots. The total size of the field which was measured by a tape was 757.02 m2 (34.1m x 22.2m). Each experimental sub-sub plot received same fertilizer application as recommended for the study area – 100 kg N, 30 kg P_2O_5 and 30 kg K_2O per hectare.

Data collection and measurement

The following rice growth variables, phenological, yield and yield components were collected, measured and recorded both on the experimental field and in the laboratory.

Rice growth variable

Plant height (PH) – (cm)

Measurement of the distance between the upper boundary of the main photosynthetic tissues of a plant and the ground level was measured in centimeter. Plant height was taken at 2 weeks intervals from 4 weeks after planting (WAP) to 14 weeks after planting (WAP) until harvesting depending on the maturity period of different varieties used. This was done on randomly selected 5 plants per plot.

Leaf area index (LAI)

This was to track the growth and health of plants over time; it was done on randomly selected 5 plants per plot through direct non-destructive measurements which involved taking the length and width of a leaf and then using weighted regression equations for rice species to get the leaf area. The equation used is: $A = b \times l \times w$; where l is the length, w is the width of the leaf at its widest point, b is the leaf shape coefficient that varies from species to species, and A is the leaf area. The general coefficient of 0.78 from the study carried out by Bruno et al. (2019) was very close from those found in IRRI's Rice Experimental Station, Los Baños, for dry (0.73) and wet season (0.75) (Palaniswamy and Gomez 1974). In other words, similar leaf shape between old and modern cultivars allows to use the general coefficient (0.78) for new cultivars LAI estimation, with no need to estimate new specific coefficients for new cultivars.

Number of tillers (NOT)

The total number of tillers produced were counted on randomly selected 5 plants per plot and recorded at dough stage to determine total tillers.

Productive tillers (PT)

The number of effective tillers produced were counted on randomly selected 5 plants per plot and recorded at dough stage to determine productive tillers.

Root length (RL) - (cm)

The procedure was to trace and measure the roots on paper. This was done after harvesting and recorded in centimeter on randomly selected 3 plants per plot.

Dry matter weight of rice straw (g/plant)

Straw yield samples from three (3) randomly selected plants per plot were dried at 80 degree Celsius for more than 48 hours (max. 72 hours) until a constant weight was attained. The dried samples was presented as oven-dry weight basis.

$$\text{Dry matter weight: } \frac{\text{Dry Sample Weight}}{\text{Wet Sample Weight}}$$

Total weed count

All weed types within the quadrant of 0.1m^2 in a sample plot were identified, counted and recorded. Total count (about 20 plants per quadrant) of each species were added together to give relative abundance of each specie per plot. This was estimated in percentage (%) of each weed type. Weed Count was taken and weeds were classified into broadleaved, grasses and sedges.

Rice phenological variable

Days to first heading (DTFH)

Days to first heading was counted and recorded from seed sowing date to the first day of reproductive heading as determined by visual observation on randomly selected 5 plants per plot.

Days to 50% heading (DT50%H)

Days to 50% heading was counted and recorded from seed sowing date to days of 50% reproductive heading attainment as determined by visual observation of experimental plots.

Rice yield and other yield variables

Panicle weight (PW) (g)

The average weight of the main shoot panicle at harvest in gram was measured using a laboratory sensitive scale on 5 randomly selected plants and the average was taken for analysis.

Seed yield per plant (g)

Seed yield per plant was weighed and recorded in grams using sensitive scale after harvest and processing on randomly selected 3 plants per plot.

Seed yield per hectare (t ha^{-1})

Seed yield per hectare was done after harvest by the plot yield calculated and extrapolated into tons per hectare.

Harvest index (%)

Harvest index is defined as the pounds of seed divided by the total pounds of above ground biomass (stover plus seed/grain). It was calculated according to the equation of Kemanian *et al*. (2007), done for each plot and expressed in percentage.
Seed harvest index (%) = Grain yield/Total biomass x100.

Statistical analysis

Standard procedures were adopted to record the data on various growths, phenological, yield and other covariates during the course of study. All data from the growth, phenology, yield and other covariates were subjected to analysis of variance (ANOVA) using SAS statistical software package (SAS Institute, 2012. Cary, NC). For significant main effects, means separation was performed using the Duncan Multiple Range Test (DMRT) tests at P

Table 1: Response Surface regression analysis of rice data with the model (days to first heading).

		Variety			
Model (with days to first heading) and Y = Seed Yield (t/ha)	Model No.	FARO-44	FARO-59	FARO-66	FARO-67
Seed rate + Planting techniques	1	3.488 ± 0.120	3.536 ± 0.104	3.521 ± 0.111	**3.234 ± 0.097**
Seed rate + Planting techniques + Days to first heading	2	3.435 ± 0.149	Out of range	Out of range	Out of range
Seed rate + Planting techniques + Days to first heading + Productive tillers	3	Out of range	**4.964 ± 0.525**	Out of range	Out of range
Seed rate + Planting techniques + Days to first heading + Productive tillers + Plant height @ maturity	4	3.481 ± 0.216	3.839 ± 0.170	Out of range	Out of range
Seed rate + Planting techniques + Days to first heading + Productive tillers + Plant height @ maturity + Dry matter weight of rice straw	5	Out of range	Out of range	Out of range	Out of range
Seed rate + Planting techniques + Days to first heading + Productive tillers + Plant height @ maturity + Harvest index	6	3.427 ± 0.256	3.749 ± 0.266	**3.924 ± 0.336**	Out of range
Seed rate + Planting techniques + Days to first heading + Productive tillers + Plant height @ maturity + Leaf area index	7	3.500 ± 0.244	3.808 ± 0.310	Out of range	Out of range
Seed rate + Planting techniques + Days to first heading + Productive tillers + Plant height @ maturity + Root length	8	**3.604 ± 0.284**	Out of range	3.478 ± 0.264	Out of range
Seed rate + Planting techniques + Days to first heading + Productive tillers + Plant height @ maturity + Panicle weight	9	3.514 ± 0.134	3.393 ± 0.255	3.567 ± 0.239	Out of range
Optimal Model for FARO-44 (+ Total weed count)					
Seed rate + Planting techniques + Days to first heading + Productive tillers + Plant height @ maturity + Root length + Total weed count	10	3.153 ± 0.322			
(Optimal Model @ Planting techniques = PT_Transplant or PT_Dibbling; Seed rate = 45Kg/ha)					
Optimal Model for FARO-59 (+ Total weed count)					
Seed rate + Planting techniques + Days to first heading + Productive tillers + Total weed count	11		3.951 ± 0.174		
(Optimal Model @ Planting techniques = PT_Transplant; Seed rate = 42Kg/ha)					
Optimal Model for FARO-66 (+ Total weed count)					
Seed rate + Planting techniques + Days to first heading + Productive tillers + Plant height @ maturity + Harvest index + Total weed count	12			Out of range (=3.066)	
(Optimal Model @ Planting techniques = PT_Transplant or PT_Dibbling; Seed rate = 45Kg/ha)					
Optimal Model for FARO-67 (+ Total weed count)					
Seed rate + Planting techniques + Total weed count	13				Out of range (<3.234)
(Optimal Model @ Planting techniques = PT_Transplant or PT_Dibbling; Seed rate = 45Kg/ha)					

< 0.05. Response surface regression analysis was done to determine the optimum value of seed-yield given the set of planting techniques, seed-rates and rice varieties. Response surface analysis was implemented by RSREG procedure in SAS (SAS Institute, 2012. Cary, NC). The RSREG procedure uses the method of least squares to fit quadratic response surface regression models. Response surface models are a kind of general linear model in which attention focuses on characteristics of the fit response function and in particular, where optimum estimated response values occur. In addition to fitting a quadratic function, the RSREG procedure to do the following: test for lack of fit, test for the significance of individual factors, compute the ridge of optimum response and predict new values of the response, among others.

RESULTS

Multivariate response surface regression analysis of rice varieties

Response surface regression analysis of rice varieties with planting pattern and seed rates

A response surface regression analysis of rice varieties with planting techniques and seed rates fitted into two models (days to first heading on (Table 1) and (days to 50% heading on (Table 2) with y = seed yield (t/ha). The models were analysed separately to reduce number of variables in the models as they all measured heading parameter. The varietal models that gave optimal values of seed yield (t/ha) are coloured in yellow and black in each set of model. For each varietal optimal model, total weed count was added to check the effect of weeds on seed yield. The optimal yield values were generally lower when total weed count was included in the model which signifies the suppressing effect of weed (broadleaves, sedges and tree) on seed yield. The planting technique and seed rate at the optimal values are indicated on the (Table 2).

Table 2: Response surface regression analysis of rice data the model (with days to 50% heading).

		Variety			
Model (with days to 50% heading) and Y = Seed Yield (t/ha)	Model No.	FARO-44	FARO-59	FARO-66	FARO-67
Seed rate + Planting techniques	14	3.488 ± 0.120	3.536 ± 0.104	3.521 ± 0.111	3.234 ± 0.097
Seed rate + Planting techniques + Days to 50% heading	15	3.473 ± 0.144	Out of range	Out of range	Out of range
Seed rate + Planting techniques + Days to 50% heading + Productive tillers	16	**3.865 ± 0.274**	3.770 ± 0.138	Out of range	Out of range
Seed rate + Planting techniques + Days to 50% heading + Productive tillers + Plant height @ maturity	17	3.821 ± 0.308	3.759 ± 0.143	Out of range	Out of range
Seed rate + Planting techniques + Days to 50% heading + Productive tillers + Plant height @ maturity + Dry matter weight of rice straw	18	Out of range	**4.065 ± 0.395**	Out of range	**3.264 ± 0.243**
Seed rate + Planting techniques + Days to 50% heading + Productive tillers + Plant height @ maturity + Harvest index	19	3.589 ± 0.245	3.659 ± 0.262	3.865 ± 0.329	3.200 ± 0.272
Seed rate + Planting techniques + Days to 50% heading + Productive tillers + Plant height @ maturity + Leaf area index	20	3.696 ± 0.246	3.814 ± 0.206	**5.671 ± 0.912**	Out of range
Seed rate + Planting techniques + Days to 50% heading + Productive tillers + Plant height @ maturity + Root length	21	Out of range	3.957 ± 0.236	3.444 ± 0.256	Out of range
Seed rate + Planting techniques + Days to 50% heading + Productive tillers + Plant height @ maturity + Panicle weight	22	3.507 ± 0.279	3.500 ± 0.212	3.503 ± 0.240	Out of range
Optimal Model for FARO-44 (+ Total weed count)					
Seed rate + Planting techniques + Days to 50% heading + Productive tillers + Total weed count	23	3.502 ± 0.238			
(Optimal Model @ Planting techniques = PT_Transplant or PT_Dibbling; Seed rate = 40Kg/ha)					
Optimal Model for FARO-59 (+ Total weed count)					
Seed rate + Planting techniques + Days to 50% heading + Productive tillers + Plant height @ maturity + Dry matter weight + Total weed count	24		6.625 ± 0.883		
(Optimal Model @ Planting techniques = PT_Transplant; Seed rate = 44Kg/ha)					
Optimal Model for FARO-66 (+ Total weed count)					
Seed rate + Planting techniques + Days to 50% heading + Productive tillers + Plant height @ maturity + Leaf area index + Total weed count	25			3.670 ± 0.403	
(Optimal Model @ Planting techniques = PT_Dibbling; Seed rate = 40Kg/ha)					
Optimal Model for FARO-67 (+ Total weed count)					
Seed rate + Planting techniques + Days to 50% heading + Productive tillers + Plant height @ maturity + Dry matter weight + Total weed count	26				3.133 ± 0.290
(Optimal Model @ Planting techniques = PT_Transplant or PT_Dibbling; Seed rate = 45Kg/ha)					

Out of range = when optimal value is outside the range of design factors/variables used. In such case the precision (standard error) is not estimated, and any estimate of design variables outside the range used in the trial will have little meaning.

The model with days to first heading on (Table 1), showed that FARO 44 variety with the optimal model (Seed rate + Planting techniques + Days to first heading + Productive tillers + Plant height @ maturity + Root length) gave optimal Planting techniques (Transplant or Dibbling) at a Seed Rate of 45kg/ha (minimum) resulted into average yield of (3.604 ± 0.284 t/ha). When subjected to Total Weed Count variable, the suppressing effect of weed was noticed as yield reduced to (3.153 ± 0.322 t/ha). However, for model (with days to 50% heading) on (Table 2), FARO 44 variety with the optimal model (Seed rate + Planting techniques + Days to 50% heading + Productive tillers) gave optimal Planting techniques (Transplant or Dibbling) at a Seed Rate of 40kg/ha (minimum) resulted into average yield of (3.865 ± 0.274 t/ha); and when subjected to Total Weed Count variable, the suppressing effect of weed was noticed as yield reduced to (3.502 ± 0.238 t/ha). FARO 59 variety with model days to first heading on (Table 1), the optimal model (Seed rate + Planting techniques + Days to first heading + Productive tillers) resulted to optimal Planting Pattern (Transplant) at a Seed Rate of 42kg/ha (minimum) with an average yield of (4.964 ± 0.525 t/ha); and when subjected to Total Weed Count variable, the suppressing effect of weed was noticed as yield reduced to (3.951 ± 0.174 t/ha). However, for model with days to 50% heading on (Table 2), FARO 59 variety with the model (Seed rate + Planting techniques + Days to 50% heading + Productive tillers + Plant height @ maturity + Dry matter weight) gave optimal Planting techniques (Transplant) at a Seed Rate of 44kg/ha (minimum) resulted into average yield of (4.065 ± 0.395 t/ha); and when subjected to Total Weed Count variable, the suppressing effect of variety was unexpectedly noticed as yield increased to (6.625 ± 0.883 t/ha).

FARO 66 variety with model with days to first heading on (Table 1), the optimal model (Seed rate + Planting techniques + Days to first heading + Productive tillers + Plant height @ maturity + Harvest index) resulted to optimal Planting techniques (Transplant or Dibbling) at a Seed Rate of 45kg/ha (minimum) with an average yield of (3.924 ± 0.336 t/ha). When subjected to Total Weed Count variable, the suppressing effect of weed was noticed as yield reduced to (3.066 t/ha). However, for model with days to 50% heading in (Table 2), FARO 66 variety with the model (Seed rate + Planting patterns + Days to 50% heading + Productive tillers + Plant height @ maturity + Leaf area index) gave optimal Planting techniques (Dibbling) at a Seed Rate of 40kg/ha (minimum) resulted into average yield of (5.671 ± 0.912 t/ha); and when subjected to Total Weed Count variable, the suppressing effect of weed was noticed as yield reduced to (3.670 ± 0.403 t/ha).

On FARO 67 variety with model days to first heading in Table 1, the optimal model (Seed rate + Planting patterns) resulted to optimal Planting techniques (Transplant or Dibbling) at a Seed Rate of 45 kg/ha (minimum) with an average yield of (3.234 ± 0.097 t/ha); and when subjected to Total Weed Count variable, the suppressing effect of weed was noticed as yield reduced to (less than 3.234 t/ha). However, for model with days to 50% heading on (Table 2), FARO 67 variety with the model (Seed rate + Planting patterns + Days to 50% heading + Productive tillers + Plant height @ maturity + Dry matter weight) gave optimal Planting techniques (Transplant or Dibbling) at a Seed Rate of 45kg/ha (minimum) resulted into average yield of (3.264 ± 0.243 t/ha); and when subjected to Total Weed Count variable, the suppressing effect of weed was noticed as yield reduced to (3.133 ± 0.290 t/ha).

The out of range in both models explained when optimal value is outside the range of design factors/variables used. In such case the precision (std error) is not estimated, and any estimate of design variables outside the range used in the trial will have little meaning.

Interaction of planting techniques and seed rate on seed yield per hectare produced by rice plant in 2019, 2020, 2021 and combined-year analysis

The interactions of Planting techniques (PT) x Seed rate (SR) on seed yield per hectare in 2019 are presented in (Table 3). Dibbling planting technique planted at 25 kg/Ha and 50 kg/Ha seed rates produced significant ($P < 0.05$) similar but higher seed yield per hectare with transplant planting technique at 25 kg/Ha; and broadcast planting technique at 50 kg/Ha seed rate. However, dibbling and transplant planting techniques with 75 kg/Ha seed rate and broadcast at 50 kg/Ha seed rate produced less seed yield per hectare than other interactions.

The interactions of PT x SR on seed yield per hectare in 2020 are presented in (Table 4). Dibbling planting technique planted at 25 kg/Ha and 50 kg/Ha seed rates produced significant ($P < 0.05$) similar but higher seed yield per hectare with transplant planting technique at 25 kg/Ha seed rate. However, Dibbling and broadcast planting techniques with 75 kg/Ha and 25 kg/Ha seed rates respectively produced less seed yield per hectare than other interactions.

The interactions of PT x SR on seed yield per hectare in 2021 are presented in (Table 5). Dibbling and transplant planting techniques planted at 25 kg/Ha and 50 kg/Ha seed rates; and broadcast planting technique planted at 50 kg/Ha and 75 kg/Ha produced significant ($P < 0.05$) higher seed yield per hectare than other interactions. However, dibbling and transplant planting techniques with 75 kg/Ha seed rate produced similar but less seed yield per hectare with broadcast planting technique at 25 kg/Ha seed rate.

The interactions of PT x SR on seed yield per hectare in combined-year analysis are presented in (Table 6). Dibbling planting technique planted at 50 kg/Ha seed rate produced significant ($P < 0.05$) higher seed yield per hectare than other interactions. However, broadcast planting technique with 25 kg/Ha seed rate produced less seed yield per hectare than other interactions.

DISCUSSION

Response surface regression analysis of rice varieties as influenced by planting techniques and seed rates

Determination of optimum seed rate is an effective

Table 3: Interaction of planting techniques and seed rate on seed yield per hectare produced by rice plant in 2019.

Planting Technique	Seed rate (kg/Ha)		
	25	50	75
Broadcast	2.71[c]	3.41[ab]	3.36[b]
Dibbling	3.52[a]	3.69[a]	2.68[c]
Transplant	3.45[ab]	3.47[ab]	2.78[c]

Means with the same letter(s) are not significantly different at P<0.05 according to Duncan Multiple Range Test (DMRT).

Table 4: Interaction of planting techniques and seed rate on seed yield per hectare produced by rice plant in 2020.

Planting Technique	Seed rate (kg/Ha)		
	25	50	75
Broadcast	2.72[c]	3.38[b]	3.35[b]
Dibbling	3.52[a]	3.67[a]	2.84[c]
Transplant	3.47[ab]	3.34[b]	2.51[d]

SE± 0.14
Means with the same letter(s) are not significantly different at P<0.05 according to Duncan Multiple Range Test (DMRT).

Table 5: Interaction of planting techniques and seed rate on seed yield per hectare produced by rice plant in 2021.

Planting Technique	Seed rate (kg/Ha)		
	25	50	75
Broadcast	2.40[bc]	3.32[a]	3.27[a]
Dibbling	3.31[a]	3.39[a]	2.53[b]
Transplant	3.37[a]	3.30[a]	2.66[b]

SE± 0.14, Means with the same letter(s) are not significantly different at P<0.05 according to Duncan Multiple Range Test (DMRT).

Table 6: Interaction of planting pattern techniques and seed rate on seed yield per hectare produced by rice plant in combined-year analysis.

Planting Technique	Seed rate (kg/Ha)		
	25	50	75
Broadcast	2.61[g]	3.37[c]	3.32[d]
Dibbling	3.45[b]	3.58[a]	2.68[e]
Transplant	3.43[b]	3.37[c]	2.65[f]

SE± 0.01, Means with the same letter(s) are not significantly different at P<0.05 according to Duncan Multiple Range Test (DMRT).

strategy to improve the efficiency of available resource usage and to increase the yield per unit area. From our findings, transplant or dibbling planting technique with seed rate of 45 and 40 kg/ha gave the optimal model for FARO 44 in the first and second models (with days to first heading and days to 50% heading) respectively with a significant yield reduction from 3.604 t/ha to 3.153 t/ha and 3.865 t/ha to 3.502 t/ha for the two model set respectively when subjected to weed count variables. This simply signifies the effect of weed on rice seed production and effectiveness of transplant and dibbling planting pattern which had been reported by Kumar and Ladha (2011) that rice yields in transplanted and direct seeded rice were almost the same.

The study also revealed that transplant planting techniques with seed rate of 42 and 44 kg/ha gave the optimal model for FARO 59 variety in the first and second models respectively with a significant yield reduction from 4.964 t/ha to 3.951 t/ha and unexpected yield increase from 4.065 t/ha to and 6.625 t/ha respectively when subjected to weed count variables. Weed effect was significantly observed as it affects rice seed productivity in first set model but however, unexpected result was discernible in FARO 59 variety as the variety suppresses the weed growth due to effectiveness of the transplant planting technique. The observed results may be as a result of higher plant population which played favourable role in reducing the weed number and growth of varying weed fauna, added to that application of manual, mechanical or herbicidal treatments further improved, the suppressive effect on weeds thereby increasing the weed control efficiency. These results are well supported by Yadav *et al.* (2009); it also corroborates the findings of Maqsood (1998) who achieved higher grain yield in transplanted technique as compared to direct sowing.

For FARO 66 variety, either of transplant or dibbling planting technique with seed rate of 45 and 40 kg/ha gave the optimal model in the first and second models respectively with a significant yield reduction from 3.924 t/ha to 3.066 t/ha in the first model set and 5.671 t/ha to 3.670 t/ha for the second model set when subjected to weed count variables. Weed effect was significantly discerned as it affects rice seed productivity. This is similar to the findings of Naeem *et al*. (2002) who reported that despite transplanting method produced greater plant height, grain panicle and 1000 grain weight but at the same time produced statistically similar paddy yield as obtained with direct sowing.

Moreover, an optimal model of transplant or dibbling planting technique with combined seed rate of 45 kg/ha gave the optimal model for FARO 67 variety in the first and second models with a significant yield reduction from 3.234 t/ha to a less than 3.234 t/ha in the first model set and 3.264 t/ha to 3.133 t/ha for the second model set when subjected to weed count variables. Total weed count effect was significantly noticed as it affects rice seed productivity. This supports the findings of Naeem *et al*. (2002) and Kumar and Ladha (2011) as earlier reported.

Notwithstanding the differences in varieties, the findings from this study showed that the optimal seed rate and planting pattern techniques for each model set were from FARO 59 variety at 42 kg/ha seed rate with transplant planting pattern techniques in first model (with days to first heading) and FARO 66 variety at 40 kg/ha seed rate with dibbling planting techniques in second model (with days to 50% heading). Naeem *et al.* (2002) had suggested that super rice variety can safely be directly sown in line to obtain good yield because it showed suitable growth and development under all sowing methods; and Naeem *et al*., (2002) who reported that direct sown in line is more effective due to easy inter cultural operations like weeding, etc., and uniform plant stand.

Looking at the results from another dimension with respect to ANOVA analysis, interaction effects occurred among the factors (variety, planting patterns, seed rate) studied with respect to the values recorded for seed yield per hectare. The planting technique by seed rate (PT*SR) interactions were significant in all years of the study and in combined-year analysis. The variations in the interaction may be attributed to the significant effects of all factors studied. This is in contrast with the findings of Dendup *et al.,* (2018). The result from the ANOVA further established that planting technique with seed rate combination of (broadcast + 50 kg/ha), (dibbling + 50 kg/ha) and (transplant + 25 kg/ha) were consistently optimal for high productivity per hectare in rice field establishment in 2019, 2020 2021 and in the combined-year analysis. The optimal yield produced as a result of the lower seed rates irrespective of the planting techniques may be due an increase in some growth and yield components in rice as well as less competition for available soil nutrients. This is in conformity with the report of Tilahun *et al.* (2019) who suggested that the higher productivity in rice may be related to it increased spikelets per panicle, number of panicle produced, grains per panicle, tiller per plant and productive tiller per plant, less competition in lower plant density for available soil moisture and nutrients since productivity of crop plants is highly dependent on the availability of different growth resources. Similarly, the variations in seed rate by planting techniques as observed in this study may be as a result of the efficiency of different planting techniques and seed rate required for optimal yield. Susmita *et al*. (2020) had reported that grain yield differed significantly among different sowing techniques and further reported that it was more in line sowing (5682.84 kg ha^{-1}) than broadcasting (5430.62 kg ha^{-1}).

Conclusion

This study used response surface methodology and Central Composite Design (CCD) to determine the optimum seed rate and corresponding planting techniques for dependent variable (seed yield). It was shown that the optimal seed yield values generally decreased when total weed count was subjected to the analysed model which signifies the suppressing effect of weed on seed yield. Considering the varietal effect on yield, transplant or dibbling planting techniques with seed rate 40 kg/ha was concluded to be optimal for FARO 44 (3.87 t/ha); transplant technique with seed rate of 44 kg/ha for FARO 59 (4.96 t/ha); dibbling technique with seed rate of 40 kg/ha for FARO 66 (5.67 t/ha) and transplant or dibbling techniques with seed rate of 45 kg/ha for FARO 67 (3.26 t/ha). However, it is also concluded that transplant technique at seed rate of 44 kg/ha sprung up unexpected increase in seed yield when subjected to total weed count (from 4.065 t/ha to 6.625 t/ha) which otherwise shows the suppressing effect of the independent variable (transplanting technique) on weed.

Furthermore, it is concluded from ANOVA analysis that the significant interactions of planting techniques (PT) by seed rates (SR) on seed yield per hectare with optimal SR x PT in 2019, 2020, 2021 and in combined years were 50 kg/ha with broadcast, 50 kg/ha with dibbling and 25 kg/ha with transplant.

It is generally concluded from this study especially from the response surface regression analysis that, FARO 66 variety planted through dibbling or transplant planting technique with 40 kg/ha was the most productive and optimal combination for planting a hectare of rice field with enhanced productivity (5.67 t/ha). But result from the ANOVA interactions of planting technique and seed rate established that the combination of (broadcast + 50 kg/ha), (dibbling + 50 kg/ha) and (transplant + 25 kg/ha) were optimal for high productivity per hectare in rice field establishment.

We therefore, concluded that the optimal combination of planting technique and seed rate with (dibbling + 40 kg/ha), (broadcast + 50 kg/ha) and (transplant + 25 kg/ha) could be recommended to farmers, seed producers and research institutions for enhanced rice seed yield. However, where weed becomes a major problem, transplant planting technique with an increased seed rate of 44 kg/ha could be recommended as the best planting technique and seed rate with suppressing effect on weed.

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