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Evaluation of field fertility gradient based on plot-to-plot soil characteristics and major nutrient N, P, K

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Abstract
Field experiments conducted over five consecutive years (2015-2020) at the Department of Agronomy, IGKV, Raipur, started with plotting the graphical pattern of N, P, K nutrients. The graphical fertility patterns were found to change for the years 2015-2016 to 2019-2020. These fertility gradients were found to be curvilinear, and not straight-line across the field. So, the ANCOVA with fertility covariates, N, P, K individually or their sum (N+P+K) plot to plot, were found to reduce error variance more effectively than the RBD, thereby improving the precision of treatment comparisons. Both methods of covariate adjustment, using N, P, K separately and using their sum of N, P and K, performed well, often competing with each other in efficiency. Thus, ANCOVA using soil fertility data offers a robust alternative to RBD, especially when blocks cannot be correctly determined apriori. Overall, ANCOVA consistently reduced experimental error more effectively than RBD, improving reliability of results. So, in field experiments with unknown fertility gradient, ANCOVA with soil nutrient covariates proves to be a superior and more efficient analytical alternative compared to conventional RBD.

Keywords: ANCOVA, RBD, soil fertility gradient, N, P, K nutrients

Introduction
Experimental designs form the foundation of agricultural research, where proper planning and analysis are essential to draw valid inferences. Traditionally, most field experiments are conducted using the Randomized Block Design (RBD), which is based on three principles: randomization, replication, and local control. Among these, local control is especially important as it helps reduce experimental error by accounting for variation within the field. However, in long-term experiments, the same RBD layouts are often reused for several years without reassessing the fertility gradient of the field. Over time, due to continuous cropping and nutrient management practices, soil fertility patterns may change, leading to biased treatment comparisons and reduced precision. (Fisher, R.A. 1932) [1]

To overcome this limitation, Analysis of Covariance (ANCOVA) offers a powerful alternative. ANCOVA is a statistical method that combines Analysis of Variance (ANOVA) with regression by including additional continuous variables, called covariates, along with treatment effects. In agricultural experiments, soil nutrients such as Nitrogen (N), Phosphorus (P), and Potassium (K) can serve as important covariates because they directly influence crop performance and vary from plot to plot. By adjusting for this variability, ANCOVA reduces experimental error and increases the precision of treatment comparisons, even when fertility gradients are unknown or uneven across the field (Yang, R.C. and Juskiw, P. 2011) [10].

ANCOVA can be used as a technique for estimating the missing observations, whereby the experimenter needs to define one covariate corresponding to each one of the missing observations of the study/dependent variable (1945). Gomez and Gomez (1984) [2], page 454-457 and Steel and Torrie (1980) [9], page 426-428 have both given the procedures and illustrations with examples for one missing observation. While most statistics textbooks (*e.g.*, Snedecor and Cochran 1980 [7]; Gomez and Gomez 1984 [2]; Steel *et al.* 1997) [8] have one chapter that is exclusively devoted to ANCOVA, there are books (*e.g.*, Milliken and Johnson 2002) [4] that are totally devoted to the subject. Never theless, ANCOVA is an advanced topic that is only taught cursorily or ignored completely in many statistics classes (Piepho H.P. 2012) [5].

In the present study, the fertility gradient of an experimental field was assessed through plot-to-plot soil nutrient data (N, P, K). The study further evaluated the efficiency of ANCOVA compared to the traditional RBD in long-term chickpea Jukanti *et al*. (2012) [3] varietal experiments conducted at IGKV, Raipur, over five consecutive years (2015-2020). The objective was to demonstrate how ANCOVA with soil nutrient covariates can provide a more reliable and robust analytical framework for field experiments, particularly when fertility gradients are not clearly defined.

Materials and Methods

There was a national project on "All India Network Programming on Organic farming", whose sub-projects were run in the Department of Agronomy, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur. One such sub-project entitled "Evaluation of the response of different varieties of major crops for organic farming", was carried out at Instructional farm, IGKV, Raipur from 2015-2020. The proposed study is based on the primary data of this experiment, using their post-kharif-experiment soil N, P, and K data of paddy before their chickpea experiment in the following rabi season and the rabi experiment data.

Statistical Methods

Analysis of covariance (ANCOVA) is a mix of analysis of variance (ANOVA) and regression analysis, whereby the experimental error/residual error is reduced as a local control by first estimating (and thereby removing) the effect of regressor/covariate variable on the response variable, and then carrying out the ANOVA of the residuals so obtained on the levels of the treatment to finally estimate the effects of treatments more precisely than had it been estimated without first removing, as local control, the effect of the regressor variable/covariate from the response variable.

Ancova in Crd

Analysis of covariance in completely randomized design (CRD) with three covariates N, P and K as separate repressors. However, a separate case of single covariate ANCOVA in CRD also deals with the plot-to-plot (N+P+K) as the covariate. As already mentioned above the main focus would be on the three-covariate related methodology. To avoid the unnecessary increase in the length of the methodology further, for one covariate methodology it is sufficient to mention that all the methodology of three covariates will remain the same, except that only one covariate, say N will be replaced by the sum (N+P+K) as repressor and two covariates will be dropped. Singh, A.K. (2020) [6].

$$y_{ij} = \mu + \beta_1(x_{1ij} - \bar{x}_1) + \beta_2(x_{2ij} - \bar{x}_2) + \beta_3(x_{3ij} - \bar{x}_3) + \tau_i + \epsilon_{ij},$$

$$i = 1,2, \ldots t\ ;\ j = 1,2, \ldots r$$

Where;
y_{ij} =The plot-to-plot observation of a given character for the j^{th} plot and its
treatment; $i = 1,2, \ldots t; j = 1,2, \ldots r$
μ = General mean
β_k = Partial regression coefficient of the k^{th} covariate, which is centered; that is
the corresponding covariates have been used after subtracting them from their
respective means before using in the covariance analysis model; $k = 1,2,3$
x_{1ij} = Plot to plot available soil Nitrogen (N);$i = 1,2, \ldots t; j = 1,2, \ldots r$
x_{2ij} = Plot to plot available soil Phosphorus (P); $i = 1,2, \ldots t; j = 1,2, \ldots r$
x_{3ij} = Plot to plot available soil Nitrogen (K);$i = 1,2, \ldots t; j = 1,2, \ldots r$
τ_i = It is the i^{th} treatment effect, each level of which is replicated *r* times;$i = 1,2, \ldots t$
ϵ_{ij} = Residual of the j^{th} plot corresponding to i^{th} treatment;$i = 1,2, \ldots t; j = 1,2, \ldots r$

$$y_{ij} = \mu + \gamma(x_{ij} - \bar{x}) + \tau_i + \epsilon_{ij}, i = 1,2, \ldots t\ ;\ j = 1,2, \ldots r$$

Where;
y_{ij} = The plot-to-plot observation of a given character for the j^{th} plot and i^{th}
treatment; $i = 1,2, \ldots t; j = 1,2, \ldots r$
μ = General mean
γ = Partial regression coefficient of the k^{th} covariate, which are centered; that is
the corresponding covariates have been used after separating them from their
respective means before using in the covariance analysis model.
x_{ij} = Sum of plot-to-plot available soil nitrogen (N), soil phosphorus (P) and soil
potash (K);$i = 1,2, \ldots t; j = 1,2, \ldots r$

Results and Discussion

Determine the fertility gradient of the field where the fertility gradient was not known, despite the availability of plot-to-plot N, P, K values of the soil. The soil fertility data (N, P and K) collected plot-to-plot for the experimental fields during rabi season clearly indicated that the fertility gradient was not uniform across the experimental area. The combined fertility index (N+P+K) showed a curvilinear trend rather than a straight-line pattern. This confirms that assuming the same block structure as in the previous kharif season (rice experiment) would not adequately account for the existing fertility variation

When the experiment was analyzed using Randomized Block Design (RBD) alone, the block effect did not significantly reduce the error variance, suggesting that the assumed blocks were not in alignment with the actual fertility gradient. However, when analysis of covariance (ANCOVA) was applied, taking N, P and K (individually and in combination) as covariates, the error mean square was substantially reduced compared to the standard RBD analysis. This shows that the inclusion of soil fertility values as covariates more effectively adjusted for fertility differences among plots.

The adjusted treatment means after removing the effect of fertility covariates provided a more precise comparison of treatments. In most cases, the treatment differences became more distinct and statistically significant under ANCOVA, which were either masked or less significant under simple RBD analysis.

Table 1: Analysis of Covariance (ANCOVA) as an Adjusted ANOVA for RBD, along with one Covariate

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F	P-value
Regression covariate (N)	1	$E_{yy_1} = S_{yy} - \frac{E^2_{x_1y}}{E_{x_1x}}$	$RegrMS = \frac{E_{yy_1}}{1}$	$F_R = \frac{RegrMS}{EMS}$	$Pr(> F_R)$
Regression covariate (P)	1	$E_{yy_2} = E_{yy_1} - \frac{E^2_{x_2y}}{E_{x_2x}}$	$RegrMS = \frac{E_{yy_2}}{1}$	$F_R = \frac{RegrMS}{EMS}$	$Pr(> F_R)$
Regression covariate (K)	1	$E_{yy_3} = E_{yy_2} - \frac{E^2_{x_3y}}{E_{x_3x}}$	$RegrMS = \frac{E_{yy_3}}{1}$	$F_R = \frac{RegrMS}{EMS}$	$Pr(> F_R)$
Adj. Treat	(t – 1)	$TrS = SS'_E - SS_E$ $[E_{yy_2} - \frac{E^2_{x_3y}}{E_{x_3x}}] - [E_{yy_3} - \frac{E^2_{xy}}{E_{xx}}]$	$TrMS = \frac{TrSS}{t-1}$	$F_T = \frac{TrMS}{EMS}$	$Pr(> F_T)$
Adj. Error	[t. (r – 1) – 1 – 1 – 1	$SS_E = [E_{yy_3} - \frac{E^2_{xy}}{E_{xx}}]$	$EMS = \frac{SS_E}{[t.(r-1)-1-1-1]}$		
Total	(n – 1)	$TSS = S_{yy} = [\sum_{i=1}^{t}\sum_{j=1}^{r} y^2_{ij} - \frac{G^2_y}{n}]$			

Fertility Gradient of the field in rabi season during (2015-2020)

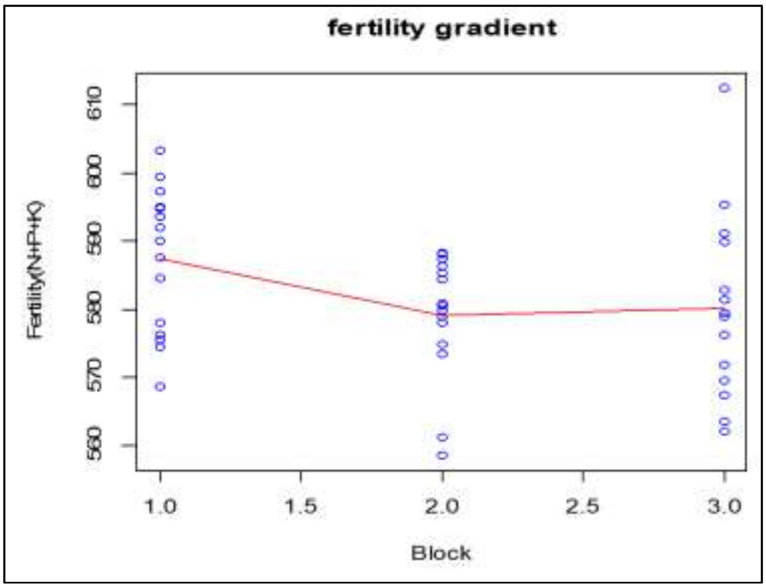

Fig 1: Fertility Gradient of the field in Rabi season during 2015-201

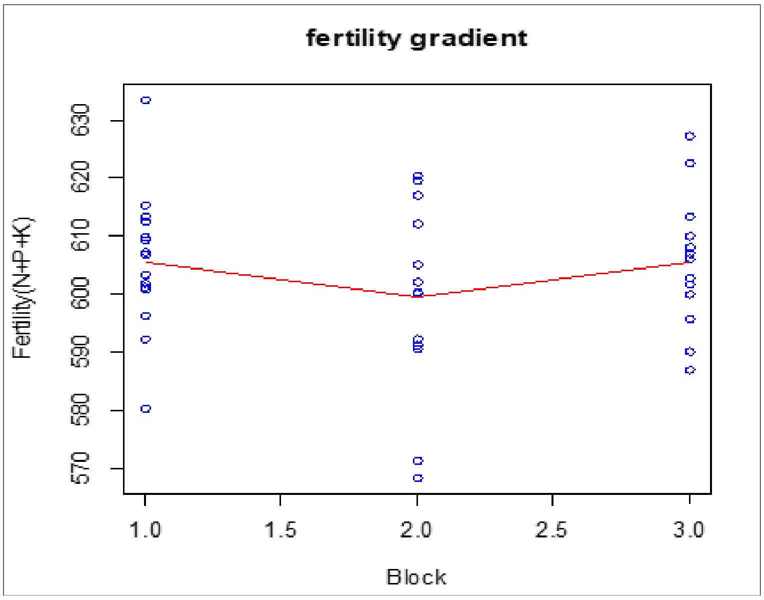

Fig 2: Fertility Gradient of the field in Rabi season during 2016-2017

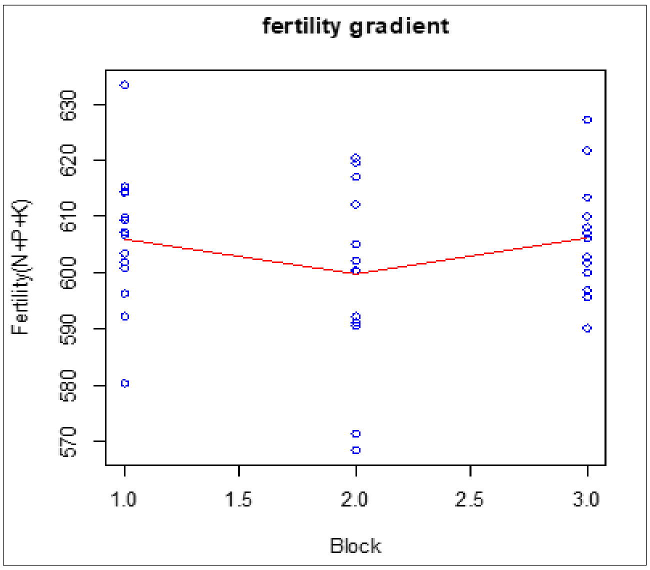

Fig 3: Fertility Gradient of the field in Rabi season during 2017-2018

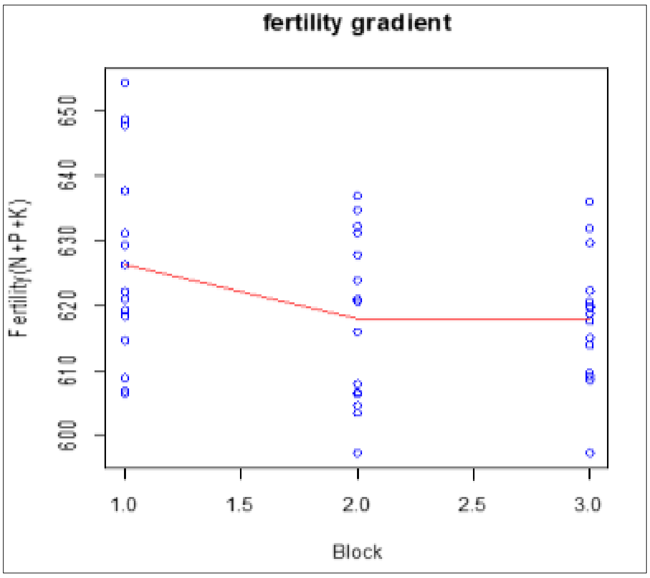

Fig 4: Fertility Gradient of the field in Rabi season during 2018-2019

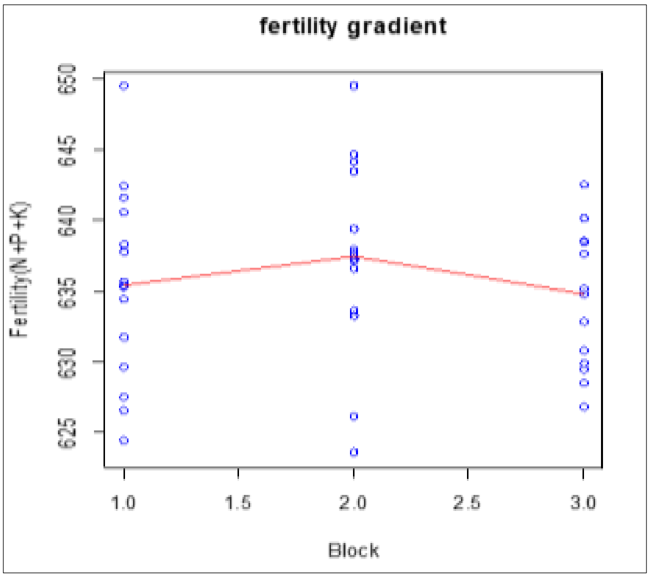

Fig 5: Fertility Gradient of the field in Rabi season during 2019-2020

Conclusion

The study revealed a non-uniform fertility gradient across the field, rendering the standard RBD inadequate for controlling variability. Incorporating N, P, and K as covariates through ANCOVA significantly reduced error variance and improved treatment precision. Hence, ANCOVA proved to be a statistically efficient method for adjusting fertility effects and enhancing the reliability of experimental results on heterogeneous fields.

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