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Rice crop response to site variability in a multi-locational trial: A call for site specific management

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ABSTRACT

Yield is a net expression of genotype (G) x environment (E) interactions including management. However, the segregation of 'E' into respective causes is seldom done while 'G' is a constant. Soil is a component of 'E' with imminent variability in attributes among multiple locations. Data on yield response of varieties to a set of treatments in different soils from multi-locational yield maximisation trial under All India Coordinated Rice Improvement Project were regularly gathered. A dataset pertaining to a trial conducted in Karaikal district of Puducherry Union Territory was analysed to ascertain the site-specific crop responses with inherent variability in soils.

*Rice varieties, ADT 46, BPT 5204 and CR 1009 were tested for responses at 17 sites with farmer fertiliser practices (FFP), regional recommended fertiliser dose (RDF) and software, 'Nutrient Expert®' (2016) (NE) derived fertiliser quantities. Analysis of variance showed that test sites explained 59.3% variability in yield. A multivariate technique, Factor Analysis extracted two factors, which are linear combinations of soil attributes those explained 76% of variance in soils. Factor scores classified soils into four groups, owing to variability in soil properties. Soil texture influenced yield significantly (across varieties and treatments) (R^2 = 11.1%). Sites varied in excess duration in nursery ranging from 2 - 26 days. However, this excess duration reduced number of panicles m^{-2} only in CR 1009 (r = -0.328**).*

General linear model with sites and treatments as fixed factors, their interactions and panicles m^{-2} as covariate predicted better (R^2 = 90.3%) with their significant contribution to the model. The order of R^2 (%) was Sites (59.3) > Varieties (27.4) > Treatments (13.6%) in explaining variability in yield highlighting site-specific responses. Mean differences between ADT 46 and BPT 5204; BPT 5204 and CR 1009 were significant. Yield significantly changed across sites and treatments when fertiliser management shifted from non-specific (FFP) to site-specific NE based calculations through RDF (region specific). Results of this trial placed emphasis on soil test-based crop management to realise the uniform best, which clearly is site specific crop management.

Key words: *Site differences, rice yield, factor analysis, excess duration in nursery, soil test- based crop management*

INTRODUCTION

Potential yield is the yield of a current cultivar "when grown in environments to which it is adapted; with nutrients and water non limiting; and with pests, diseases, weeds, lodging, and other stresses effectively controlled" (Evans and Fischer, 1999; Lobell et al., 2009). Yield potential is a concept, rather than a quantity, which makes estimation both challenging and complicated (Cassman, 1999). Therefore, to achieve yield potential requires perfection in the management of all other yield determining production factors (such as plant population; the supply and balance of 17 essential nutrients; and protection against losses from insects, weeds, and diseases) from sowing to maturity. Such perfection is impossible under field conditions, even in relatively small test plots let alone in large production fields. At this juncture, variation of yield within fields becomes the focus of site-specific management (Cassman, 1999) to get closer to realisation of potential yield of a given crop variety.

Soil management research is site specific and interaction of several factors define a given management site. Soil specific management refers to a field management concept that allows for variable management practices within a field according to soil or site conditions (Robert, 1993). Spatial variability is a natural and inevitable characteristic of all soil bodies (Hole, 1978). Variation of soil properties directly or indirectly influences almost any conceivable use or study of the soil (Campbell, 1979). Soil spatial variability is present over short distances not only in natural ecosystems, but also in agricultural systems with presumed uniform management and vegetation cover (Mariotti, 1997; Goovaerts, 1998). The scales of spatial variation may differ between different soil properties, because the processes that cause variability may occur at different scales, e.g., from the single plant scale to larger topographical scales (McBratney and Pringle, 1997; Goovaerts, 1998).

Many authors reported that soil properties vary across agricultural fields, causing spatial variability in crop yields (Stein and Brouwer, 1997; Rockstrom et al., 1999; Gaston et al., 2001; Mzuku et al., 2005). Fertilizer recommendations are often based on crop response data averaged over large areas, though farmers' fields show large variability in terms of nutrient-supplying capacity and crop response. Thus, blanket fertilizer application recommendations may lead farmers to over-fertilize in some areas and under-fertilize in others, or apply an improper balance of nutrients for their soil or crop. Crop growth and demand for nutrient are strongly influenced by climate and crop-growing conditions, which can vary greatly among locations, seasons, and years (Ahmad and Mahdi, 2018). Thus, site specific nutrient management (SSNM) aims to optimize the supply of soil nutrients over time and space to match the requirements of crops through four key principles i.e., product, rate, time and place (Roberts, 2007).

In this context, ICAR-Indian Institute of Rice Research (IIRR) conducts research in multi-locational trial mode to highlight the significance of site-specific nutrient management to improve the nutrient use efficiency, reduce losses of nutrients and maintain the balanced plant nutrition. In this series, IIRR organised multi-locational trial titled, "Yield maximization in farmers' fields using Nutrient Expert software (Kharif)". The idea was to compare farmer fertiliser practices (FFP), recommended dose of fertiliser (RDF) and software-based fertiliser dosages, using 'Nutrient Expert®'(NE) (2016) developed by International Plant Nutrition Institute, Canada to realise yield improvement from the best combination of soil and crop factors coupled with management options. Though this was conducted at several locations in the country, the trial conducted at 17 different sites within an area was selected for analysis to highlight a point that soils varied even in a given area and impact on the yield. In this process, the data collected from one of the multi-site crop performance evaluation trials was analyzed to check; 1. whether site specific response was observable, 2. to identify the source of variance in site analysis in the context of crop performance and 3. to compare the grain yield of different varieties, with an assumption that each site is characterised by one kind of soil (since the experimental area was actually not large).

MATERIALS AND METHODS

Study area

Seventeen individual farmers' fields under an irrigated and transplanted rice eco-system in Karaikal district, Puducherry Union Territory were chosen for the study. Karaikal district is located between 10° 49'36" to 16° 45' 45" N latitude and 75° 31'40" to 82° 18' 44" E longitude. The experimental data collected from these 17 sites during Samba season (July to October) in 2018 were used for analysis.

Experimental details

Popular rice varieties in Tamil Nadu region, ADT46, BPT5204 and CR 1009 were grown in two, six and nine sites, respectively. The crop duration was 135, 150 and 160 days with an average yield of 6656, 6000 and 5300 kg ha^{-1}, respectively (www.agritech.tnau.ac.in). Table 1 included site wise geographical position, variety cultivated with dates of sowing, transplanting and season. As per the definition (www.agritech.tnau.ac.in), the sowing during July, August and September to October makes it 'Early samba', 'Samba' and 'Late Samba' seasons, respectively. GPS (Global Positioning System) readings

Table 1. Geographical location, variety and seasons of cultivation.

Site no.	Latitude	Longitude	Variety	DOS	DOP	Season
1	10° 58' 7.6"	79° 43' 57.6"	ADT 46	27.09.2018	28.10.2018	Late samba
2	10° 56' 13.3"	79° 47' 7.5"	ADT 46	15.09.2018	25.10.2018	Late samba
3	10° 56' 53.6"	79° 45' 11.1"	BPT 5204	09.09.2018	05.10.2018	Late samba
4	10° 55' 31.0"	79° 45' 20.9"	BPT 5204	15.09.2018	12.10.2018	Late samba
5	10° 57' 48.5"	79° 43' 46.5"	BPT 5204	28.09.2018	30.10.2018	Late samba
6	10° 56' 36.2"	79° 46' 19.9"	BPT 5204	10.09.2018	12.10.2018	Late samba
7	10° 56' 33.6"	79° 46' 31.4"	BPT 5204	15.09.2018	13.10.2018	Late samba
8	10° 56' 37.3"	79° 46' 54.9"	BPT 5204	20.09.2018	25.10.2018	Late samba
9	10° 57' 38.2"	79° 44' 32.0"	CR 1009	27.09.2018	28.10.2018	Late samba
10	10° 55' 28. 5"	79° 44' 24.0"	CR 1009	12.08.2018	13.09.2018	Samba
11	10° 55' 20.5"	79° 44' 48.6"	CR 1009	15.08.2018	13.09.2018	Samba
12	10° 55' 36.9"	79° 45' 33.1"	CR 1009	24.08.2018	09.10.2018	Samba
13	10° 58' 7.0"	79° 43' 34.9"	CR 1009	12.08.2018	04.09.2018	Samba
14	10° 56' 53.6"	79° 44' 14.1"	CR 1009	20.09.2018	21.10.2018	Late samba
15	10° 55' 20.6"	79° 44' 37.8"	CR 1009	30.07.2018	15.09.2018	Early samba
16	10° 55' 25.8"	79° 44' 35.9"	CR 1009	30.07.2018	15.09.2018	Early samba
17	10° 57' 53.2"	79° 44' 32.0"	CR 1009	15.10.2018	16.11.2018	Late samba

DOS = Date of sowing; DOP = Date of planting.

were collected to indicate the distribution of the test sites in the given area for verification in any verifiable map including Google Earth. The plot size varied from 85 m^2 to 900 m^2 for all practical reasons including the test sites were being individual farmer fields with different extents. However, the yield was measured from a 15 m^2 grid and calculated per hectare. Table 2 contained details of soil texture and initial soil properties including pH (1:2.5 soil water ratio), electrical conductivity (EC) (dS m^{-1}) (1:2.5 soil water ratio), organic carbon (OC) (%), available nitrogen (N), phosphorus (P) and potassium (K) (kg ha^{-1}) that highlighted site differences among selected attributes.

Treatments (replicated thrice) included farmer fertilizer practice (FFP) (T_1), regional recommended fertilizer dose (RDF) (T_2) as suggested by Crop Production Guide (2012) and Nutrient Expert® based fertilizer dosage (NE) (T_3). Fertilizer N, P and K were supplied in the form of urea, diammonium phosphate and muriate of potash, respectively. Based on FFP, RDF and NE, various quantities of fertiliser materials were added to different sites creating different soil fertility conditions (Table 3).

All cultural operations given in Crop Production Guide (2012) and standard methods of soil sampling and analysis were followed. Soil texture was determined by feel method with an idea to establish the textural differences among the test sites. Rice crop was harvested and expressed grain yield in kg ha^{-1}. Factor analysis technique was applied to pre-cropping soil data to understand the latent data structure as described by Tabachnick and Fidell (2018). Other statistical analysis including correlations, one-way analysis of variance (ANOVA) and general linear modelling were applied using SAS (version 9.3) and results were discussed.

Table 2. Soil properties prior to cropping in the test sites.

Site no.	Soil type	pH	EC dS m^{-1}	OC (%)	N	P	K
						kg ha^{-1}	
1	Sandy clay loam	7.71	0.39	0.56	94	51	422
2	Loamy sand	8.61	0.58	0.33	135	58	184
3	Sandy clay	8.44	1.16	0.39	116	49	685
4	Sandy loam	8.59	0.43	0.12	94	41	435
5	Sandy clay loam	8.14	1.36	0.56	204	38	572
6	Sandy clay loam	7.77	0.63	0.54	95	83	830
7	Sandy loam	6.96	0.64	0.54	169	55	774
8	Sandy clay loam	7.45	0.43	0.60	113	63	579
9	Sandy clay	7.39	1.27	0.11	35	41	389
10	Loamy sand	7.23	0.55	0.51	160	49	377
11	Sandy loam	8.24	1.15	0.54	151	43	479
12	Sandy loam	8.06	0.41	0.33	91	59	224
13	Sandy clay loam	7.31	0.47	0.51	169	47	607
14	Sandy clay loam	8.03	0.94	0.56	135	44	698
15	Sandy loam	7.88	0.48	0.48	72	76	417
16	Sandy loam	7.19	0.70	0.33	163	72	212
17	Sandy clay loam	7.19	0.99	0.30	132	33	327

EC = Electrical conductivity, OC = Organic carbon, N, P, K = Available N, P, K.

Table 3. Fertilisers applied in different treatments (kg ha^{-1}).

Site	T_1			T_2			T_3		
no.	N	P	K	N	P	K	N	P	K
1	92	25	30	150	26	50	140	25	58
2	119	25	0	150	26	50	141	26	58
3	45	25	0	150	26	50	141	26	58
4	45	25	0	150	26	50	141	26	58
5	69	25	31	150	26	50	141	26	58
6	86	25	13	150	26	50	125	26	43
7	93	0	0	150	26	50	138	26	58
8	107	25	18	150	26	50	125	26	43
9	109	25	94	150	26	50	125	26	43
10	196	15	125	150	26	50	125	36	58
11	101	25	0	150	26	50	141	26	58
12	81	0	19	150	26	50	141	26	43
13	18	8	0	150	26	50	126	26	58
14	40	25	0	150	26	50	141	26	43
15	52	25	44	150	26	50	126	26	58
16	81	25	0	150	26	50	125	26	48
17	109	25	63	150	26	50	141	26	43

T_1 = Farmer Fertiliser Practice (FFP), T_2 = Recommended Dose of Fertiliser (RDF), T_3 = Software (Nutrient Expert) derived fertiliser quantities (NE), N = Applied nitrogen as urea, P = Applied phosphorus as diammonium phosphate, K = Applied potassium as muriate of potash.

RESULTS AND DISCUSSION

A structured description was presented under different heads and subheads for a convenient understanding.

First source of variance

Geo-coordinates (Table 1) showed the spatial distribution of test sites within study area, Karaikal district. Table 1 also indicated that the rice varieties including ADT 46, BPT 5204 and CR 1009 were the initial source of variance in terms of duration and average production potential (www.agritech.tnau.ac.in) as well. The difference in average yield among the cultivars was ranging from 656 to 1356 kg ha^{-1}. It was seen among the tested varieties that that crop duration and average yield potential were inversely related.

Second source of variance

Variance in soils properties in different sites was another source of variance (Table 2). The texture of the soils in experimental sites included sandy loam, sandy clay loam, sandy clay and loamy sand. Sites varied in soil reaction (1:2.5 soil water ratio), which is a master variable, from neutral to moderately alkaline range (7.0 to 8.6) that could influence nutrient solubility and availability. EC (1:2.5 soil water suspension) varied from 0.4 to 1.4 dS m^{-1} and OC content measured between 0.1 to 0.6 %. Available N, P and K contents varied from 35 to 204, 33 to 83 and 184 to 830 kg ha^{-1}, respectively. According to the ratings followed in Tamil Nadu (www.agritech.tnau.ac.in), OC status was low in fourteen sites and medium in remaining sites. All sites were low in nitrogen, high in phosphorus while fourteen and three sites recorded high and medium, respectively in available K content.

For a better understanding of the variance in soils, a multivariate statistical technique, Factor analysis was applied to initial soil data. Principal Component extraction method with Varimax rotation and Kaiser Normalisation were the analysis settings in the Factor Analysis of soil initial properties including EC, OC, available N and P measured in 17 soils to understand the latent structure in the data. The reason for removing pH and available K from Factor Analysis was the low communality thus resultant low variance explained by the factors. In this analysis, two factors with > 1.0 Eigen value were extracted, which explained 75.87% of cumulative variance in the soils (Table 4). Rotated components showed that EC was associated positively while available P negatively associated with Factor 1 while OC and available N were positively associated with Factor 2. Selected soil initial properties had communalities of 0.711, 0.798, 0.743 and 0.782 for EC, OC, available N and P, respectively where the communality is the proportion of each variable's variance that can be explained by the factors. The % of variance explained by factors 1 and 2 was 38.63 and 37.24, respectively.

The scatter plot with scores on Factors 1 and 2 on X and Y axes, respectively arranged soils into four

Table 4. Rotated component matrix with variance.

Variable	Component		Communality
	1	2	
EC	0.836	0.107	0.711
OC	-0.096	0.888	0.798
Available N	0.233	0.830	0.743
Available P	-0.884	-0.004	0.782
% Variance	38.63	37.24	
% Cumulative variance	38.63	75.87	

groups (Fig. 1). The scatter plot had values on both sides of reference lines at zero on both axes. The first group of soils comprised five sites 3, 5, 11, 14 and 17 with positive values on both factors while two sites 4 and 9 were grouped with positive values on Factor 1 and negative values on Factor 2. In the third group two sites *i.e.*, 8 and 12 were placed with negative values on both the factors. Last group included eight sites namely 1, 2, 6, 7, 10, 13, 15 and 17 on the negative side of Factor 1 and positive side of Factor 2 which was the largest number of soils.

The characteristic association of soil variables to the factors helped recognising a 'P limitation factor' (Factor 1) to which available P and EC were related and indicated the negative interaction between these two variables and 'Nitrogen availability factor' to which OC and available N were positively related highlighting the synergy between OC and available N.

Third source of variance

Quantity of applied N, P and K in treatments (Table 3) was the third source of variance. Nitrogen in T_1 (FFP) varied from 18 to 196 while phosphorus ranged from 0 to 25 and potassium was between 0 to 125 kg ha^{-1}. RDF (kg ha^{-1}) in T_2 included 150 N, 26 P and 50 K and NE calculated site-specific contents (kg ha^{-1}) in T_3 ranged from 125 to 141 N, 25 to 36 P and 43 to 58 K. It was seen that the range between the lowest and the highest narrowed down from random (T_1) to site-specific (T_3) application of N, P and K because of the refinement in fertiliser management from random to site-specific applications of nutrients.

Fourth source of variance

Another source of variation among sites that brought in a potential change in the varietal performance was excess duration of stay in nursery (time delay in transplantation). A normal period of 21 days in nursery *i.e.*, the period between sowing and transplanting was taken as the base and excess stay was used to analyse its influence on rice grain yield. The variety ADT 46 stayed in nursery for more duration by 10 to 19 days (in two sites) while BPT 5204 (in six sites) had an excess stay of 5 to 14 days. The third variety, CD 1009 had an excess period in nursery by 2 to 26 days (in nine sites). In terms of seasons, both ADT 46 and BPT 5204 were raised during Late Samba; CR 1009 was grown in Early Samba, Samba and Late Samba seasons

Rice crop response to variance in crop production factors

Mean yield of ADT 46, BPT 5204 and CR 1009 across

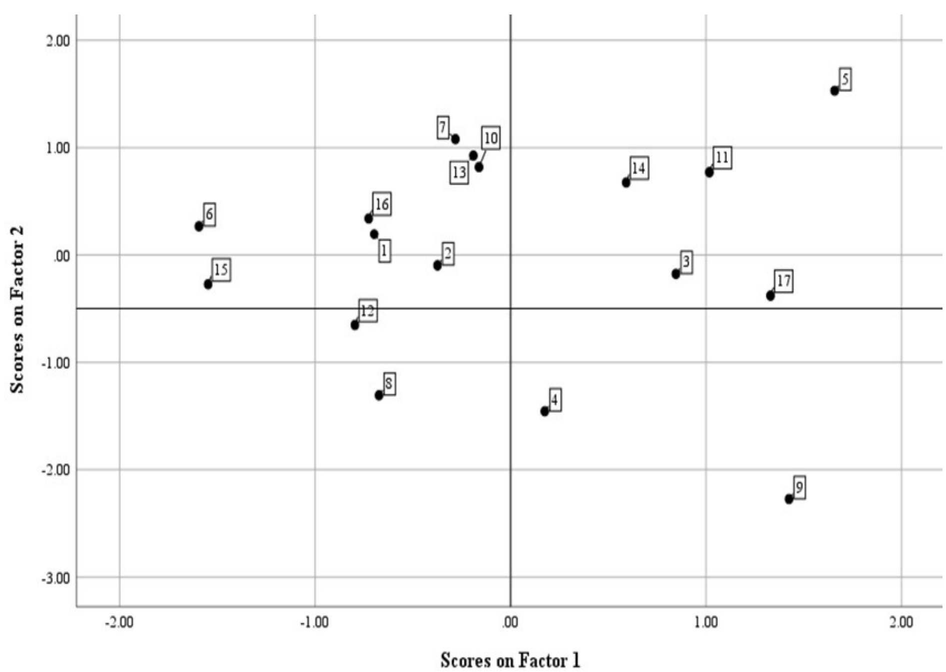

Fig. 1. Grouping of sites based on factor scores.

sites was 4804, 3554 and 4708 in T_1, 5281, 3968 and 5316 in T_2 and 5677, 4551 and 5786 kg ha^{-1} in T_3 (Fig. 2). Grain yield increased from T_1 to T_3 of course, with varied percentage. Since the mean yields averaged the impact of sites, the deviation from each variety's highest yield among sites was considered and presented in Fig. 3 to highlight relative performance of a variety among the sites. Only two sites were cultivated with ADT 46. Maximum grain produced was in 2nd site in T_1 (5360 kg ha^{-1}) and T_3 (5729 kg ha^{-1}) while 1st site recorded maximum in T_2 (5553 kg ha^{-1}). The deviation from maximum was 1111 kg ha^{-1} and 104 kg ha^{-1} in T_1 and T_3, respectively while 2nd site deviated by 545 kg ha^{-1}. BPT 5204 was grown in six sites and fourth site recorded maximum yield in all three treatments (4949, 5002 and 5689 kg ha^{-1}, respectively). The deviation from the highest yield ranged from 969 to 2173 kg ha^{-1} in T_1, from 818 to 1887 kg ha^{-1} in T_2 and from 445 to 2329 kg ha^{-1} in T_3. Similarly, out of nine sites cultivated with CR 1009, 1st site registered maximum (6209 kg ha^{-1}) in T_1 while ninth site recorded maximum grain yield of 6536 in T_2 and 6398 kg ha^{-1} in T_3. The deviation from the highest yield ranged from 24 to 2771, 455 to 2611 and 127 to 2075 kg ha^{-1} in T_1, T_2 and T_3, respectively. The lowest deviation was by 24 while the highest deviation was by 2771 kg ha^{-1} both in CR 1009, among treatments, sites and varieties. The data indicated clearly the yield differences were due to varieties, sites and treatments.

Table 5. Grain yield based homogenous subsets of sites.

Site	Subset						
no.	1	2	3	4	5	6	7
3	3139						
7	3487	3487					
10	3919	3919	3919				
5	4030	4030	4030	4030			
4	4048	4048	4048	4048			
8	4227	4227	4227	4227	4227		
11		4693	4693	4693	4693	4693	
12		4730	4730	4730	4730	4730	
1			5142	5142	5142	5142	5142
6				5213	5213	5213	5213
13				5268	5268	5268	5268
15				5300	5300	5300	5300
2					5366	5366	5366
14					5372	5372	5372
16						5840	5840
9						5933	5933
17							6373

T_3 was superior over other two treatments while T_2 proved better over T_1 in almost all sites except one site (under CR 1009). There were some more exceptions like in 2nd site under ADT 46 and 5th site under CR 1009 where T_1 was better than T_2.

Statistical analysis

Correlation studies

Correlation analysis (n=153) showed that yield was influenced positively by panicles m^{-2}, tillers m^{-2} and 1000 grain weight (r = 0.774**, 0.739** and 0.544**, respectively (at 1% level). Yield was also influenced by applied N and K (r = 0.214** and 0.263**, respectively), although the association was weak. Panicles m^{-2} were correlated with tillers m^{-2} and 1000 grain weight (r = 0.919** and 0.682**, respectively). Among applied nutrients, N had correlation with P and K (r = 0.327** and 0.781**, respectively) while N and K were also correlated positively (r = 0.261**). Another important source of variance, the delay in transplantation had its negative impact on the number of panicles per m^2 as was seen by a correlation coefficient of -0.328**.

Analysis of variance

One-way analysis of variance (ANOVA) (n=153) indicated that sites significantly differed in yield (p = 0.001) across treatments and varieties. The model explained 59.3% variability in yield with an adjusted R^2 of 54.7% and predicted R^2 of 48.4%. Tukey's HSD based homogenous subsets were shown in Table 5. The members of a homogenous sub-sets were insignificantly different among themselves while differed significantly from the members of other subsets. It also meant that site-specific responses were similar in intra-subset comparisons while dissimilar in inter-subset comparisons. Treatment effects (across sites and varieties) on yield were also subjected to one-way ANOVA. Though the model was highly significant (p = 0.001), it explained only 13.6% of variability in yield (across sites and varieties) with adjusted and predicted R^2 values of 12.4% and 10.1%, respectively. Tukey's HSD used in post-hoc test showed the significant mean difference in grain yield between T_2 & T_1 and T_3 & T_1 was 524.6 and 1025.3 kg ha^{-1}, respectively highlighting the benefit of specific fertiliser management be it region (RFD) or site-specific one (NE derived).

One-way analysis of variance caused by

Table 6. ANOVA of GLM of effects of sites and treatments on grain yield.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	178206471.1	51	3494244.5	18.5	0.001
Intercept	11785.8	1	11785.8	0.1	0.803
Panicles m^{-2}	12905721.8	1	12905721.8	68.3	0.001
Sites	41162141.9	16	2572633.9	13.6	0.001
Treatment	4038509.8	2	2019254.9	10.7	0.001
Sites * Treatment	15238175.8	32	476193.0	2.5	0.001
Error	19090292.8	101	189012.8		
Total	3764258594.1	153			
Corrected Total	197296763.9	152			

Model summary: $R^2 = 0.903$; Adj. $R^2 = 0.854$; Pred. $R^2 = 0.777$

varieties (across sites and treatments) was significant ($p = 0.001$) with an R^2, adjusted and predicted R^2 values of 27.4, 26.4 and 24.9%, respectively. Multiple comparisons showed that the means of pairs of ADT 46 and BPT 5204; BPT 5204 and CR 1009 differed significantly. ADT 46 produced more than BPT 5204 (with mean difference of 1229.8 kg ha^{-1}) while CR 1009 also produced more than BPT 5204 (with mean difference being 1245.5 kg ha^{-1}). ADT 46 (mean production potential of 6656 kg ha^{-1}) was on par with CR 1009 (mean production potential of 5300 kg ha^{-1}) across all sites. It was because CR 1009 in several sites produced more than the average production potential (highlighting the impact of crop management).

General linear modelling

A general linear model (GLM) to discern the effects of fixed factors ***i.e.***, sites, treatments, their interaction and panicles m^{-2}, as covariate, on rice yield was run. Among the yield components, only panicles m^{-2} was included to avoid multi-collinearity effects. The model was good in the predictability with an R^2, adjusted R^2 and predicted R^2 values of 90.3%, 85.4% and 77.7%, respectively with insignificant lack of fit. Sites, treatments, their interaction terms and panicle m^{-2} contributed highly significantly to the model in explaining the variability in yield (Table 6).

Since a management site is resultant of

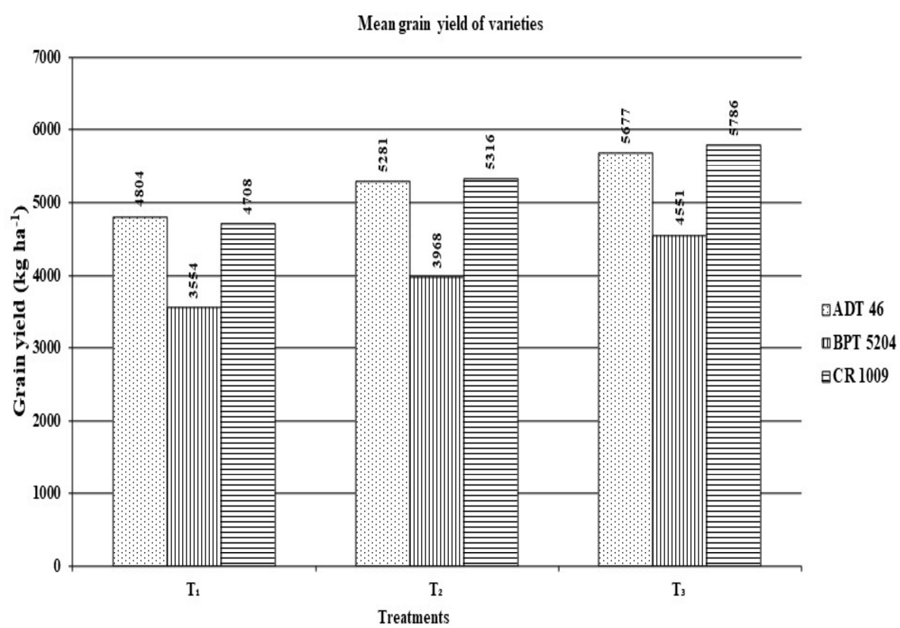

Fig. 2. Mean yield of rice varieties across sites. T_1 = Farmer's Fertiliser Practice (FFP), T_2 = Recommended Fertiliser Dosage (RDF), T_3 = Software (Nutrient Expert) derived fertiliser quantities (NE).

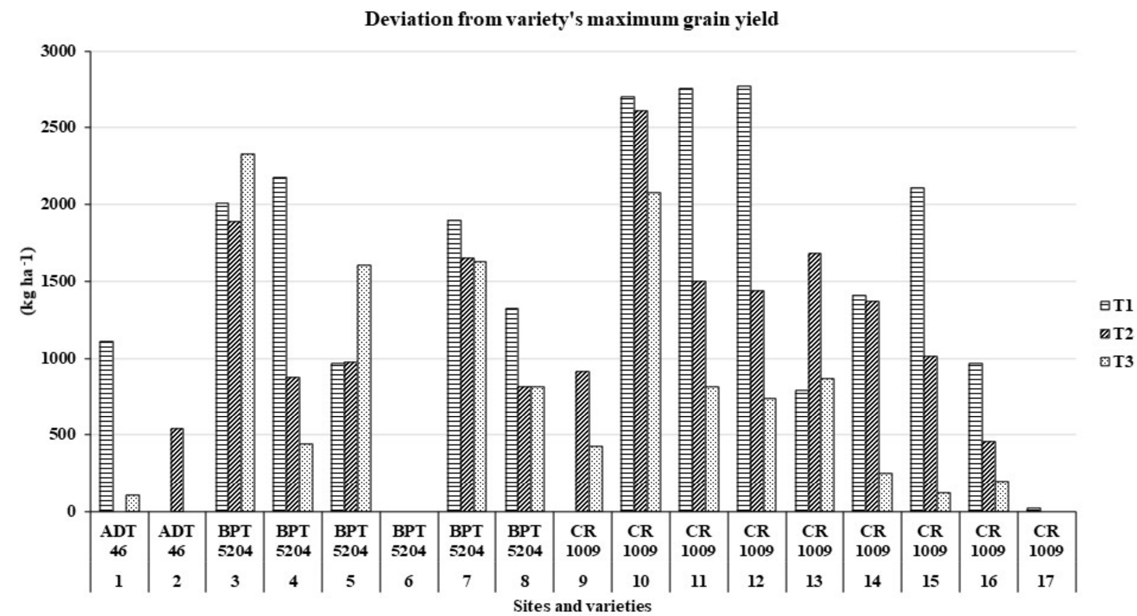

Fig. 3. Deviation from maximum of grain yield across sites of variety's cultivation. T_1 = Farmer's Fertiliser Practice (FFP), T_2 = Recommended Fertiliser Dosage (RDF), T_3 = Software (Nutrient Expert) derived fertiliser quantities (NE).

interaction of several factors, further analysis was also done. For instance; since certain physical properties are relatively static for relatively longer period and not altered by the treatments unlike chemical properties, soil texture was subjected to one-way ANOVA to discern its effect on rice grain yield. Besides, soil texture was one of the differentiating properties to assess the soil-based site differences. Soil texture significantly impacted the yield across varieties and treatments with an R^2, adjusted R^2 and predicted R^2 values (%) of 11.78, 10.01 and 7.12 and the model was highly significant ($p = 0.001$). Tukey's HSD based post-hoc tests showed a significant difference between sandy loam and remaining textural classes namely sandy clay loam, sandy clay and loamy sand where sandy loam yielded less than remaining textural classes ranging from 704 to 1000 kg ha^{-1} (rounded off).

A GLM of effects of textural class as a fixed factor, excess duration in nursery as a covariate and their interaction together described grain yield (across varieties and treatments) with an R^2, adjusted R^2 and Predicted R^2 values (%) of 42.3, 39.5 and 37.4, respectively, which was fairly good. In fact, these textural differences, site variations in the period of delay in transplantation and their interaction effect largely covered the influences caused by site variations (59.3%).

Test sites represented Eco-Sub Region (ESR) 18.2 of Agro-Ecological Zone No. 18, which is defined as North Tamil Nadu Plains (Coastal), hot moist semi-arid ESR (eco-sub region) with deep clayey and cracking coastal deltaic and deltaic alluvium-derived soils, high available water capacity and LGP (length of growing period) of 120-150 days (Ahmad et al., 2017). Initial soil characterisation discriminated sites in certain crop production factors even within a given ESR corroborating with several authors who reported occurrence of soil spatial variability present over short distances not only in natural ecosystems, but also in agricultural systems with presumed uniform management and vegetation cover (Mariotti et al., 1997; Goovaerts, (1998). However, further characterization with additional variables would help understanding soil resources at hand. In this regard, good-resolution theme maps developed from soil health cards (www.soilhealth.dac.gov.in) by interpolation methods could be of use (Rao, 2018,) whereby 12 different soil theme maps could be easily prepared in digital form to facilitate analysis while using certain geospatial tools (Rao, 2021).

Factor analysis is one of the data dimension reduction techniques and primarily used to understand the latent structure in the data. Factor analysis was applied to several kinds of datasets including soil data (Rao et al., 2002; Rao and Tripathi, 2011). In an earlier instance, Rao et al. (2002) extracted 'P limitation factor' from the dataset pertaining to laterites of Kerala with an association of P deficiency and excess aluminium posing limitation on the availability of P. In the present context also, a 'P limitation factor' was extracted from the data pertaining to Karaikal area (which are not laterites) but had a different association of increasing salinity and deficiency of P posing limitation on the availability. It is imperative from the analysis that there could be a specific latent structure in the data with certain association of variables to the factors, depending on the nature of data. However, the purpose of the application of factor analysis to the present data was to show the site differences and classification of soils based on factor scores to highlight site-specific management to realise the best.

Although, sites explained the largest variance in the yield (across varieties and treatments) to the tune of 59.3%, the requirement was to disaggregate the impact due to different components, which actually characterised the sites. With the available information and possible analysis, it was seen that the soil texture caused variance (across varieties and treatments) in grain yield to the extent of 11.1% while the ANOVA model was significant. A GLM with textural class as a fixed factor, excess duration in nursery as a covariate and their interaction term described large part of variance (R^2 = 42.3%) in yield within what sites explained as a whole (59.3%). It appeared that these two variables i.e., soil texture, excess duration in nursery and their interaction were the larger contributors to the variance in grain yield due to sites with some other minor factors. There were several reports about the effect of soil texture on rice yield (Dou et al., 2016) where rice grain yield was significantly affected by soil texture's role in water productivity, influence on root growth, and nutrient supply capacity etc. Similarly, the effect of excess duration in the nursery was reported to impact negatively the number of panicles per m^2, an important yield attribute. Experience was documented on the effect of delay in transplanting of rice on the yield (Shahi et al., 1977; Liu et al. 2015; Liu et al.; 2017), which ultimately found that delayed transplantation resulted in decreased rice yield.

The tested crop varieties differed from each other in crop duration and yield. It was known that varieties had their own theoretical potential yield. Yield potential is an idealized state and it is impossible to realise it under field conditions, even in relatively small test plots let alone in large production fields (Cassman, 1999) thus causing a gap between realisable and realised yields. Differential crop performance is expected in response to the combinations of site characteristics, input management in addition to farmers' experience in crop husbandry, which is important to reduce the gap and realise the uniform best.

Application of different quantities of N, P and K was another source of variance. The increase in mean yield from FFP to RDF and to NE based fertilisation (across sites and varieties) indicated positive impact of need-based fertilisation. The observed positive and significant correlations (n = 153, including all sites, treatments and replications) of grain yield with N and K was because of low native N in all sites while in majority sites the K content was medium and high only in three sites. The content of P was high in all sites thus there was no limitation leading to insignificant relationship. In this exercise, the response of rice to applied fertilisers was documented in different soil conditions. Anyway, the crux of the present study was about the site-specific fertiliser management to realise the best from in combinations of production factors.

However, the impact of site characteristics got either masked or averaged leading to a gap in understanding differential crop performance. Thus, the deviation from a variety's maximum, the resultant of a genotype's response to the environment, helped in assessing the responses to site characteristics. The results certainly called for site-specific nutrient management (SSNM) that enables the tailoring of nutrient management to field- and location-specific conditions (IRRI, 2007).

Although, the sites were studied more in terms of soil differences, the analysis also reminded about the impact of negative impact of excess duration in nursery in the nursery on the rice yield in combination with soil differences. Nevertheless, varieties, treatments across sites had their prominent influence on the yield though there were some differences due to delayed transplantations while other factors remained apparently constant.

CONCLUSION

The results showed that the largest variability in grain yield was caused by the spatial differences in site characteristics followed by varieties and treatments calling for site-specific management. The inferences highlighted the necessity of studying soil, an integral part of the environment (E) to which genotypes respond accordingly, to make decisions for better yields.

The data analysis indicated that the benefit of site-specific fertilizer management was certainly realised when moved from a random fertiliser application adopted by a farmer (FFP) to a highly specific fertiliser quantity derived from Nutrient Expert® (NE) through regional recommended dosages (RDF) suggested by the agricultural authorities. It is additive to the existing information and knowledge that site-specific fertilizer management reaped better yields.

The parity between CR 1009 (average production potential of 5300 kg ha^{-1}) and ADT 46 (average production potential 6656 kg ha^{-1}) across testing sites reminded the better performance of the variety in response to the environment, to reduce the gap between realisable and realised yield. In this regard, digital soil maps derived from soil health cards (SHCs) could be useful to get additional information of other elements in unsampled areas. This kind of database can best be put into AICRIP related trials profitably to help decision making to realise the uniform best yields across different growing situations.

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