STATISTICAL ANALYSIS OF REPLICATED FIELD TRIALS ON CULTIVATORS' FIELDS

S.K. RAHEJA and B.N. TYAGI*

Institute of Agricultural Research Statistics, New Delhi

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1. INTRODUCTION

For formulation of fertilizer recommendations for any tract or area, conduct of suitably planned simple scientific experiments has become a generally accepted practice. These experiments are conducted on cultivators fields with the treatments being superimposed over cultivators' normal practices so that the results may be directly applicable to the cultivators' conditions and thus form the basis of suitable recommendations. However, for these recommendations to be stable, they must take into account the effect of seasonal fluctuations. For this purpose, the experiments are normally repeated for 3-4 years and the results pooled over the years to obtain stable estimates.

The principles governing the planning of these experiments and statistical analysis of data of experiments conducted at different places in a year have been given by Uttam Chand and Abraham (1957) and by Panse and Abraham (1960). In this paper it is proposed to outline the method of statistical analysis when these experiments are repeated over time and place. For the purpose of illustration, data of simple fertilizer trials conducted during 1958-59 to 1960-61 in the district of Muzaffarpur (Bihar) under the All India Coordinated Agronomic Experiments Scheme of the I.C.A.R. were utilized.

It may be added that the main object of this scheme was to determine the average responses of cereals and cash crops to nitrogen, phosphorus and potash applied alone and in combination under different soil and climatic conditions. The method of statistical analysis developed in this paper is, therefore, directed towards obtaining

*Present Address: Joint Director of Agriculture (Statistics), U.P., Lucknow.

the expected values of the mean sums of squares for different components leading to appropriate tests of significance and standard errors for differences in mean yields of various treatments.

2. Design

Stratified multi-stage random sampling procedure was adopted for selection of primary and secondary units. Each selected district under the scheme was first divided into 4 homogeneous zones or strata approximately of equal area. One block consisting of about 100 villages (or about 250 sq. km. in area) was randomly selected within each zone which constituted the primary sampling unit. However, since only one block was selected in each stratum, no estimate of error between blocks within a stratum would be available. Within each block, villages were selected depending upon the crop and season for which the selection was being made. In each selected village only one experiment was conducted in a randomly selected cultivator's field.

The treatments consisted of all combinations of two levels of N, P and K, the levels of each nutrient being 0 and 22.4 kg/hectare.

3. Model

An appropriate model for such types of experiments is the following :

$$y_{ijk}=m+s_i+v_{ij}+t_k+(st)_{ik}+(vt)_{ijk} \qquad \ldots(1)$$

where m is a constant, s_i $(i=1, 2, ..a)$ the effect of year i ; v_{ij} $(j=1, 2...bi)$ the effect of j-th village in the i-th year ; t_k $(k=1, 2,...c)$ the effect of k-th treatment ; $(st)_{ik}$ the interaction of treatments with years and $(vt)_{ijk}$ is interaction of k-th treatment with j-th village in i-th year. Leaving m and t_k, all other parameters in (1) are random variables with zero expectations and the following variances :

$$E\,(s_i^2) = \sigma_s^2$$

$$E\,(v_{ij}^2) = \sigma_v^2$$

$$E\,(st)^2_{ik} = \sigma_{st}^2$$

and

$$E\,(vt)^2_{ijk} = \sigma^2$$

4. Analysis of Variance

The analysis of variance table and the expected m. s. are given in Table 1.

TABLE 1

Analysis of variance for the data of experiments in cultivators' fields

Source	*d. f.*	*m. s.*	*Expected value of m. s.*
Years	$a-1$		
Treatments	$c-1$	T_1	$\frac{1}{c-1}\sum_{i=1}^{a} b_i \sum (t_k-\bar{t})^2$ $\frac{\Sigma b_i^2}{\Sigma b_i}\sigma_{st}^2+\sigma^2$
Villages within years	$\sum_{i=1}^{a}(b_i-1)$		
Treatments x years	$(a-1)(c-1)$	T_2	$\frac{1}{a-1}\left(\Sigma b_i-\frac{\Sigma b_i^2}{\Sigma b_i}\right)\sigma_{st}^2+\sigma^2$
Villages within years x Treatments	$(c-1)\sum_{i=1}^{a}(b_i-1)$	T_3	σ^2

Variance of any treatment average based on $\sum_{i=1}^{a} b_i$

experimental units is given by :

$$V(t)=\frac{\Sigma b_i^2}{(\Sigma b_i)^2}\sigma_{st}^2+\frac{\sigma^2}{\Sigma b_i} \qquad \text{...(2)}$$

As this is 2^3 factorial experiment, the variances of all main effects and interactions are equal and given by $[\frac{1}{2} V(t)]$. The estimate of $V(t)$ is given by

$$\text{Est. } V(t)=\frac{(a-1)(T_2-T_3)\sum_{i=1}^{a} b_i^2}{\Sigma b_i\,[(\Sigma b_i)^2-\Sigma b_i^2]}+\frac{T_3}{\Sigma b_i} \qquad \text{...(3)}$$

In case the number of villages is equal, say b, in all the years, we have

$$\left.\begin{aligned} E(T_1)&=\frac{ab}{c-1}\sum(t_k-\bar{t})^2=b\sigma^2_{st}+\sigma^2 \\ \text{and} \quad & \\ E(T_2)&=b\sigma^2_{st}+\sigma^2 \end{aligned}\right\} \qquad \text{...(4)}$$

The expressions (2) and (3) also reduce to

$$V(t)=\frac{\sigma^2_{st}}{a}+\frac{\sigma^2}{ab} \qquad \text{...(5)}$$

and

$$\text{Est. } V(t) = \frac{T_2}{ab} \qquad \ldots(6)$$

5. EXAMPLE

For purpose of illustration, the data of experiments conducted in Muzaffarpur (Bihar) were utilized and are given in Appendix. The model for a specific zone, say zone III, would be

$$y_{ijk} = m + s_i + v_{ij} + t_k + (st)_{ik} + (vt)_{ijk}$$

where

$$i = 1, 2, 3$$

$$j = 1, 2, 3, 4 \text{ for the 1st and 3rd year}$$

$$= 1, 2, 3 \text{ for 2nd year}$$

$$k = 1, 2 \ldots\ldots\ldots 8.$$

The analysis of variance for the data of zone III is given in Table 2.

TABLE 2

Analysis of variance of the data of zone III in (Q/ha)²

Source	*d. f.*	*s. s.*	*m. s.*	*Expectation of m. s.*
Years	2	2,355.17	1,177.58	
Treatments	7	905.60	129.37	$1.57 \sum_{k=1}^{8} (t_k - \bar{t})^2 + 3.73\sigma_{st}^2 + \sigma^2$
Years X Treatments	14	43.67	3.12	$3.64\ \sigma_{st}^2 + \sigma^2$
Between villages	8	604.30	75.54	
Villages X Treatments	56	108.89	1.94	σ^2

From (3), estimate of standard error of any treatment is given by

$$\sqrt{V(t)} = \sqrt{(0.107 + 0.173)}\ Q/ha$$

$$= 0.529\ Q/ha.$$

The two components of variances σ^2_{st} and σ^2 are 0.32 and 1.94 respectively. As there is not much difference among the number of villages selected in various years, we can also use formula (6) which gives $\sqrt{V(t)}=0.533$ Q/ha, the two estimates of standard error $\sqrt{V(t)}$ agreeing very closely. From practical point of view, the use of formula (6) is recommended, particularly in cases when the number of villages do not vary much from year to year.

In a factorial experiment, the estimates of the main effects and interactions are generally required. These estimates can be built up in the usual way. The variances of the main effects and interactions also do not present any difficulty. As each main effect and interaction is a linear contrast among c treatments ($c=8$ in this case), the standard error of main effect, say of nitrogen, in this case is given by

$$\begin{aligned} V(N) &= \sqrt{\tfrac{1}{2}\,V(t)}\ Q/ha \\ &= \sqrt{0.14}\quad Q/ha \\ &= 0.37\qquad Q/ha \end{aligned}$$

It is also fairly easy to work out the critical differences for comparisons of various effects. The calculations are illustrated by two-way table of $N \times P$ for zone III.

TABLE 3

Yield of Paddy (Q/ha)

	N_0	N_1	*Means*
P_0	15.23	20.13	17.68
P_1	17.97	23.67	20.82
Mean	16.60	21.90	19.25

C.D. for marginal means $=\sigma_N \times t=0.37\times 2.145=0.79$

and

C.D. for the cell means $=\sqrt{2}\,\sigma_N \times t=1.12$ Q/ha

where t is the t-value corresponding to .05 probability and 14 d.f.

The results would be generally required to be presented at the district level instead of presenting these at the zonal level. For obtaining estimates at the district level, one can use weighted averages, the area under the crop being taken as weight. In this case, however, simple mean has been taken as the zones were approximately of equal size. Hence the variance of any main effect, say of nitrogen, denoted by $\overline{N}$ is given by

$$V(\overline{N})=\frac{1}{16}\sum_{h=1}^{4} V_h\ (N)$$

where $V_h\ (N)$ is the variance of the main effect of nitrogen in the h-th zone.

Table 4 gives the values of the main effects, interactions and their standard errors.

TABLE 4

Responses of paddy in quintals/hectare of nitrogen, phosphate and potash singly and in combinations.

	Zones				*District average*
	I	*II*	*III*	*IV*	
N	4.28	2.92	5.90	3.78	4.22
P	2.78	2.59	3.13	2.11	2 65
NK	—0.24	—0.02	0.39	1.42	0.39
K	1.18	1.19	1.41	1.00	I.20
NK	0.38	0.20	0.53	0.24	0.34
PK	0.89	0.53	0.38	0.34	0.54
NPK	0.58	0.73	0.79	0.57	0.67
S.E.	0.63	0.64	0.37	0.72	0.30

It would be seen from the above table that the responses of paddy to N, P and K were 4.22, 2.65 and 1.20 quintals per hectare respectively with a standard error of 0.30 Q/ha. These are the significant responses, the others being not significant.

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Appendix

Yield data (Q/ha) of 8 plot fertilizer experiments on kharif paddy in cultivators' fields, Muzaffarpur, Bihar, 1958-59.

Block	*Village*	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	*Total*
1	1	19·02	21·21	20·28	23.05	20·52	22·94	21·55	24·67	173·24
	2	16·14	17·28	17·28	21·90	18·44	19·60	18·44	23·05	152·13
	3	20·17	18·44	18·44	21·44	19·02	22·71	24·44	21·55	166·21
	4	15·44	16·59	16·71	18·21	16·02	17·52	16·37	18·56	135·42
Total		70·77	73·52	72·71	84·60	74·00	82·77	80·80	87·83	627·00
2	1	15·98	18·39	17 05	19·05	16 95	19·00	18·05	22·77	147·24
	2	10 26	11·64	11·07	12·10	9·68	9·68	13·28	14·29	92 00
	3	14·29	18·54	17·86	18·86	16·39	17·89	20·86	18·79	143·48
	4	16·14	20·86	20 89	21·01	17·06	20·74	20 63	21·24	158·57
Total		56·67	69·43	66·87	71·02	60 08	67·31	72·82	77·09	541·29
3	1	12·68	17·98	15·68	20·98	14·75	19·82	15·21	23·40	140·50
	2	13·95	19 94	17·29	23·05	15·45	21·44	18 10	26·28	155·50
	3	12·68	17 98	15·68	20·98	14 64	19·82	15·33	23·40	140·51
	4	13·49	19 71	15 21	22·82	14·98	21·44	17·52	25·70	150·87
Total		52·80	75·61	63·86	87 83	59·82	82·52	66·16	98·78	587·38
4	1	12·10	17·87	15·10	19·94	13·14	20·05	16 02	24·44	138 66
	2	13·95	19·94	17·29	23·05	15·33	21·32	18·10	26·17	155·15
	3	14·87	20 63	18·10	23·86	16·37	22.36	19·02	27·20	162·41
	4	15 56	21·55	19·25	24·55	17·06	22·94	19 60	28·12	168 63
Total		56·48	79·99	69·74	91·40	61·90	86·67	72·74	105·93	624·85
G.T.		236 72	298 55	273·18	334·85	255·80	319·27	292·52	369·63	2380·52

Note : T_1—Control (farmers' normal practice) ;
T_2—Application of 22·4 kg/ha of nitrogen ;
T_3—Application of 22·4 kg/ha of phosphorus , (P_2O_5) ;
$T_4-T_2+T_3$;
T_5—Application of 22·4 kg/ha of potash (K_2O) ;
$T_6-T_2+T_5$;
$T_7-T_3+T_5$;
$T_8-T_2+T_3+T_5$;

Appendix (contd.)

Yield data (Q/ha) of 8 plot fertilizer experiments on kharif paddy in cultivators' fields, Muzaffarpur, Bihar 1959-60

Block		*Village*	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	*Total*
1		1	14·52	27·32	17·98	21·67	14·29	20·06	18·56	25·59	159·99
		2	15·91	21·78	19 36	23·86	16·94	21·90	19·83	28·93	168 51
		3	12·45	18·44	16·71	18·67	12·33	18·67	18 33	22·48	138·08
		4	12·79	18·67	16·94	20 40	12·91	19·02	18·21	23 05	141·99
	Total		55·67	86·21	70·99	84·60	56·47	79·65	74·93	100·05	608·57
2		1	11·30	15·21	15·91	17·06	13 02	15·10	14·87	22·13	124·60
		2	10·49	14·06	13·14	16·14	12·45	14·52	14·29	17·87	112·96
		3	11·53	17·87	17·06	18·44	12·68	14·98	16·02	23·28	131·86
		4	7·95	13·37	10·60	15·21	9·45	12·68	11·30	15·91	96·47
	Total		41·27	60·51	56·71	66·85	47·60	57·28	56·48	79·19	465·89
3		1	12·56	17·87	15·56	22·02	14·52	19·71	15·10	23·28	140·62
		2	8·30	14·06	16·14	15·33	9·45	11·99	10 60	18·44	104·31
		3	3·69	10·14	4·61	5·53	4·15	5·53	5·99	11·53	51·17
	Total		24·55	42·07	36·31	42·88	28·12	37·23	31·69	53·25	296·10
4		1	16·14	18·44	17·06	16·60	16·83	17·29	17·06	19·83	139·62
		2	17·52	19·36	18·44	21·67	17·98	20·29	20·06	23·05	158·37
		3	17·06	20 29	20·29	23·05	18·90	21·21	20·98	24·44	166·22
		4	16·14	18·21	17·29	19·36	16·60	18·67	17·98	20·75	145·00
	Total		66·86	76·30	73 08	80·68	70·31	77·46	76·08	88·07	608·84
	G.T.		188·35	265·09	237·09	275·01	202·50	251·62	239·18	320·56	1979·40

Appendix (contd)

Yield data (Q/ha) of 8 plot fertilizer experiments on kharif paddy in cultivators' fields, Muzaffarpur, Bihar, 1960-61

Block		*Village*	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	*Total*
1		1	11·53	17·06	15·45	18·90	12·45	16·02	15·33	21·21	127·95
		2	13·26	18·90	16·37	19·36	13·49	18·44	16·37	23·63	139·82
		3	13·60	19·59	17·64	20 63	14·87	18·79	17·52	16·63	149·27
		4	10·95	17·06	15·10	17 17	10·26	17·87	16·60	22·25	127·26
	Total		49·34	72·61	69·56	76·06	51·07	71·12	€5·82	93·72	544·30
2		1	7·03	11·07	10·49	12·56	8·88	11·53	11·18	14·87	87·61
		2	7·03	9 34	7·61	10·60	7·38	12·22	8 30	14·75	77·23
		3	7·38	7·38	8·76	11·99	8·99	12·91	11·07	16·60	85 08
		4	9·68	12·91	12·45	13·37	10·37	11·06	12·45	15·68	97·97
	Total		31·12	40·70	39·31	48·52	35·62	47·72	43·00	61 90	347 89
3		1	23·98	25·82	26·74	30 43	24·90	27·66	29·51	33·20	222·24
		2	18·44	23·05	22·13	25·82	21·21	23·97	24·90	23·59	188 11
		3	20·29	28·59	23·05	28·59	18·44	27·66	23·98	31·35	201·95
		4	20·29	22·13	23·05	27·66	22·13	26·74	23·98	32·27	198 25
	Total		83·00	99·59	94·97	112·50	86·68	106 03	102·37	125·41	810 55
4		1	4·61	7·38	5·30	5·88	4·84	5·30	5·07	6·22	44·60
		2	5·65	9·68	7·49	8·88	6·45	7·26	7 03	8 07	60·51
	Total		10·26	17·06	12·79	14·76	11·29	12·56	12·10	14·29	105·11
	G.T.		173·92	229·96	211·63	251·34	184·66	237·43	223·29	295·32	1807·55