MANURIAL EXPERIMENTS ON NITROGEN, PHOSPHATE AND POTASH.

(REVIEW)

The General Experiment Station of the A. V. R. O. S. in Sumatra has recently concluded a series of field trials on the Haboko Estate (1) using replicated treatments with a view to obtaining a higher standard of accuracy than is attainable where only one or two plots of each treatment are used. The paper under review gives results of experiments devoted to the effects of nitrogen, phosphoric acid, and potash manuring, an account of the technique employed and the advantages it entails.

The work is of interest from two points of view; firstly, the purely technical side which is of importance to other scientific officers engaged in similar investigations; and secondly, the practical side which appeals to both the experimentalist and the agriculturist. The account which follows deals with both these outlooks, and for the convenience of the non-technical reader they are dealt with separately, the agricultural considerations being dealt with in Part II.

1. METHOD OF EXPERIMENTATION.

The field experimental method used in these trials is put on record as a first attempt to deal with a number of problems, including soil heterogeneity, variation in plucking capacity and interference of climatic conditions, which affect the apparent yields of leaf collected in the field. A typical experiment (H5) may be taken as a basis for discussion. The arrangement of the plots is given on next page. The yield figures over twenty months are given as half-kilogrammes. The treatments are labelled according to the following scheme:—

a = unmanured.

b = nitrogen 30 lb. per acre + phosphoric acid 30 lb. per acre.

c = nitrogen 30 lb. per acre + phosphoric acid 30 lb. per acre + potash 30 lb. per acre.

Each plot received two applications with a year's interval between.

I	II	III	IV	V	VI	Totals
1534 a	1823 c	1453 b	1580 a	1714 c	1659 b	9763
1515 b	1410 a	1375 c	1425 b	1373 a	1331 c	8429
1691 c	1678 b	1441 a	1782 c	1763 b	1415 a	9770
4740	4911	4269	4787	4850	4405	27962

An examination of the design of the experiment shows that each treatment occurs once in each of the columns numbered I-VI and twice in each row. The columns were made the basis of the plucking task so that with different teams of pluckers picking different columns, a difference in plucking capacity between them will not disturb yield comparisons between treatments in the same column. It is an advantage thus to eliminate the possibility of error from variable standards of plucking amongst the coolies though the results of the Nuwara Eliya uniformity trial to be published shortly indicate that under our conditions the variation is not serious. In order to counteract errors arising from the variations in the amount of extraneous moisture adhering to the leaf in wet weather, the columns were plucked in opposite directions alternately. This device is the only palliative available if sampling for dry weight determinations is not adopted. It does not altogether meet the requirements as it cannot allow for rains at various times of day.

It is noticeable that the column totals vary despite their similar treatments; such variation is accordingly caused by soil or bush heterogeneity, and in order to eliminate this type of variation from the calculation of errors, the so-called "Student's" method of comparison was used. This consists of comparing plots within the same columns thus:—

I b - I a
II b - II a
III b - III a

and so on. The error is then calculated from the discrepancies in the resulting figures. This device ensures that differences in columns which do not enter into the treatment comparisons shall not artificially increase the error. A similar variation in fertility is apparent for rows as well as columns, and since each treatment occurs twice in each row a similar method might have been employed there. This possibility has been overlooked, for the paper states: "It is not possible however to eliminate their influence, (*i.e.*, that of fertility gradients) altogether since in this instance differences in yield occur in two directions perpendicular to each other." "Student" himself has pointed out [2] that his method can be extended so as to eliminate fertility gradients in more than one direction and that his solution is more simply and adequately performed by Fisher's analysis of variance [3]. The method consists of taking the row and column totals and using their deviations from the mean total as a measure of their contribution to the total variability of the experimental results as a whole. The analysis for experiment H5 is as follows:—

Variance due to	Sum of Squares of Deviations	Degrees of Freedom (n—1)	Mean Square Deviation.
Treatment	84704	2	42352
Rows	198770	2	99385
Columns	113182	5	22636
Remainder	38943	8	4868
Total	435599	17	

The results show strikingly how much disturbing effect is due to soil heterogeneity in rows and columns. It is particularly noteworthy that the row heterogeniety as measured by the mean square deviation is more serious than that of the columns. The method applied in the original publication thus removed only the lesser of the two evils.

The variance labelled remainder is that from which the standard error is derived and relates to all treatment comparisons. It has the further advantage of being derived from eight degrees of freedom instead of five by the application of "Student's" method. From this remainder variance the appropriate calculated standard error of a difference between two means is 40·3 which for the experiment as a whole represents an increase in accuracy.

The next step in the examination of method is to consider the mean differences in relationship to error. In the following tables the results arrived at by the two methods outlined are set out side by side; errors by "Student's" method are quoted from the original paper:—

Treatment Comparison	Difference	Student		Fisher	
		S. Error	t	S. Error	t
b-a : *Nitrogen/phosphoric acid—unmanured*	123	35·5	3·47	40·3	3·05
c-a : Complete manure—unmanured	160	70·0	2·28	40·3	3·97
c-b : Complete manure—Nitrogen/phosphoric acid	37	65·0	0·57	40·3	0·92

In addition to the actual error value, that of the statistic t is included in order to test the significance of the results; t being

$$\frac{\textit{mean difference}}{\textit{S.E. of mean}}.$$

The value of t that has been largely used in statistical computation as indicating real and significant differences is 2. Since the first two comparisons are claimed to be absolutely reliable on the basis of "Student's" method, this value has evidently been used here. It is not always realised that $t=2$ is an adequate criterion of significance only when the error calculation is based on a large population. As the number of comparisons decreases, the value at which t becomes significant increases. Fisher (*loc. cit.*) publishes tables showing how the significant value of t changes. For the probability that a result would appear significant once in twenty times, when in reality it is due to chance, the following are some of the values:—

(n-1)	4	5	8	10	20	infinity
t	2·776	2·571	2·306	2·228	2·086	1·960

The criterion in this experiment for errors computed by "Student's" method is $t=2{\cdot}571$; for those by Fisher's method $t=2{\cdot}306$. These values throw some doubt on the reliability of gains due to treatment (c) according to the first method, but with the fertility slope interference eliminated in both directions, as in Fisher's method, the superiority of treatment (c) is confirmed. It may be pointed out that a non-significant result for comparison (c-a) gives rise to an anomalous result, since it is unlikely that where nitrogen and phosphoric acid (b) is successful, nitrogen, phosphoric acid and potash (c) should be unsuccessful. The failure of "Student's" method is here due to the trough of low production caused by the middle row. By Fisher's method the results are completely intelligible: both nitrogen plus phosphate and the complete manure give significant increases, but the apparent superiority of the latter is not great enough to be relied upon.

It remains now to consider the practical bearings of the whole of the experiments. In so doing the more accurate criterion of t just mentioned will be applied to the results.

II. PRACTICAL RESULTS.

Table I gives a summary of the results of the five experiments. These have been expressed in pounds per acre fresh leaf for the purpose of this review: reliable results are printed in heavy type. The standard dose for all nutrients is 30 lb. per acre, which in manurial equivalents is equal to 150 lb. of sulphate of ammonia, 164 lb. superphosphate and 60 lb. sulphate of potash. Some treatments involve a double dose of one nutrient.

TABLE I.

Yield increases in lb. per acre fresh leaf for various treatments under varying conditions.

Increase due to	2 applications	2 applications	1 application	Complete followed by treatment	Treatments followed by N and Phos.
	D3	H5	F5	A2	H4
N				657	288
N + Phos.	**1285**	**344**	**316**	536	277
N + 2 Phos.				**670**	486
2N + Phos.				**1038**	
N + Phos + Pot.	**1370**	**447**	**410**		
Potash	288	103·5	95		

Figures in heavy type are statistically reliable

The first three experiments D3, H5, F5, are similar but, whereas D3 and H5 were given two applications of manure at intervals of a year, F5 received only one application five months after the commencement of the experiment. The addition of nitrogen and phosphoric acid in all cases gives a reliable increase. The further addition of potash (making a complete manure) gives an increase over the nitrogen plus phosphate which cannot be considered reliable even when the results of all three experiments are pooled. These experiments give no indication as to whether nitrogen or phosphoric acid or both nutrients are responsible for the increase.

Experiment A2 shows the result of giving different treatments six months after the application of a complete manure. The addition of a single dose of nitrogen after a complete manure gives no reliable increase and the same applies to additions of nitrogen plus phosphate in single doses. The results when double doses of either phosphate or nitrogen in the presence of a single dose of the other is applied show a reliable increase. Such a result is difficult to interpret since the previous comparisons suggest that the preliminary application of a complete manure has met the nutritional requirements for the whole period. The explanation appears to be that the section of the experiment devoted to double doses occupies more uniform land than that assigned to single doses since, in point of fact, the errors are much lower. It is again impossible definitely to decide whether nitrogen or phosphoric acid or both are responsible for the increased yields.

Experiment H4 gives the combined results of various treatments followed six months later by a uniform application of nitrogen and phosphoric acid. The author remarks on the unsatisfactory nature of the experimental ground. An examination of the results on the stricter lines dealt with in Part I indicates that none of the results is reliable.

Considering the series as a whole, it appears that a combination of nitrogen and phosphoric acid gives reliable results when compared with land unmanured, and that further increases of yield probably occur from the use of additions of these two manures six months after a complete dressing. We cannot, however, agree that nitrogen has always given satisfactory results, nor that the increase due to potash is real.

The paper mentions that these experiments followed and were designed on the basis of extensive analyses of the Haboko Estate soils and yields at the Rothamsted Experiment Station. The writer of this review took some part in these investigations, the results of which indicated a correlation between phosphoric acid content in the soil and yield. The experiments here outlined fail to follow up that finding since only one direct test of phosphate is included and this gives negative results. They, however, indicate that the results of soil analyses in the absence of related field experiments must be accepted with reserve.

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REFERENCES.

(1) Kortleve, A.—*Manuring Experiments in Tea Cultivation, Archief v.d. Theecultuur*, 1930, No. 2, 120.

(2) 'Student'—*On Testing Varieties of Cereals, Biometrika* 1923, XV, 271.

(3) Fisher, R. A.—*Statistical Methods for Research Workers*, 3rd Edition, 1930.