RASHI 3 (1) : 12-20 (2018)

Response surface modelling for optimizing yield parameters of green gram

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Received : 15-07-2018 ; Revised : 01-12-2018 ; Accepted : 10-12-2018

ABSTRACT

This paper is an attempt to optimize the two main factors, plant density and phosphorous, for enhancing yield performance of green gram (Vigna radiata) in foothill regions of Nagaland, India. The experiment was conducted in split plot layout and various parameters were statistically analyzed as per convention. Thereafter, response surface method with restricted randomization was used to optimize the selected responses using a quadratic model. Seed yield of green gram was observed to be optimum at 696.604 kg ha^{-1} by using spacing of 30 x 10 cm for row-to-row and plant-to-plant respectively and application of phosphorous P_2O_5 at 40 kg ha^{-1}.

***Keywords*:** Model, optimization, response surface

1. INTRODUCTION

Green gram is an important pulse crop in Nagaland with 740 hectares area under green gram and production of 620 metric ton during year 2013-14 (Statistical Handbook of Nagaland, 2014). For enhancing productivity of green gram in such hilly topography of Nagaland, various measures have been initiated and much research undertaken.

Generally in agriculture experiments, maximisation of yield is prime motive for a researcher; hence it is of interest to determine the optimum level of combination of factors that fulfil the objective. In this regard, the response surface methodology seeks to relate an average response of the subject under study to the values of input factors (Rangaswamy, 2005). In the current study, there were two factors viz., spacing and phosphorous (P_2O_5) application laid out in Split Plot design with spacing as main plot factor. Responses of the factors were observed in terms of the growth and yield parameters of green gram.

Conventional response surface *f* model for the study was

$$Y = f(S, P) + \epsilon,$$

Where Y is quantitative response measured in respective SI units.
S is spacing (Row to row (cm) x Plant to Plant (cm))
P is phosphorous application (P_2O_5 kg/hectare)
ϵ is error in the model.

Since, response surface *f* is difficult to comprehend at initial stage of analysis hence a prior analysis through conventional Analysis of Variance (ANOVA) for two factors was studied first. The main effects as well as interaction effects of response variables were observed for 'peaks' or 'troughs' corresponding to gradual increase of levels of each factor. Identifying such effects was considered here as basic requirement for utilisation of second order response surface modelling. The Central Composite design (CCD) is widely used for fitting a second-order response surface (Montgomery *et al.*, 2007) which means ideally at least 12 experimental runs are needed for the model.

Optimum combination was obtained by partially differentiating the surface relation with respect to the independent factors under study and then equating such differentials to zero. Thus, the normal equations obtained help in optimizing the factor combinations (Das and Giri, 2006). Proper choice of design is very important in any response surface investigation because the quality of prediction, as measured by the size of the prediction variance, depends on the design matrix D (Bello, 2014).

2. MATERIALS AND METHODS

An experiment was conducted in Experimental Farm, Department of Agronomy, School of Agricultural Sciences and Rural Development, Nagaland University, Medziphema, Nagaland, India to assess effect of spacing and phosphorous on growth and yield parameters of green gram (*vigna radiata*). The experiment was conducted in split plot design with spacing as main plot factor and phosphorous levels as sub plot factor. There were three spacing (S_1 : 20 × 10 cm, S_2 : 30 × 10 cm and S_3 : 40 × 10 cm). Phosphorous was applied as P_0: Control; P_1: 20 kg P_2O_5 ha^{-1}; P_2 : 40 kg P_2O_5 ha^{-1} and P_3 : 60 kg P_20_5 ha^{-1}. All combinations were replicated three times.

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Various quantitative parameters on growth parameters at 50 Days after Sowing, yield parameters and nutrient status of green gram were recorded on five randomly sampled plants from inner plot area for each replicated treatment combinations.

For assessing the significance of treatment contrast for each response, Analysis of Variance (ANOVA) for Split Plot Design was adopted. Optimization of the spacing and phosphorous was done for selected yield based parameters by applying Response Surface Method (RSM) with restricted randomization of second order polynomial. Analytical as well as graphical software developed by Stat-Ease Inc. (USA) *i.e*., Design-Expert® version 10.0 was used to find the optimum levels of spacing and phosphorous levels that resulted in highest performance in six selected parameters. The second-order design proposed for fitting second-degree model-[The Central Composite design (CCD)] - Orthogonality, Rotatability and Uniform Precision are desired properties as CCD consist of full factorial runs (Hinkelmann and Kempthorne, 1994).

Response Surface Method applies the result of one experiment to provide direction for other experiments involving different conditions. Also, it prompts to collect more data for fitting a higher-order model or confirm the findings (Russell V. Lenth, 2012).

In this paper, the following second order polynomial function was considered for fitting using multiple linear regression,

$$Y = a + b_1S + b_2P + b_{11}S^2 + b_{22}P^2 + b_{12}SP$$

Each factor was studied with minimum three levels at equidistant spacing for obtaining maximum response as two levels would be insufficient to provide suitable model. Due to evolving computing technology, graphical presentation of the response of the model and simulation is perceived a necessity by applying suitable software *i.e*., Design Expert 10.0.

3. RESULTS AND DISCUSSION

From the analysis of the observations on various growth at 50 days after sowing, yield and nutrient parameters, following deductions were noted. Plant height, number of leaves, shoot dry weight and leaf area index of green gram was influenced significantly by spacing at 50 days after sowing. The highest value was recorded at spacing 30 cm × 10 cm and the lowest values at 20 × 10 cm spacing respectively [Table 1(a)]. Sathyamoorthi *et al*. (2008) also reported that green gram raised at 30 × 10 cm spacing permitted 3.33 lakh plants ha^{-1} recording more number of functional leaves. Crop growth rate was also observed by them to be influenced significantly by different spacing where highest value (5.98 g m^{-2} day^{-1}) was recorded at spacing 20 ×10 cm.

Plant height of green gram was significantly affected due to different levels of phosphorus where highest plant height (49.37 cm) were recorded with treatment 40 kg P_2O_5 ha^{-1} followed by 60 kg P_20_5 ha^{-1} [Table 1(a)]. The increased in plant height at 40 kg P_2O_5 ha^{-1} might have been on account of stimulation of root growth of the crop as phosphorus plays in an important role in various physiological process including root development, nodulation and N- fixation. Further, increase in the level of phosphorus resulted in decreased plant height which may be due to the genetic makeup of the variety indicating a 'peak' in response. The results are in close conformity with the findings of Kadam and Kanvikar (2015) where they observed that the highest plant height was obtained with 40 kg $P_20_{5.}$ Similar results were also observed by Sipai *et al.* (2015) where their findings revealed that plant height of green gram significantly increased with 40 kg P_2O_5 ha^{-1}.

There was also significant influence of phosphorus on number of leaves (5.73) and shoot dry weight (3.34 g $plant^{-1}$) where highest value was recorded with treatment 40 kg P_2O_5 ha^{-1} followed by 60 kg P_20_5 ha^{-1} and 20 kg P_2O_5 ha^{-1} and the lowest number of leaves were observed in control [Table 1(a)]. Leaf area index and crop growth rate was also significantly affected due to different levels of phosphorus where application of 40 kg P_2O_5 ha^{-1} recorded highest value (3.34) and (6.37 g m^{-2} day^{-1}) respectively [Table 1(a)]. The results are in conformity with the findings of Bhattacharya and Pal (2001) where they reported that application of 40 kg P_2O_5 ha^{-1} influenced number of nodules, dry matter of shoot, crop growth rate and plant height of green gram. All the growth parameters were influenced significantly by interaction of spacing and phosphorus application except number of leaves and crop growth rate. The highest value of plant height, shoot dry weight and leaf area index was recorded in interaction between spacing 30 × 10 cm and application of 40 kg P_2O_5 ha^{-1} [Table 1(b)].

The number of pods per plant and length of pods varied significantly due to different spacing, where the highest values (17.00) and (6.81cm) respectively was recorded at spacing 30 ×10 cm, followed by spacing at 40 × 10 cm

[Table 2(a)]. The highest number of pods per plant (17.56) and highest length of pods (6.91 cm) was recorded when 40 kg P_2O_5 ha^{-1} was applied, which was also statistically superior than all the other levels of phosphorus. The seed yield and stover yield varied significantly due to different spacing, where the highest seed yield (688.54 kg ha^{-1}) and stover yield (1917.81 kg ha^{-1}) was recorded at spacing 30 × 10 cm and the lowest stover yield (1790.13 kg ha^{-1}) was observed at 20 × 10 cm spacing, which may be due to less availability space under dense population, suppressing individual plant growth. Seed yield and stover yield of green gram was significantly influenced by different levels of phosphorus. The highest seed yield (737.42 kg ha^{-1}) and stover yield (1973.01 kg ha^{-1})was recorded with 40 kg P_20_5 ha^{-1} and the lowest seed yield (563.63 kg ha^{-1}) was recorded at control [Table 2(a)]. Yadev and Jakhar (2001) also found similar result on green gram. Harvest index varied significantly due to spacing, where highest value (26.36 %) was recorded at 30 × 10 cm spacing which was at par with 40 × 10 cm spacing. Harvest index of green gram was significantly influenced by different levels of phosphorus. The highest harvest index (27.19 %) was recorded with 40 kg P_20_5 ha^{-1}, treatment and the lowest value (24.39 %) was recorded in control [Table 2(a)]. The interaction effect of spacing and levels of phosphorus on yield attributes and yield of green gram [Table 2 (b)] showed statistically significant result on the number of pods per plant, seed yield, stover yield and harvest index where the highest value was recorded in interaction between spacing 30 × 10 cm and application of 40 kg P_2O_5 ha^{-1}.

Spacing showed significant effect on the available nitrogen in the soil at harvest. The highest available soil nitrogen (253.48 kg ha^{-1}) was observed at spacing 30 × 10 cm, followed by 40 × 10 cm spacing. Application of different levels of phosphorus showed significant influenced on the available nitrogen in the soil where highest available soil nitrogen (273.53 kg ha^{-1}), was observed in the treatment 40 kg P_2O_5 ha^{-1}. Spacing at 30 × 10 cm showed the highest values of total nitrogen uptake by plant (40.89 kg ha^{-1}) [Table 3 (a)]. These results are in close conformity with the findings of Patel (2013) where he reported that green gram sown at 30 × 10 cm spacing recorded the highest total nutrient uptake. Application of different levels of phosphorus also showed significant influenced on total nitrogen uptake by green gram where highest uptake nitrogen (46.61 kg ha^{-1}) was observed in the treatment 40 kg P_2O_5 ha^{-1}. The application of phosphorus might have improved the nutritional environment in rhizhosphere as well, as in plant system leading to increased uptake and translocation of nutrients especially of N, P and K in the reproductive structures which led to higher content and uptake. The interaction effect of spacing and levels of phosphorus showed statistically significant result on the total nitrogen uptake by green gram where highest value was recorded at spacing 30 × 10 cm in combination with of 40 kg P_2O_5 ha^{-1}[Table 3 (b)]

Table 1(a): Effect of spacing and phosphorous on growth variables at 50 DAS

Treatment	Plant height (cm)	Number of leaves	Shoot dry weight (g $plant^{-1}$)	Leaf Area Index (LAI)	Crop Growth Rate (g m^{-2} day^{-1})
Spacing					
S_1	46.44	4.95	2.53	2.51	5.98
S_2	48.10	5.47	2.88	2.88	4.84
S_3	47.09	5.20	2.68	2.72	3.24
SEm(±)	0.06	0.05	0.02	0.03	0.06
LSD (p=0.05)	0.31	0.25	0.10	0.14	0.31
Phosphorous					
P_0	45.21	4.60	2.17	2.18	3.35
P_1	46.43	5.09	2.49	2.48	4.04
P_2	49.37	5.73	3.34	3.34	6.37
P_3	47.82	5.40	2.77	2.80	4.99
SEm(±)	0.08	0.08	0.03	0.03	0.12
LSD (p=0.05)	0.26	0.28	0.10	0.10	0.41

Table 1(b): Interaction effect of spacing and phosphorous on growth variables at 50 DAS

Treatment combinations	Plant height (cm)	Number of leaves	Shoot dry weight (g plant^{-1})	Leaf Area Index (LAI)	Crop Growth Rate (g m^{-2} day^{-1})
S_1P_0	44.63	4.53	2.11	2.14	4.52
S_1P_1	45.29	4.87	2.33	2.33	5.27
S_1P_2	48.77	5.40	3.10	3.04	7.93
S_1P_3	47.07	5.00	2.57	2.53	6.18
S_2P_0	45.92	4.67	2.25	2.25	3.26
S_2P_1	47.47	5.40	2.72	2.70	4.19
S_2P_2	50.12	6.00	3.58	3.58	6.63
S_2P_3	48.89	5.80	2.96	2.99	5.30
S_3P_0	45.08	4.60	2.16	2.16	2.28
S_3P_1	46.54	5.00	2.42	2.42	2.68
S_3P_2	49.25	5.80	3.35	3.41	4.53
S_3P_3	47.50	5.40	2.78	2.89	3.48
SEm(±)	0.16	0.14	0.05	0.05	0.20
LSD (p=0.05)	0.55	NS	0.17	0.17	NS

Table 2(a): Effect of spacing and phosphorous on yield parameters of green gram

Treatment	Number of pods plant^{-1}	Length of pods (cm)	Seed yield (kg ha-1)	Stover yield (kg ha-1)	Harvest index
Spacing					
S_1	16.19	6.50	605.96	1790.13	25.21
S_2	17.00	6.81	688.54	1917.81	26.36
S_3	16.50	6.70	642.38	1875.01	25.47
SEm(±)	0.04	0.02	5.34	4.98	0.18
LSD (p=0.05)	0.18	0.12	26.41	24.61	0.90
Phosphorous					
P_0	15.64	6.46	563.63	1743.93	24.39
P_1	16.36	6.62	613.61	1830.36	25.10
P_2	17.56	6.91	737.42	1973.01	27.19
P_3	16.69	6.70	667.85	1896.63	26.04
SEm(±)	0.05	0.03	4.93	4.75	0.17
LSD (p=0.05)	0.18	0.09	17.03	16.42	0.58

Table 2(b): Interaction effect of spacing and phosphorous on yield parameters

Treatment combinations	Number of pods plant^{-1}	Length of pods (cm)	Seed yield (kg ha-1)	Stover yield (kg ha-1)	Harvest index
S_1P_0	15.04	6.25	506.55	1699.09	22.97
S_1P_1	16.03	6.48	582.53	1729.43	25.20
S_1P_2	17.42	6.70	697.17	1919.63	26.64
S_1P_3	16.25	6.57	637.57	1812.38	26.01
S_2P_0	16.03	6.66	613.56	1799.19	25.43
S_2P_1	16.87	6.75	657.01	1898.16	25.71
S_2P_2	17.80	7.05	789.45	2016.38	28.14
S_2P_3	17.31	6.78	694.15	1957.52	26.18
S_3P_0	15.85	6.48	570.79	1733.52	24.77
S_3P_1	16.17	6.63	601.28	1863.48	24.39
S_3P_2	17.45	6.96	725.63	1983.02	26.79
S_3P_3	16.51	6.74	671.83	1920.00	25.92
SEm(±)	0.09	0.04	8.53	8.22	0.29
LSD (p=0.05)	0.32	NS	29.50	28.44	1.01

Table 3 (a): Effect of spacing and phosphorous on available soil NPK (kg ha^{-1}) and NPK uptake by green gram

Treatment	Nitrogen	Phosphorus	Potassium	Nitrogen uptake	Phosphorus uptake	Potassium uptake
Spacing						
S1	235.64	22.77	228.64	31.90	3.28	16.02
S2	253.48	26.89	239.82	40.89	4.44	19.06
S3	244.02	24.48	234.37	35.72	3.84	17.46
SEm(±)	1.17	0.24	0.75	0.43	0.05	0.14
LSD(p=0.05)	5.26	1.20	3.72	2.11	0.25	0.70
Phosphorous						
P0	219.86	20.43	220.44	26.40	2.50	14.63
P1	232.34	23.09	228.86	32.95	3.38	16.40
P2	273.53	29.19	250.87	46.61	5.26	20.59
P3	252.81	26.15	236.93	38.71	4.28	18.43
SEm(±)	1.73	0.21	1.56	0.43	0.05	0.14
LSD(p=0.05)	5.96	0.74	5.39	1.47	0.16	0.48

Table 3(b): Interaction effect of spacing and phosphorous on available soil NPK (kg ha^{-1}) and NPK uptake by green gram

Treatment	Nitrogen	Phosphorus	Potassium	Nitrogen uptake	Phosphorus uptake	Potassium uptake
S1P0	216.81	19.11	216.67	22.87	1.98	12.66
S1P1	221.31	20.89	225.88	28.40	2.83	15.12
S1P2	262.19	27.01	240.72	41.32	4.49	18.85
S1P3	242.26	24.09	231.30	34.99	3.83	17.43
S2P0	221.16	22.46	224.08	30.06	2.89	16.34
S2P1	244.85	26.02	233.20	37.80	4.05	17.94
S2P2	285.22	31.02	260.41	54.28	6.10	22.58
S2P3	262.70	28.06	241.57	41.42	4.72	19.39
S3P0	221.60	19.71	220.58	26.27	2.63	14.90
S3P1	230.86	22.35	227.49	32.63	3.25	16.14
S3P2	273.18	29.54	251.47	44.25	5.18	20.34
S3P3	250.46	26.31	237.93	39.73	4.30	18.48
SEm(±)	2.99	0.37	2.70	0.74	0.08	0.24
LSD (p=0.05)	NS	1.28	NS	2.55	0.28	0.83

RESPONSE SURFACE MODEL

The split plot analysis showed that there were six study parameters viz., number of pods per plant, pod length, seed yield, stover yield and available nitrogen and nitrogen uptake, influenced by spacing and phosphorous application. Hence these parameters were studied under RSM technique for optimization. Since the two factors under research were quantitative in nature and equally spaced levels maintained, actual numerical values of the factors were taken for describing the model.

The following tables Table 4 and Table 5 shows the coding and description of the model with estimated coefficients for each of the six selected responses respectively. The estimates of coefficients were tested at 1% and 5 % level of significance for testing hypothesis that the coefficients equal to zero.

Table 4: Details of factors affecting six responses

Factor	Name	Level	Low Level	High Level	Coding
A	Spacing	37.93	20	40	Actual
B	Phosphorous	13.14	0	60	Actual

Table 5: Response surface model for yield responses and nitrogen parameters

Response	Intercept	A	B	AB	A^2	B^2
R_1 (no. pods per plant)	17.498	0.155*	0.653**	-0.131^{NS}	-0.662**	-0.892**
R_2 (Pod length)	6.924	0.102**	0.150**	-0.007^{NS}	-0.208**	-0.205**
R_3 (Seed yield)	725.898	18.2123*	65.469**	-6.019^{NS}	-64.372**	-67.241**
R_4 (Stover yield)	1968.690	42.438**	90.114**	11.170^{NS}	-85.243**	-91.579**
R_5 (Available N)	45.405	1.913*	7.589**	0.205^{NS}	-7.082**	-8.126**
R_6 (N uptake)	31.888	1.381*	5.766**	0.467^{NS}	-5.113**	-6.148**

*Note: * significant at 5% level of significance, ** significant at 1% level of significance*

The second order model shown in Table 5 shows that second order model for each responses were adequately represented by respective estimate of coefficients and the range of the coefficient of multiple determination (R^2 = 0.791 to 0.901) indicated that the model represents the experimental results with greater information.

The following table 6 presents a set of ten best predicted results generated for combination of two factors on each response and finally selection of optimum combination of factors on overall responses. The result showed that spacing of 30 x 10cm and Phosphorous of 20 kg P_2O_5 ha^{-1} (in bold) was the most desirable combination for overall optimum response. Other combinations can be checked out in table 6 with highest desirability on optimizing overall response.

Table 6: Prediction on responses at row spacing and phosphorous levels (P_2O_5 kg ha^{-1})

Spacing	Phosphorous	No. pods plant^{-1}	Pod length	Seed yield	Stover yield	Soil available N	N uptake
37.932	13.139	16.614	6.728	644.495	1864.17	35.544	24.376
20	20	16.321	6.539	612.013	1804.52	33.046	22.946
30	**20**	**17.181**	**6.851**	**696.604**	**1928.48**	**41.972**	**29.283**
40	0	15.578	6.469	553.048	1733.02	24.317	15.776
20	0	15.006	6.252	504.585	1670.49	20.9	13.948
30	60	17.259	6.869	724.125	1967.22	44.868	31.506
20	60	16.573	6.566	647.56	1828.37	35.669	24.546
40	60	16.621	6.755	671.947	1935.59	39.903	28.241
20	40	16.843	6.643	659.672	1857.15	37.969	26.478
40	40	17.066	6.842	692.084	1949.47	41.93	29.55

From the second order model generated, following figures were obtained which depicts the response for each varying levels of two factor combinations. Figure 1(a) to 1(f) represents couloured representation of the six responses with dense color area representing optimum solutions at the respective fator levels of phosphorous and spacing.

The surface prediction of the responses has been presented graphically using three dimensional plots for each of the six responses (Figure 2(a) to 2(f)). It can be observed the optimum surface areas on the curved surface for each response representing the optimum predicted values of responses to factor combinations of spacing and phosphorous application levels.

4. CONCLUSION AND RECOMMENDATION

From the study it can be concluded that spacing and phosphorous applications are important to improve growth and yield parameters of Green gram. Interaction effect of both factors was also observed to be significant for many yield parameters. From the study, spacing of 30 x 10cm was found be significantly better for seed yield with 688.54 kg ha^{-1} compared to other spacing levels and phosphorous application of 40 kg P_2O_5 ha^{-1} was highest in many growth and yield parameters and highest seed yield was 737.42 kg per hectare was observed. Interaction effect of spacing of 30 x 10cm and 40 kg P_2O_5 ha^{-1} was 789.45 kg per hectare indicating significant synergy of two factors. Hence, for optimizing combination of two factors, RSM with restricted randomization was used. With the model, optimum seed yield at 696.604 kg ha^{-1} was predicted for spacing of 30 x 10cm and application of 40 kg P_2O_5 ha^{-1}.

The full factorial designs are suitable as initial base work to identify significant factors and interaction effects affecting growth and yield parameters of green gram and also to determine appropriate response variables that are of importance to the researcher. However, to optimize the significant responses given the priority to conserve resources

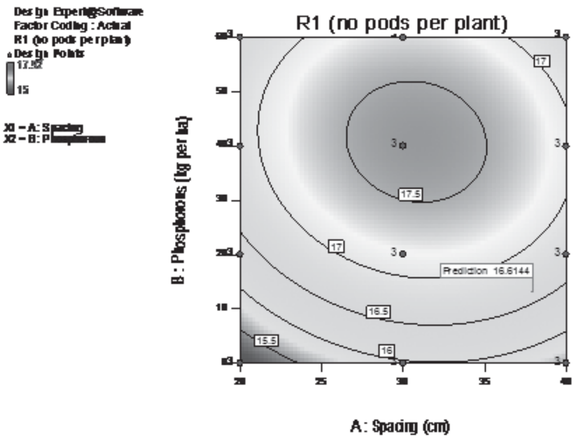

Fig. 1(a): No. of pods plant^{-1}

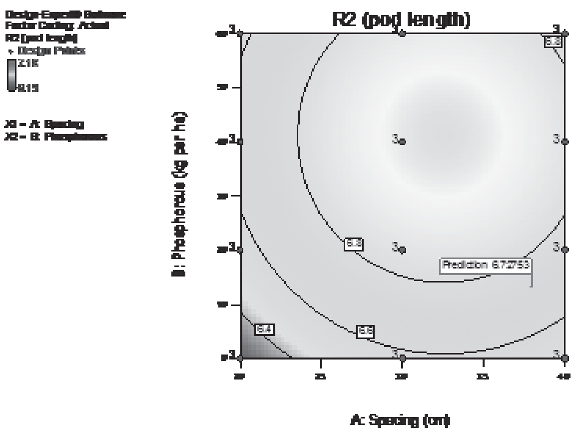

Fig. 1(b): Pod length (cm)

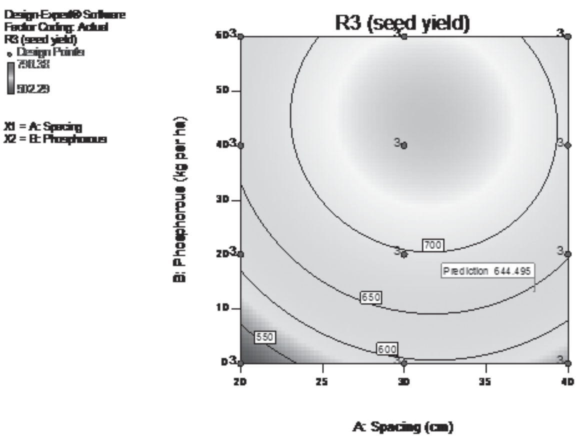

Fig. 1(c): Seed yield (kg ha^{-1})

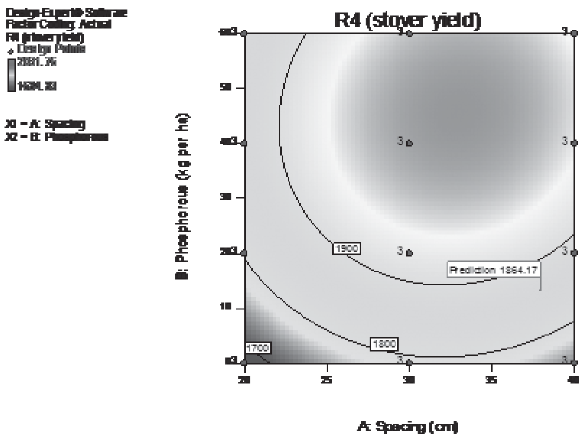

Fig. 1(d): Stover yield (kg ha^{-1})

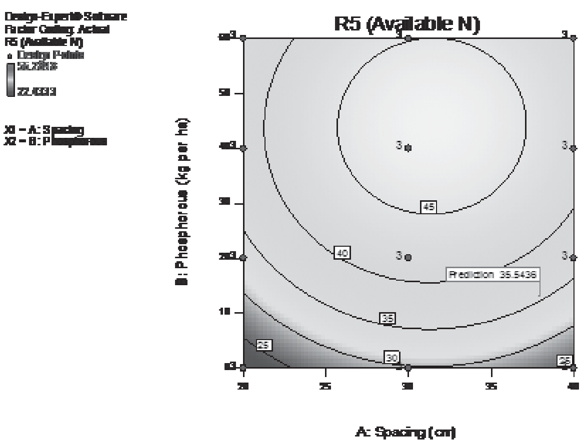

Fig. 1(e): Available N (kg ha^{-1})

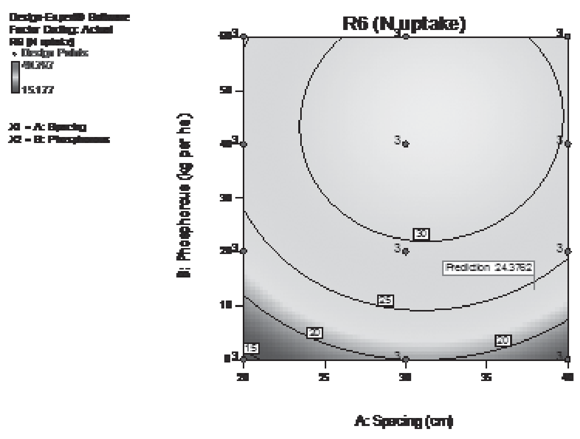

Fig. 1(f): N uptake (kg ha^{-1})

Figure 1 (a-f): Two dimensional contour map of predicted responses to factors

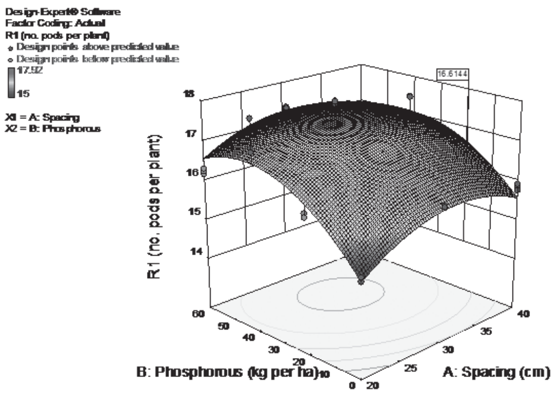

Fig. 2(a): No. of pods plant^{-1}

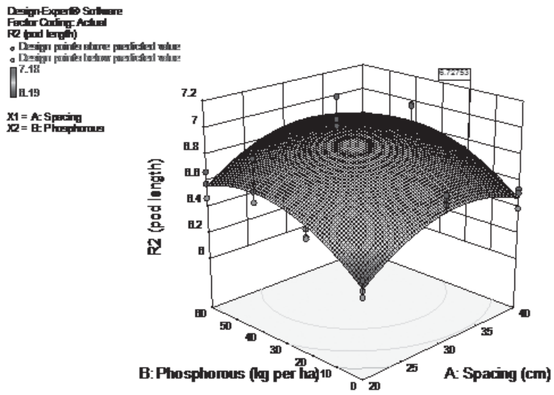

Fig. 2(b): Pod length (cm)

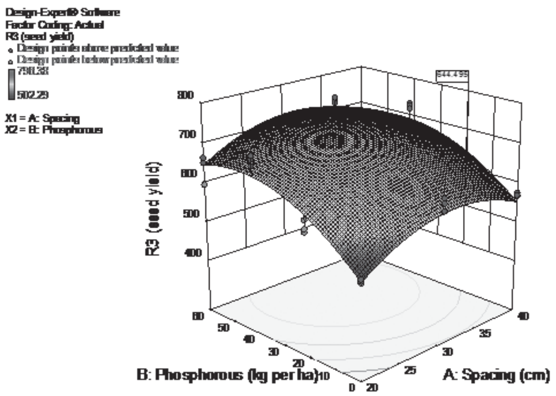

Fig. 2(c): Seed yield (kg ha^{-1})

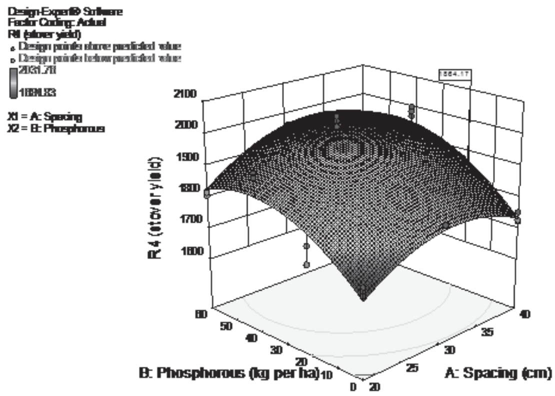

Fig. 2(d): Stover yield (kg ha^{-1})

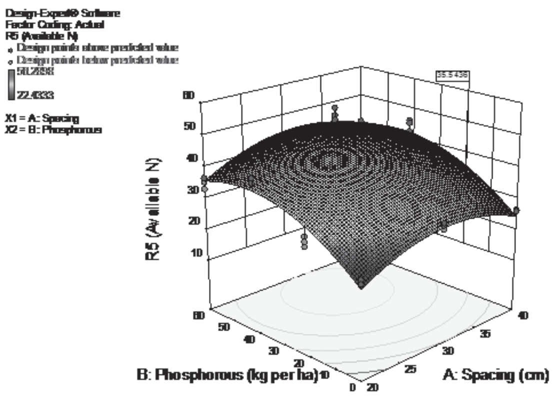

Fig. 2(e): Available N (kg ha^{-1})

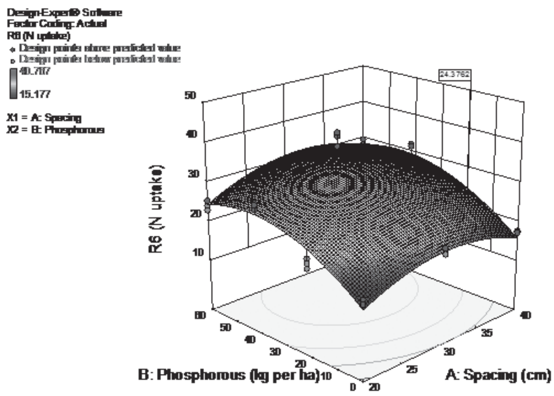

Fig. 2(f): N uptake (kg ha^{-1})

and to recommend farmers, it is response surface method that is needed. The combinations must be studied with economic perspectives as it was not taken into consideration in the current study for final selection of levels of factors.

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