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Application of analysis of covariance model on mango crop based agro-forestry experiments

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ABSTRACT

The study mainly aimed at the comparison of analysis of experiments through ANOVA model and ANCOVA model. The selection of covariate is one of the most important parts of the analysis through ANCOVA model to reduce the residual error. The study includes the necessary conditions for selection of best covariate for analysis of covariance (ANCOVA) model in field experiments using the homogeneity of regression slopes (HOS) test (Karen ,2004) and the test based on the correlation coefficient value of dependent variable (y) and the covariate (x) (Cochran, 1957). The relative gains in efficiencies of ANCOVA models in the above field experiments were also calculated. The layout of the conducted experiment was done under randomized block design set up with 6 treatments and 3 replications. The used covariates, taking a single covariate at a time, for the above experiments were soil pH, Organic Carbon (%), amount of Nitrogen (kg ha^{-1}) in soil, amount of Phosphorus (kg ha^{-1}) in soil and amount of Potash (kg ha^{-1}) in soil. In experiment, soil pH for the year 2012 and amount of Potash (kg ha^{-1}) in soil for the year 2013 were selected as best covariates, respectively. The relative efficiencies were 425.392 and 996.295per cent for the years 2012 and 2013, respectively.

***Keywords*:** Covariate, homogeneity of regression slopes, relative efficiency, scatter plot method

The three basic principles of experimental designs *viz*., Randomization, Replication and Local control are aimed to minimize the error sum of squares or to control of errors in the designed experiment and increase the precision of the experiment. Specially, local control is one of the most desirable practices for reduction of error in experimental designs. There is another well-known method by which the error affecting the treatment comparisons may be minimized, known as 'Analysis of Covariance' or ANCOVA models. In ANCOVA models, measurements of character of primary interest of the experimenter is recorded for analysis as is done for analysis of variance (ANOVA) (y), in addition measurement of one or more characters (x) are also recorded for analysis. These additional character (or characters) or variable (or variables) is (are) known as 'concomitant' variable (or variables) or simply covariate (or covariates). It is also to be noted that y has a linear regression on x. The typical mathematical model of analysis of covariance of a two way classified data is,

$$y_{ij} = \mu + \alpha_i + \beta_j + \bar{x}\,(x_{ij} - \bar{x}_{.}) + \varepsilon_{ij} \qquad (1)$$

Here, y_{ij} is the yield of (i, j)th cell, while x_{ij} is the covariate or concomitant variable of (i, j)th cell and $\bar{x}$. is the mean of x_{ij}. Again, y_{ij} has a linear regression relation on x_{ij} with regression coefficient γ. If the data is recorded through a randomized block design with v treatments with r replication for each treatment then μ, α_i and β_j have their usual meanings (i = 1, 2… v; j = 1, 2… r). The residuals or the errors ε_{ij} are random variables to be distributed independently as normal with zero mean and common variance (σ^2)

Analysis of covariance requires the fulfillment of the following mandatory assumptions,

- The covariate should be independent of the treatment effects.
- The relationship between the dependent variable (y) and the covariate (x) is linear for each independent variable.
- The lines expressing the above linear relationships for different independent variables are mutually parallel to each other (homogeneity of regression slopes).

Further, the following conditions are necessary for experiments with ANCOVA model,

A. To reduce the effect of extraneous variation on the responses of estimated treatment by the application of ANCOVA is that the concomitant variable (x) should be unaffected by treatments, either by direct relation or through correlation with another affected character (Fairfield Smith; 1957).

B. Cochran (1957) defined the average precision factor as, if σ_e^2 is the experimental error variance in analysis of variance model, the adjustments with only one covariate will reduce the above error variance to a value (approximately) $\sigma_e^2(1-\rho^2)\left\{1+\frac{1}{f_e - 2}\right\}$, where f_e is the experimental error degrees of freedom. ρ is the correlation coefficient between y and x i.e. variable under study and covariate. Cochran (1957) also suggested the followings for reduction of error variance:

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a. If ρ is less than about 0.3, there will be a little gain in efficiency.

b. If ρ is greater than 0.9, there will be a sufficient gain in efficiency.

c. If error degree of freedom is small it is not desirable to use more than two concomitant variables.

Several statisticians have applied the procedure of analysis of covariance in agricultural field experiments. Some of the recent works on the above topic applied in agricultural field experiments are discussed below.

Noureldin *et al*. (2000) observed that ANCOVA was a highly efficient tool for increasing the precision of field experiments. Stevenson *et al*. (2001) discussed the advantages of ANCOVA in experiments with three crop rotations *viz*. Pea (*Pisum sativum*)-wheat (*Triticum aestivum*)-barley (*Hordeum vulgare*), rape (*Brassica napus*)-wheat-barley and wheat-wheat-barley. Karen (2004) reported that despite a strong importance of ANCOVA in field experiments, the experimenters not been able to utilize the benefits of the ANCOVA due to wrong or unjust selection of covariates as well as lack of knowledge of assumptions of ANCOVA. Karen (2004) also discussed some useful methods for testing the statistical assumptions of ANCOVA. Zafar *et al*. (2007) described the methods of adjustment of the treatment effects by controlling covariates in research of agriculture purpose. Goaszewski *et al*. (2009) reported the usefulness of ANCOVA instead of ANOVA in 35 field experiments on traits of pea (*Pisum sativum* L.). Masood *et al*. (2012) discussed the application of ANCOVA on chilli cultivars. The error mean square was reduced by using the method.

Keeping in view the paramount importance of the ANCOVA model in field experiments, the present paper also aims to study the application procedure of analysis of covariance (ANCOVA) model on mango based agro-forestry experiments for consecutive two years (2012 and 2013) with the relative gain in efficiency of ANCOVA model over ANOVA model. The study also includes a selection of the best covariate for analysis of covariance (ANCOVA) model for the above mango based agro- forestry experiments.

MATERIALS AND METHODS

The experiment for the present study was conducted on "Agri-Horti-Silvicultural" system of cropping at Regional Research Station (Red and Laterite Zone) under Bidhan Chandra Krishi Viswavidyalaya, Jhargram, Paschim Medinipur, West Bengal (21^0 45' to 24^0 35' N and 85^0 45' to 88^0 45' E) during 2012 and 2013. The experiments were conducted under the trails of AICRP on Agro-Forestry, ICAR, New Delhi. The experimental details are given below:

Lay out : RBD with 3 replications

Treatment details : **Mango based cropping system**

$\mathbf{T_1}$ = Mango + Pigeon pea

$\mathbf{T_2}$ = Mango + Blackgram (*kharif*) + Mustard (*rabi*)

$\mathbf{T_3}$ = Mango + Bottle gourd (*kharif*) + Mustard (*rabi*)

$\mathbf{T_4}$ = Mango + Lady's finger (*kharif*) +Mustard (*rabi*)

$\mathbf{T_5}$= *Eucalyptus tereticornis* + Mango and

$\mathbf{T_6}$ = Mango (var. Amrapally)

Duration : 2 years (2012 and 2013)

Here, the yields of treatments of the above experiments (*i.e*., Mango in $t.ha^{-1}$) were recorded for the years 2012 and 2013. For every year, before conducting an experiment the information on soil parameters (*viz*., soil pH, Organic Carbon (%), Nitrogen (kg ha^{-1}), Phosphorus (kg ha^{-1}) and Potash (kg ha^{-1})) of each plot of the experiments were collected.

According to the objectives of the study, the analysis of each experiment was done under the ANCOVA model in a randomized block design layout. The soil information parameters like soil pH, Organic Carbon (%), Nitrogen (kg ha^{-1}), Phosphorus (kg ha^{-1}) and Potash (kg ha^{-1}) were used as concomitant variables or simply covariates of the experiments, separately.

Before proceeding with the ANCOVA model, there are a number of assumptions and conditions to be fulfilled in analysis as mentioned previously. The experiments can also be tested by Johnson- Neyman procedure as mentioned by Karen (2004) for homogeneity.

Test of homogeneity of regression slopes for each treatment (or group) of covariates by scatter plot method

The dependent variable (Y) is plotted against the covariate variable (X) with separate regression lines for each Treatment (or group). The main focus of the Y versus X Graph will be to test whether the slope of the regression lines expressing in linear relationships for

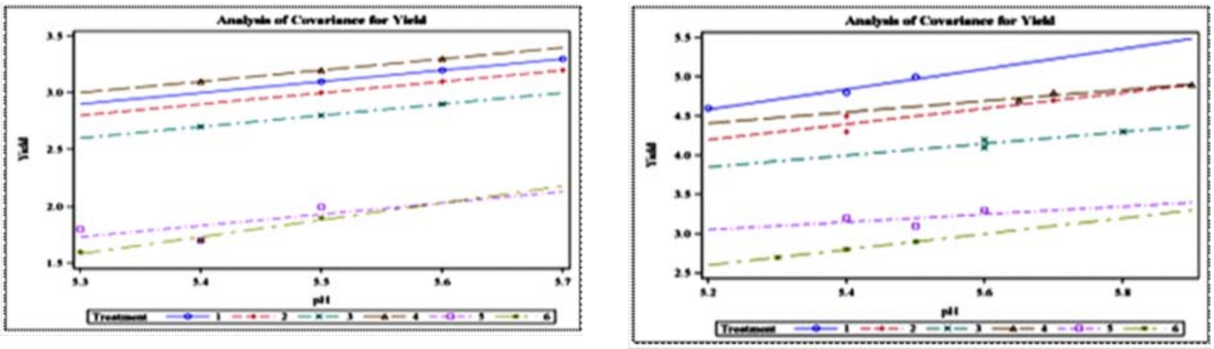

Fig. 1: Scatter-plots to test HOS of pH as covariate vs. yield with separate regression lines for six treatments for experiments on Mango

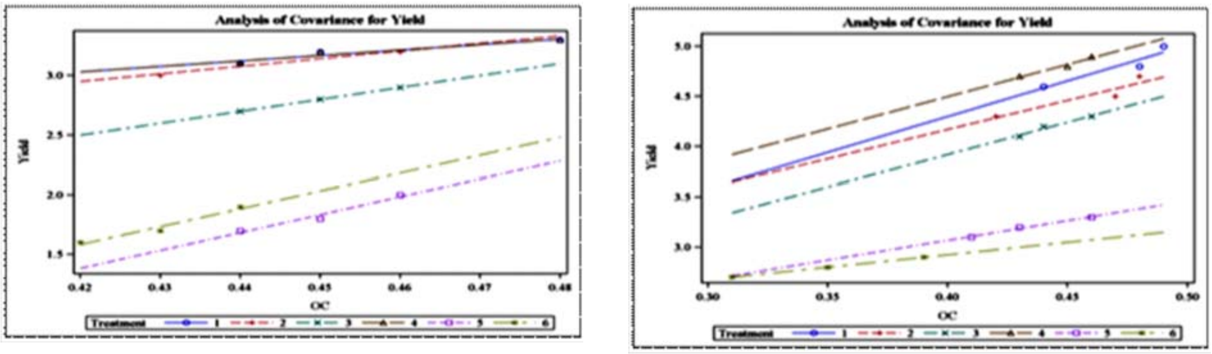

Fig. 2: Scatter-plots to test HOS of organic carbon (%) as covariate vs. yield with separate regression lines for six treatments for experiments on mango

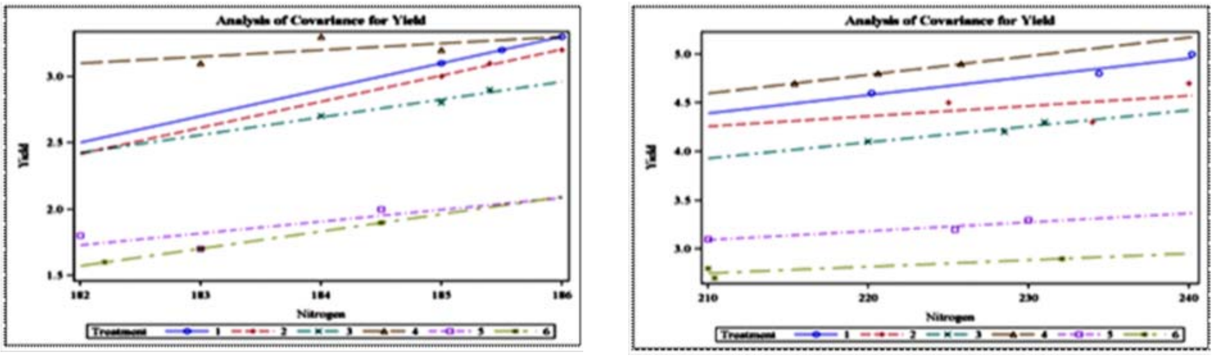

Fig. 3: Scatter-plots to test HOS of nitrogen (kg ha^{-1}) as covariate vs. yield with separate regression lines for six treatments for experiments on mango

Table 1 : Year wise correlation between dependent variable (DV) and covariate variable (CV) for mango

Covariates	Mango	
	2012	2013
Soil pH	0.910	0.922
OC	0.852	0.901
N (kg ha^{-1})	0.849	0.759
P (kg ha^{-1})	0.525	-0.035
K (kg ha^{-1})	0.802	0.957

Note: OC as organic carbon (%), N as nitrogen (kg ha^{-1}), P as phosphorus (kg ha^{-1}) and K as potash (kg ha^{-1})

different Covariate (independent) variables are mutually parallel to each other or not. If the lines are parallel, then it can be said that the slopes of the lines are homogenous. Then the selected covariate will play a good role in the ANCOVA model.

Test of the correlation coefficient between covariate variable (X) and dependent variable (Y) to increase the precision of the experiment

According to Cochran (1957) as mentioned earlier, the reduction of the experimental error variance over the analysis through without considering the covariate

(ANOVA) will be $\sigma_e^2(1-\rho^2)\left\{1+\frac{1}{f_e-2}\right\}$, where f_e is the experimental error degrees of freedom and ρ is the correlation coefficient between the dependent variable under study (y) and the concomitant variable (x).The analysis of covariance suggests that if ρ is less than about 0.3, covariance adjustment offers a little gain in efficiency. Otherwise, if ρ is greater than 0.9, there is a sufficient gain in efficiency.

Analysis of the experiment has been done by considering the model (1) for ANCOVA in randomized block design set up as given by Das and Giri, (1986).

Relative efficiency (RE) of ANCOVA over ANOVA model

The Relative Efficiency (%) of ANCOVA compared to ANOVA will be obtained by the following way of Zafar, *et al*. (2007):

$$\text{R.E.}=\frac{(100)\ (\text{Error Mean Square of Y})}{(\text{Error Adjusted Mean Square of Y})\left(1+\frac{\text{Treatment Mean Square of X}}{\text{Error Sum of Square of X}}\right)}$$

RESULTS AND DISCUSSION

Testing for homogeneity of regression slopes (HOS)

Before going to analysis of the experiments under ANCOVA model, the experimental results were tested for assumption of homogeneity of regression slopes (HOS) by using scatter plots. This assumption of HOS can be tested by Johnson-Neyman procedure using scatter plots (Karen, 2004). A scatter-plot of the data is the best way to assess HOS while examining descriptive statistics.

In fig. 1, the scatter-plots to test homogeneity of regression slopes of pH as Covariate vs. Yield with separate regression lines for six Treatments for experiments on Mango for the years 2012 and 2013 are presented. It has observed that the lines are more or less parallel, which confirms that the selection of the factor pH as a covariate to mango yield for both the years is correct. Similar results are shown in the fig. 2, 3 and 5 for using organic carbon (%), amount of nitrogen (kg ha^{-1}) present in soil and amount of potash (kg ha^{-1}) present in soil as covariates, respectively. Thus, choices of factors, *viz.*, organic carbon (%), amount of nitrogen (kg ha^{-1}) present in soil and amount of potash (kg ha^{-1}) present in soil as covariates to mango yield for both the years (2012 and 2013) as covariates are also correct. However, it is clearly shown in figure 3.4 that the regression lines are not parallel to each other. Therefore the selection of phosphorus as covariate is not correct.

Test for choice of covariates

According to Cox and McCullagh (1982), the test is based on the simple correlation coefficients between covariate and yield or dependent variable for two years on the crop. The results are shown in table 1 for both the years (2012 and 2013). It is observed that all the simple correlation coefficient values are reasonably higher except the factor phosphorus.

Application of ANCOVA model and assessment of relative efficiencies

Table 2 represents the original mean yield and adjusted mean yield of Mango (after removal of the effect of covariate) at RRS, BCKV, Jhargram during 2012-2013. It was observed that pH of soil used as covariate gave the maximum relative efficiency percentage (425.392%) over the ANOVA model (Table 2). Other factors like organic carbon (%) in soil, available nitrogen in soil and amount of potash available in soil can also be used as covariates for the ANCOVA model but the relative efficiency percentage are lower than pH as covariate. These results are also confirmed by the precision factor given by Cox and McCullagh (1982). Therefore, we only use the adjusted mean of different treatments given by ANCOVA model with pH as covariate for the year 2012. The decision about the best or worst treatment can be taken only on the adjusted mean values when pH is used covariate.

The amount of available potash (kg ha^{-1}) in soil used as covariate gave the maximum relative efficiency percentage (996.295%) over the ANOVA model (Table 3). Other factors like pH, Organic carbon (%) in soil and available nitrogen in soil can also be used as covariates for the ANCOVA model but the relative efficiency percentage are lower than potash as covariate. These results are also confirmed by the precision factor given by Cox and McCullagh (1982). Therefore, we only use the adjusted mean of different treatments given by ANCOVA model with potash as covariate. The decision about the best or worst treatment can be taken only on the adjusted mean values when potash is used covariate for the year 2013.

Table 2: Original and adjusted mean yield (after removal of the effect of covariate) of mango at RRS, BCKV, Jhargram during 2012

Treatment	Y(t ha^{-1})	pH	Y*	OC(%)	Y*	N(kg ha^{-1})	Y*	P(kg ha^{-1})	Y*	K(kg ha^{-1})	Y*
T_1	3.200	5.600	3.094	0.457	3.142	185.500	3.071	19.933	3.165	191.967	3.107
T_2	3.100	5.600	2.994	0.443	3.129	185.467	2.975	19.933	3.065	191.933	3.010
T_3	2.800	5.500	2.800	0.450	2.786	184.800	2.750	19.400	2.858	190.267	2.831
T_4	3.200	5.500	3.200	0.457	3.142	184.000	3.241	19.667	3.212	189.400	3.295
T_5	1.833	5.400	1.940	0.450	1.819	183.167	1.969	19.333	1.903	190.367	1.857
T_6	1.733	5.400	1.840	0.430	1.849	183.233	1.861	20.133	1.664	190.233	1.767
β			**1.062**		**6.518**		**0.113**		**0.174**		**0.073**
RE (%)			**425.39**		**293.35**		**229.46**		**99.62**		**212.95**
P (CM)			**0.003**		**0.004**		**0.005**		**0.012**		**0.006**
SeM(±)			**0.034**		**0.041**		**0.046**		**0.069**		**0.048**
LSD (0.05)			**0.108**		**0.130**		**0.147**		**0.222**		**0.153**

Table 3: Original and adjusted mean yield (after removal of the effect of covariate) of mango at RRS, BCKV, Jhargram during 2013

Treatment	Y(t ha^{-1})	pH	Y*	OC(%)	Y*	N(kg ha^{-1})	Y*	P(kg ha^{-1})	Y*	K(kg ha^{-1})	Y*
T_1	4.800	5.367	4.971	0.470	4.626	231.600	4.723	20.133	4.799	202.667	4.742
T_2	4.500	5.500	4.532	0.457	4.389	233.000	4.406	19.800	4.497	202.200	4.483
T_3	4.200	5.667	4.058	0.443	4.153	226.500	4.184	20.267	4.200	201.667	4.229
T_4	4.800	5.750	4.570	0.447	4.737	220.600	4.855	20.200	4.800	203.233	4.693
T_5	3.200	5.500	3.232	0.433	3.200	221.800	3.240	20.867	3.205	201.200	3.269
T_6	2.800	5.400	2.937	0.350	3.196	217.500	2.892	20.267	2.800	201.033	2.884
β			**1.05**		**4.75**		**0.01**		**-0.01**		**0.09**
RE (%)			**440.64**		**292.02**		**188.92**		**84.47**		**996.30**
P (CM)			**0.004**		**0.005**		**0.011**		**0.027**		**0.002**
SEm (±)			**0.043**		**0.052**		**0.065**		**0.097**		**0.028**
LSD (0.05)			**0.136**		**0.167**		**0.208**		**0.311**		**0.091**

Note: Y indicates adjusted mean values of Y (mean yield) of mango, β as regression coefficient, RE as relative efficiency over ANOVA and P (CM) as precision factor of Cox and McCullagh*

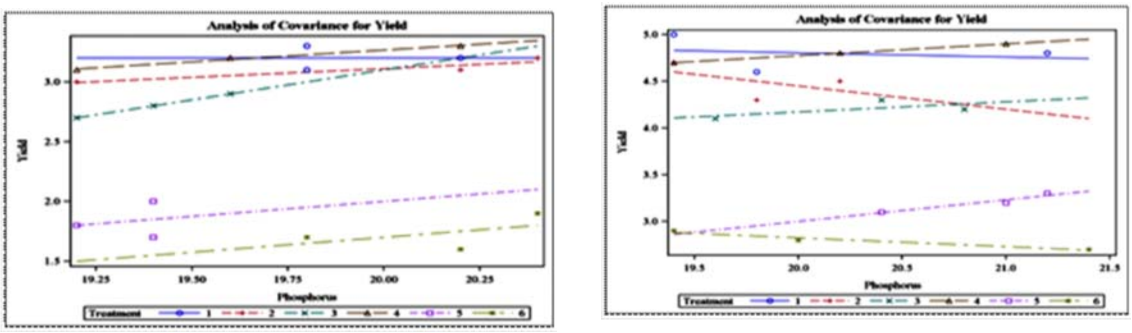

Fig. 4: Scatter-plots to test HOS of phosphorus (kg ha^{-1}) as covariate vs. yield with separate regression lines for six treatments for experiments on mango

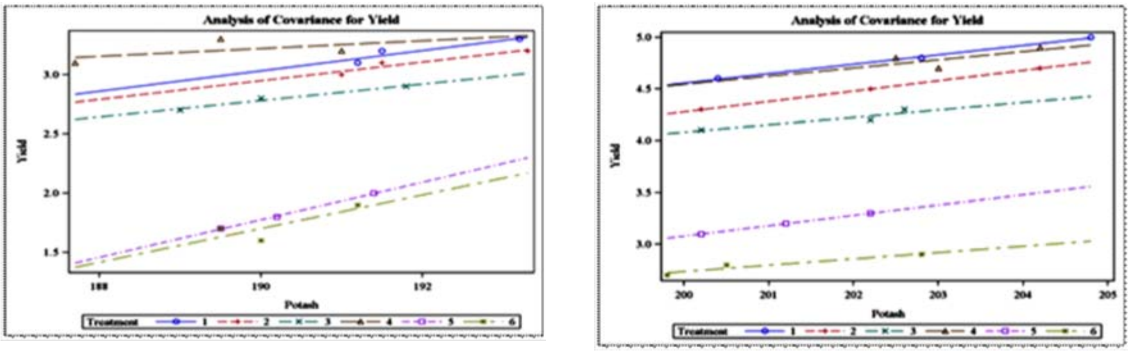

Fig. 5: Scatter-plots to test HOS of potash (kg ha^{-1}) as covariate vs. yield with separate regression lines for six treatments for experiments on mango

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