Delta yield reflects better site-specific crop response in multi-locational trial

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India is the second largest producer of rice and transformation of India from being a net importer to the world's largest exporter is a spectacular achievement. The credit for this forward leap in rice production essentially goes to the All India Coordinated Rice Improvement Project (AICRIP) of the Indian Council of Agricultural Research that was initiated in 1965. The objective of AICRIP is to conduct multi-location trials to identify suitable genotypes of high yield potential along with appropriate crop management practices. The burgeoning population in India needs to produce about 120 Mt of rice annually by the year 2025, i.e. an additional production of about 1.5 Mt per year[1]. This increased production has to necessarily come from increased productivity rather than increase in area under rice.

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'[2]. However, to achieve yield potential requires perfection in the management of all other yield determining production factors from sowing to maturity. Such perfection is impossible under field conditions, even in relatively small test plots let alone in large production fields[3]. Yield gaps, the difference between potential yield and farmer yield, provide an estimate of the yield improvement possible without any change in potential yield[4]. Large yield gaps imply that there is more scope for yield improvement. Potential yield is location-specific making it necessary to aggregate local estimates spatially and temporally to produce average estimates for larger areas[5].

Multi-locational trials are studies of crop response to environment, documenting the differential response of a given variety to variable environment. Crop yield is a net expression of soil, plant, atmospheric interactions and the analysis of data normally includes yield as dependant variable to identify cause and effect relationship. Though the analysis with actual yield as an input would identify a relationship, use of Δ yield, i.e. the difference between average production potential of a variety and realized yield is more logical to reflect the net effect of environment and its management. Hence an analysis was done on the data collected from one of the multi-locational trials conducted by the ICAR-Indian Rice Research Institute to test the impact of three different fertilizer regimes; farmer's fertilizer practice (FFP), regional recommended dose (RDF) and Nutrient Expert®, a software used to derive fertilizer dose (NE). The trial was conducted at 17 different sites in Karaikal district, Puducherry during 2018 with three rice varieties, namely ADT 46, BPT 5204 and CR 1009. The data were analysed to quantify the effects of factors on grain yield and Δ yield and to explain the variance.

Rice varieties, ADT46 (135 days), BPT5204 (150 days) and CR 1009 (160 days) having average yield potential of 6656, 6000 and 5300 kg ha^{-1} respectively (www.agritech.tnau.ac.in) were grown in two, six and nine sites, which varied in soil properties, indicating diversity (D. V. K. N. Rao, *et al*., pers. commun.). The pattern of increase in grain yield or decrease in Δ yield was more from non-specific FFP to site-specific NE treatments underscoring the importance of site-specific fertilizer management (Table 1). Mean grain yield of ADT 46 and CR 1009 was more or less similar with 5254 and 5270 kg ha^{-1} respectively, although average potentials differed widely. But Δ yield was spectacularly different from a negative difference of 30 kg ha^{-1} (CR 1009) to 1402 kg ha^{-1} (ADT 46). In fact, farmers in certain sites realized more than the average potential in case of CR 1009, reducing the gap. Nevertheless, Δ yield extracted more and useful information that reflected the yield gap due to production factors.

A general linear model (GLM) (Table 2) highlighted that the total adjusted sum of squares (SS) was higher for Δ yield than grain yield where higher SS meant a large degree of variability within the dataset. GLM results indicated that sites had higher adjusted SS for Δ yield than grain yield underscoring the impact of site characteristics on yield gap. However, *p*-values indicated that the GLM was significant in explaining variability in both grain yield and Δ yield with reference to all other terms (Table 2).

The R^2, adjusted R^2 and predicted R^2 values of 83.8%, 75.8% and 63.6% respectively, for grain yield and 88.2%, 82.4% and 73.5% respectively, for Δ yield in the GLM, emphasized the utility of Δ yield in explaining the variability. Similarly, analysis of variance in yield due to site differences yielded R^2, adjusted R^2 and predicted R^2 values of 59.3, 54.5 and 48.4 respectively, for grain yield and 70.4, 66.9 and 62.5 respectively, for Δ yield signifying the importance of Δ yield in reflecting the site difference.

Crop yield is a net expression of a complex soil, plant, atmospheric interactions and management of other crop production factors and it requires modelling to reason the differential performance.

Table 1. Yield and Δ yield (kg ha^{-1}) across sites

Variable	Treatment	Mean	Variety	Mean
Grain yield	FFP	4312	ADT 46	5254
	RFD	4836	BPT 5204	4024
	NE	5337	CR 1009	5270
Δ yield	FFP	–1395	ADT 46	–1402
	RFD	–870	BPT 5204	–1976
	NE	–370	CR 1009	–30

Table 2. GLM of effects of sites, treatments and their interactions on rice yield

Source	Attribute	DF	Adj. SS	Adj. MS	*F*-value	*P*-value
Sites	Grain yield	16	116904954	7306560	10.83	0.000
	Δ yield	16	191175497	11948469	17.71	0.000
Treatment	Grain yield	2	26811189	13405595	19.87	0.000
	Δ yield	2	26811189	13405595	19.87	0.000
Sites × treatments	Grain yield	32	21584605	674519	2.15	0.002
	Δ yield	32	21584605	674519	2.15	0.002
Error	Grain yield	102	31996015	313686		
	Δ yield	102	31996015	313686		
Total	Grain yield	152	197296764			
	Δ yield	152	271567306			

Though potential yield is unachievable, it is possible to realize uniform average production potential as large yield gaps imply more scope for yield improvement. Under AICRIP, both pre- and post-release varietal performance assessment could be attempted using Δ yield instead of grain yield. This helps in better assessment of effect of variable production environment for better management. Similarly, Δ yield analysis approach may be extended to other crops too under other All India Coordinated Research Projects for yield gap analysis for improved management options.

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