STATISTICAL NOTES FOR AGRICULTURAL WORKERS.

NO. 15. ANALYSIS OF ROTATIONAL EXPERIMENTS WITH COTTON, GROUNDNUT, AND *JUAR* IN BERAR, WITH NOTES ON DESIGNS FOR ROTATIONAL EXPERIMENTS.

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(With two text-figures)

INTRODUCTION.

Messrs. D. N. Mahta and D. L. Janoria have described in their paper* on "Groundnut as a Rotation Crop with Cotton in Berar", the important experiments conducted by them during the eight years 1923-31.

The main object of their experiments was to investigate the most economic rotation of crops for cotton in Berar, with groundnut and *juar* as possible subsidiary crops. In order to attain the maximum economic return it is, therefore, necessary to take into consideration the prices as well as the yields of the different crops.

Our object is to make the expected return in money as large as possible (on the average taken over a number of years). The enquiry, therefore, naturally splits up into two portions—one primarily agricultural concerned with the yields, and the other primarily economic concerned with the prices and the cost of cultivation. In this note I have considered only the agricultural aspect of the question.

THE EFFECT OF ROTATION ON ACTUAL YIELDS.

All the different rotations were conducted on separate fields. This has rendered an adequate statistical analysis impossible for the reasons explained below. The factors producing differences in yield in the present experiment may be broadly grouped under four heads :—

(1) Effect of different rotations.

(2) Soil-differences in different fields or different parts of the same field.

(3) Effect of different seasons.

(4) Random fluctuations.

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The object of the present experiment is to study the effect of different rotations on the yield. In order to reach a valid estimate of this effect it is necessary to eliminate the effects due to the other factors.

It is not possible to estimate or eliminate satisfactorily the effect of intrinsic differences in soil-fertility in the absence of random replications of different rotations in the same field. This constitutes an inherent defect of the original design of the present experiment and cannot be got over by any statistical expedient.

If, however, we ignore these intrinsic soil-differences, that is, assume that the average fertility of all the fields were originally more or less equal, we get the following results.

The actual mean yield of cotton (in lbs. per plot of 1/10th acre) for the different rotations are shown in Table I. The standard error of each mean is given in the last column.

Table I.

Mean yield of cotton (in lbs. per plot of 1/10th acre).

Serial number	Rotation	Total number of		Mean yield	Standard error of mean
		Years	Plots		
1	Cotton, groundnut	4	20	64·60	7·295
2	Cotton, *juar*, groundnut	3	15	73·67	4·391
3	Cotton, cotton, *juar*, groundnut	4	18	68·52	9·182
4	Cotton, cotton, *juar*	4	20	47·10	4·855
5	Cotton, *juar*	4	20	37·55	1·705
6	Cotton every year (control A)	8	40	32·75	2·222
7	Cotton, cotton, groundnut	4	20	54·10	5·349
8	Cotton every year (control B)	6	30	37·97	2·715

Rotations 2, 3 and 1 give the highest yields of cotton and do not differ significantly among themselves. Rotations 7 and 4 come next and differ appreciably from Rotation 2 but not from Rotations 3 and 1. Rotations 8, 5 and 6 which give the lowest yields do not differ appreciably among themselves, but differ significantly from Rotations 2, 3, 1 and 7, while Rotation 6 alone differs from Rotation 4.

The mean yields of groundnut for different rotations (with standard errors) are shown in Table II. It will be noticed that Rotation 7 gives an appreciably higher yield than Rotations 1 and 2, and Rotation 3 an appreciably higher yield than Rotation 2, while other differences are statistically insignificant.

TABLE II.

Mean yield of groundnut (pods) (in lbs. per plot of 1/10th acre).

	Rotation	Total number of Years	Total number of Plots	Mean yield	Standard error of mean
1	Cotton, groundnut	4	18	156·55	11·87
2	Cotton, *juar*, groundnut	2	8	139·40	10·82
3	Cotton, cotton, *juar*, groundnut	1	5	195·00	12·14
7	Cotton, cotton, groundnut	2	10	202·30	11·78
	General mean	..	41	172·78	7·226

The mean yeld of *juar* for different rotations (with standard errors) are shown in Table III. None of the differences are significant, and we must conclude that the mean yield of *juar* is not appreciably influenced by the crop rotations used.

TABLE III.

Mean yield of juar *(green) (in lbs. per plot of 1/10th acre).*

	Rotation	Total number of Years	Total number of Plots	Mean yield	Standard error of mean
2	Cotton, *juar*, groundnut	2	10	143·7	9·38
3	Cotton, cotton, *juar*, groundnut	1	5	168·0	11·50
4	Cotton, cotton, *juar*	2	10	144·3	6·23
5	Cotton, *juar*	3	15	156·8	9·88
	General mean	..	40	151·80	4·895

From the above analysis it is clear that for certain rotations the differences in the yield of different crops are inappreciable; for example between 1 and 2, 1 and 3, 1 and 4; 2 and 3; 3 and 4; 3 and 7; 4 and 5, 4 and 7, 4 and 8; 5 and 6, 5 and 8; 6 and 8. In these cases, so far as the yields of crops are concerned, rotational differences cannot be considered as established.

SEASONAL EFFECT.

In the above discussion we have so far neglected the effect of different seasons. This, however, is by no means negligible as can be easily seen from Table IV which gives the mean yield of cotton for different rotations in different years. Standard errors are also given in each case.

TABLE IV.

Mean yield of cotton (in lbs. per plot of 1/10th acre)

Year	1923-24	1924-25	1925-26	1926-27	1927-28	1928-29	1929-30	1930-31
1 Cotton, groundnut	31·8±2·56	G	50·6±6·31	G	75·8±10·99	G	100·2±13·40	G
2 Cotton, *juar*, groundnut.	..	55·4±4·50	*J*	G	90·0±2·85	*J*	G	75·6±4·80
3 Cotton, cotton, *juar*, groundnut	..	..	43·8±3·46	32·3±(3)2·54	*J*	G	122·0±8·44	61·4±4·06
4 Cotton, cotton, *juar*	..	..	33·6±1·17	37·2±5·50	*J*	37·0±3·15	80·6±5·49	*J*
5 Cotton, *juar*	..	37·4±2·84	*J*	39·0±5·50	*J*	42·0±1·22	*J*	31·8±1·32
6 Cotton every year (control A)	23·8±3·47	25·4±3·23	19·0±3·46	22·8±2·76	55·4±4·08	25·2±1·91	43·2±4·67	41·8±2·40
7 Cotton, cotton, groundnut	..	..	41·0±9·90	42·2±12·40	G	90·2±3·35	43·0±16·41	G
8 Cotton every year (control B)	..	..	38·0±3·27	46·6±4·38	77·2±2·97	36·2±1·16	44·2±3·89	46·6±1·50
9 General standard error of a single mean	3·05	3·59	3·99	4·69	6·21	1·93	7·87	3·14

TABLE V.

Seasonal effects (actual yields of cotton)

Rotation	Between years		Within years		Total		Ratio of variances	
	D. F.	Variance	D. F.	Variance	D. F.	Variance	Observed	5 per cent.
1	3	44,41·07	16	4,31·23	19	10,64·36	10·3	3·24
2	2	15,43·80	12	80·14	14	2,89·24	1,92·6	3·89
3	3	71,79·60	14	1,47·05	17	13,87·56	48·8	3·34
4	3	25,40·87	16	83·33	19	4,71·36	30·5	3·24
5	3	85·67	16	51·88	19	58·16	1·65	3·24
6	7	8,42·63	32	56·26	39	1,97·40	14·9	2·39
7	3	28,99·33	16	1,36·0	19	5,72·32	21·3	3·24
8	5	10,52·84	24	52·03	29	2,21·14	20·2	2·62

For any particular rotation, it will be noticed that the yields in different seasons differ significantly. This is brought out still more clearly in Table V, in which the variances due to seasons are shown for each rotation.

It will be noticed that the fluctuations due to the differences in the meteorological conditions in different seasons were very large (often of the order of 20 times or more of the residual variance), and statistically significant in the case of all rotations except No. 5.

The yield of groundnut in the different seasons are shown in Table VI, and the corresponding analysis of variance in Table VII.

TABLE VI.

Mean yield of groundnut

Year	1	2	3	7
	Cotton, groundnut	Cotton, *juar*, groundnut	Cotton, cotton, *juar*, groundnut	Cotton, cotton, groundnut
1924-25	1,59·0	C	—	—
1925-26	C	*J*	C	C
1926-27	99·7	1,19·0	C	C
1927-28	C	C	*J*	2,34·0
1928-29	2,30·0	*J*	1,95·0	C
1929-30	C	1,59·8	C	C
1930-31	1,37·2	C	*J*	1,70·6

TABLE VII.

Analysis of variance : Groundnut

Rotation	Years		Plots		Residual		Total		Ratio of variance	
	D. F.	Variance	D. F.	Variance	D. F.	Variance	D. F.	Variance	Years	Plots
1	3	12,519·33	4	200·75	10	467·80	17	2,531·71	26·76	<1·0
2	1	3,121·00	4	570·50	2	1,146·00	7	936·28	2·72	<1·0
3	—	..	4	737·00	—	—	4	737·00	—	—
7	1	9,581·00	4	513·25	4	213·50	9	1,388·67	44·93	2·40

The seasonal effect is definitely significant in the case of Rotations 1 and 7, inappreciable in the case of Rotation 2, and indeterminate in Rotation 3.

The mean yield of *juar* is given in Table VIII. From a glance at the critical differences given at the bottom it is seen that the seasonal effect is inappreciable.

TABLE VIII.

Mean yield of juar.

Year	2	3	4	5
	Cotton, *juar*, groundnut	Cotton, cotton, *juar*, groundnut	Cotton, cotton, *juar*	Cotton, *juar*
1924-25	C	—	—	C
1925-26	156·6	C	C	191·0
1926-27	G	C	C	C
1927-28	C	168·0	144·0	124·8
1928-29	130·8	G	C	C
1929-30	G	C	C	154·6
1930-31	C	C	144·6	C
S. E. of mean	13·26	—	8·81	17·12

In view of the large magnitude of the seasonal effect for cotton and groundnut, we may compare the yields for different rotations from year to year. But in doing so it is necessary to keep in mind the initial differences in soil fertility

In each of the three basic years, 1923, 1924, and 1925, in which new experiments were started, all the fields were treated uniformly. Had there been no difference in soil fertility, the yields in the same basic year must, therefore, have been appreciably equal. In actual fact, the yields in different fields in the same basic year differed significantly as can be seen from Table IX. The standard error of a single mean (of 5 plots) for each year was calculated from the fluctuations within fields.

TABLE IX.

Mean yield of cotton in basic years.

Years	Rotation								Standard error
	1	2	3	4	5	6	7	8	
1923-24 .	31·8	..	..	..	..	23·6	..	..	3·05
1924-25 .	..	55·4	..	..	37·6	..	..	..	3·59
1925-26 .	..	..	43·8	33·6	..	..	41·0	58·0	3·99

In view of the statistically significant differences in yield for different fields in the same basic year, we must conclude that the intrinsic fertility of the different fields were appreciably different.

COMPARISON WITH CONTROL A (ROTATION 6).

It will be remembered that Rotation 6 (cotton every year) was used as the "control". The differences in the yield of cotton from Rotation 6 are given in Table X. The critical differences were taken as 3 times the corresponding standard errors which were calculated from the fluctuations within fields.

TABLE X.

Differences in yield of cotton from control A (Rotation 6)

Year.	1 Cotton, groundnut	2 Cotton, *juar*, groundnut	3 Cotton, cotton, *juar*, groundnut	4 Cotton, cotton, *juar*	5 Cotton, *juar*	6 Cotton, cotton, groundnut	7 Cotton every year (control B)	Critical difference (3 × S. E.) of single mean
1923-24 .	+8·0	—	—	—	—	—	—	9·15
1924-25 .	G	+30·0	—	—	+12·0	—	—	10·77
1925-26 .	+31·6	*J*	+24·8	+14·6	*J*	+22·0	+19·0	11·97
1926-27 .	G	G	+9·5	+14·4	+16·2	+19·4	+23·8	14·07
1927-28 .	+20·4	+34·6	*J*	*J*	*J*	G	+21·8	18·63
1928-29 .	G	*J*	G	+11·8	+16·8	+65·0	+11·0	5·79
1929-30 .	+57·0	G	+78·8	+37·4	*J*	—0·2	+1·0	23·61
1930-31 .	G	+33·8	+19·6	*J*	—10·0	G	+4·8	9·42

Rotation 1 (Cotton and groundnut alternately). Although the difference in yield in the basic year (1923) is not significant on the 5 per cent. level, the difference (+8, which is over 33 per cent. of the control yield 23·8) is large enough to be suggestive. Ignoring soil differences, the differences in the yields of cotton were definitely significant in later years.

Rotation 2 (Cotton, *juar*, groundnut). The intrinsic difference (+30·0) in the basic year (1924) was very high being 118 per cent. above 'control' (25·4), and was definitely significant. The differences in later years were also all significant. The differences in yield, however, remained practically constant and the same as in the basic year. This naturally suggests that these differences were caused by the initial soil differences (which remained steady during the whole period), and that the effect of the rotation, if any, was completely masked by these overwhelming soil differences.

Rotation 3 (Cotton, cotton, *juar*, groundnut). The initial difference in yield in 1925 was significant, and must be ascribed to intrinsic soil differences. The difference in yield was inappreciable in 1926, but after a crop of *juar* and then a crop of groundnut there was a remarkable recovery in the yield in 1929 which was followed by a decreased yield in a second cotton year in 1930. In view of the large fluctuations in the differences it is, however, difficult to draw any reliable conclusions.

Rotation 4 (Cotton, cotton, *juar*). The differences in yield were throughout significant, and were on the whole fairly steady except in 1929 when there was a much greater yield. In view of the initial soil differences it is, however, difficult to ascribe the gain in yield to any rotational effect.

Rotation 5 (Cotton and *juar* alternately). The differences were statistically significant in 1924, 1926 and 1928, but there was an actual decrease as compared to the 'control' in 1930. In view of the initial difference in yield, and the drop in 1930, it does not appear probable that Rotation 5 possesses any real advantage over Rotation 6.

Rotation 7 (Cotton, cotton, groundnut). In the first two seasons the differences were steady and significant. In 1928, following a groundnut crop, there was a very high yield; but in 1929, in a second cotton season, there was practically no advantage over control A (Rotation 6).

Rotation 8 (Cotton every year). Initially there was a big difference in yield in 1925 which was very definitely significant. The difference, however, decreased steadily in successive seasons, until in 1929 and 1930, Rotations 6 and 8 both had practically the same yield. This suggests a gradually increasing exhaustion of the soil in the field under Rotation 8. It is, however, curious that the first 'control' field A (Rotation 6) does not show any trace of such effect. This would appear to indicate that the 'control' field A under Rotation 6 was initially poor in fertility or was already exhausted, a view which is supported by the fact that this field gave consistently the lowest yields in all three basic years 1924, 1925 and 1926.

Comparison with control B (Rotation 8).

Rotation 8 also consists of cotton every year, and there is no reason why it should not be used as a 'control'. We have already seen that Rotation 6 gave consistently lower yields than Rotation 8 in every year, showing unmistakably the existence of appreciable differences in soil fertility. It will, therefore, be safer to use Rotation 8 in preference to Rotation 6 for purposes of comparison. For comparison with Rotations 3, 4 and 7 one further advantage would be that they all started in the same year as Rotation 8.

The differences in mean yield from Rotation 8 are shown for each year in Table XI. The last column gives the critical difference calculated from the fluctuations within fields for the year as a whole. A more precise value may be obtained when necessary from the standard errors of the rotations concerned given in Table IV.

TABLE XI.

Differences in yield of cotton from control B (Rotation 8).

Year	1	2	3	4	5	6	7	Critical difference 3 × S. E. of single mean
	Cotton, ground-nut	Cotton, *juar*, ground-nut	Cotton, cotton, *juar*, ground-nut	Cotton, cotton, *juar*	Cotton, *juar*	Cotton every year (control A).	Cotton, cotton, ground-nut	
1925-26	+12·6	*J*	+5·8	—4·4	*J*	—19·0	+3·0	11·97
1926-27	G	G	—14·3	—9·4	—7·6	—23·8	+4·4	14·07
1927-28	—1·4	+12·8	*J*	*J*	*J*	—21·8	G	18·63
1928-29	G	*J*	G	+0·8	+3·8	—9·0	+54·0	5·79
1929-30	+56·0	G	+77·8	+36·4	*J*	—1·0	—1·0	23·61
1930-31	G	+29·0	+14·8	*J*	—14·8	—4·8	G	9·42

Rotations 5 and 6 gave lower yields than 8, and need not be considered further. Rotation 4 gave lower or practically the same yield in 3 years and a larger yield in only one season 1929-30; the average difference is not, however, statistically significant. This leaves Rotations 1, 2, 3 and 7.

For Rotation 1, the difference in 1925-26 is +12·6, while the standard error of the difference as calculated directly from the variances for Rotations 1 and 8 is 7·11. This difference cannot, therefore, be considered significant. The difference in 1927-28 is very small (—1·4) and insignificant, but is algebraically in favour of Rotation 8. It will be seen, therefore, that it is the difference in yield in 1929-30 (+56·0) which confers the advantage on Rotation 1. For Rotation 2, on the other hand, the differences in 1927-28 (+12·8 with a S. E. of 4·12) and in 1930-31 (+29·0 with a S. E. of 5·03) are both clearly significant. In the case of Rotation 3 the difference in earlier years, 1925-26, are insignificant (the one in 1926-27 being negative), but the differences in 1929-30 and 1930-31 are definitely significant. For Rotation 7, the differences were negligible in 3 seasons, and significant in only one year, 1928-29.

Comparing the yields in each year for the other rotations we find that all the differences are insignificant except in the season 1929-30 when the yield of Rotation 7 was significantly lower than the yields of Rotations 1 and 3.

Using Rotation 8 as the 'control' and comparing from year to year, we find that Rotation 2 gave consistently better yields in two years, Rotation 3 also gave better results in two years, but had no advantage in two other seasons, while Rotations 1 and 7 gave appreciably better results in one season each, differences in other seasons being statistically negligible. Differences between Rotations 2, 3 and 1 were negligible throughout, while Rotation 7 gave definitely worse results than these in one season only. Owing to the irregular nature of the yield in Rotation 7, it is, however, not possible to draw any reliable conclusions.

The general position may now be summarised. So far as cotton is concerned, if we ignore initial soil differences we find that Rotations 2 and 3 and possibly 1 constitute a group of rotations which all included groundnuts and which gave on the whole larger yields than Rotation 8 (cotton every year), differences within the group (that is among Rotations 2, 3 and 1) being statistically inappreciable. The differences in the case of Rotations 4, 5 and 6 were insignificant, while the small advantage in favour of Rotation 7 cannot be considered clearly established.

Effect of groundnut and *juar*.

It will be noticed that Rotations 2, 3 1 and 7 all include groundnut. The question, therefore, arises whether a crop of groundnut confers any beneficial effect on a successive crop of cotton. I have made an attempt to study this question directly by pooling together the results for the different rotations. The relevant data will be found in Table XII. The standard error of the difference in yield has been calculated in each case from the variances of the rotations concerned.

Table XII.

Mean yields of cotton following groundnuts and cotton.

Year	Following a groundnut crop			Following a cotton crop			Mean difference	Standard error of difference
	Rotations	n	Mean	Rotations	n	Mean		
1925-26	1	5	50·6	6	5	19·0	+31·6	7·20
1927-28	1, 2	10	82·9	6, 8	10	65·8	+17·1	8·79
1928-29	7	5	90·2	6, 8	10	30·7	+59·5	2·18
1929-30	1, 3	10	111·1	4, 6, 8	15	55·6	+55·5	12·15
1930-31	2	5	75·6	3, 6, 8	15	50·0	+25·6	5·59

It will be noticed that the differences in yield were always in favour of a cotton crop succeeding a groundnut crop, and were all statistically significant. The above analysis would appear to indicate that there is a real advantage in using groundnut as a rotation crop with cotton. One reservation is, however, necessary. The data for the yield following a cotton crop are predominantly based on Rotations 6 and 8, and any intrinsic deficiency in soil fertility of the fields under these two rotations would affect the results in favour of groundnut. It is worth while remarking at this stage that we have already found some evidence to show that the field under Rotation 6 was intrinsically poor.

We can in the same way study the effect of *juar* on a succeeding cotton crop. The necessary data are given in Table XIII.

TABLE XIII.

Mean yields of cotton following juar.

Year	Following a *juar* crop			Following a cotton crop			Mean difference	Standard error of difference
	Rotations	*n*	Mean	Rotations	*n*	Mean		
1926-27	5	5	39·00	3, 4, 6, 7, 8	25	36·22	+2·78	7·00
1928-29	4, 5	10	39·00	6, 8	10	30·70	+8·80	2·86
1930-31	5	5	31·80	3, 6, 8	15	49·93	—18·13	3·15
Total .	..	20	37·45		50	39·23	—1·78	4·82

The difference in 1926-27 is inappreciable, that in 1928-29 is +8·80 (with standard error 2·86) in favour of *juar* and on the verge of significance, while the difference in 1930-31 is —18·13 (with standard error 3·15) which is against *juar* and statistically significant. Combining the data for all the three seasons we get a small difference —1·78 (with standard error 4·82) against *juar* which is, however, negligible. We must conclude that *juar* did not exert any appreciable influence on the yield of a succeeding cotton crop.

YIELDS CORRECTED FOR SEASONAL EFFECTS.

We shall now try to eliminate the seasonal effect by constructing some kind of seasonal index numbers of yield. One way of doing this would be to take the mean yield over the whole period for Rotation 6 (cotton every year) as the standard of comparison (=100). The actual yield for Rotation 6 in any particular year can then be expressed as a percentage of the mean yield, and such percentages may be used as seasonal index numbers. The calculated figures are given in column 2 of Table XIV.

TABLE XIV.

Seasonal index numbers for yield of cotton.

Year (1)	Based on Rotation 6 (2)	Based on all rotations (3)
1923-24 . . .	74·2	76·9
1924-25 . . .	79·2	66·8
1925-26 . . .	59·2	77·7
1926-27 . . .	71·1	75·5
1927-28 . . .	172·7	143·4
1928-29 . . .	78·6	95·1
1929-30 . . .	134·7	148·9
1930-31 . . .	130·3	106·0

Instead of using the results for Rotation 6 only, we can use the mean yield for all rotations for the whole period as the standard (=100), and construct the seasonal index numbers from the mean yield of all rotations for different years. These figures are given in column 3 of Table XIV. It will be seen that the two series are roughly parallel, although there are considerable differences in particular years. We have actually used the mean index numbers based on all rotations (col. 3, Table XIV). In order to eliminate the seasonal effect we must divide the yields of all fields in any particular year by the corresponding seasonal index number, or multiply by its reciprocal.

We have already seen that Rotations 1, 2 and 3 are more important than Rotations 4, 5 or 7 so far as the yield of cotton is concerned. The mean yield of cotton corrected for the seasonal effect for these three rotations and for the two 'controls' 6 and 8 are given in Table XV.

TABLE XV.

Mean yields of cotton corrected for seasonal effect (in lbs. per 1/10th acre).

Year	1923-24	1924-25	1925-26	1926-27	1927-28	1928-29	1929-30	1930-31	Mean
1. Cotton, groundnut.	41·3±3·32	G	65·1±8·13	G	52·9±7·66	G	67·3±8·95	G	56·65±4·20
2. Cotton, *juar*, groundnut.	..	82·8±6·84	*J*	G	63·0±2·02	*J*	G	71·2±4·59	72·33±3·40
3. Cotton, cotton, *juar*, groundnut.	..	..	56·4±4·47	42·7±4·06	*J*	G	81·8±5·57	57·8±3·87	61·56±3·84
6. Cotton every year (control A).	31·2±4·50	37·8±4·80	24·4±4·39	30·0±3·62	38·8±1·88	26·4±2·01	29·0±3·13	38·4±2·16	32·33±1·44
8. Cotton every year (control B).	..	..	49·0±4·36	61·8±5·97	53·0±2·12	38·2±1·16	29·8±2·65	43·8±1·36	45·93±2·29

The corresponding analysis of variance is given in Table XVI.

TABLE XVI.

Analysis of Variance : yields of cotton corrected for seasonal effect.

Rotation	Between years		Within years		Total		Ratio of variance	
	D. F.	Variance	D. F.	Variance	D. F.	Variance	Observed	5 per cent.
1	3	722·08	16	273·03	19	341·30	2·64	3·24
2	2	494·90	12	119·80	14	173·40	4·13	3·89
3	3	1107·65	14	101·25	17	278·85	10·94	3·34
6	7	169·43	32	64·19	39	83·08	2·64	2·39
8	5	635·80	24	58·13	29	157·72	10·90	2·62

Comparing the ratio of variance given in Table V (actual yields) and Table XVI (yields corrected for seasonal effect), we notice the substantial reduction in the fluctuations due to seasonal effects for Rotations 2, 3 and 6, while for Rotation 1 it has become insignificant. With the help of the seasonal index numbers we have, therefore, succeeded in getting rid of the greater part of the seasonal differences in yield.

The superiority of Rotations 2, 3 and 1 over 6 remains definitely significant. Rotations 2 and 3 also give appreciably larger yields than Rotation 8, but the difference between Rotations 1 and 8 is only just on the verge of significance. The position of 1 is thus rendered slightly doubtful. The difference in yield between the two 'controls' 6 and 8 is seen to be definitely significant. This result confirms the existence of intrinsic differences in soil fertility.

FERTILITY INDEX.

We may study the effect of rotation from a different point of view. One rotation may be considered superior or inferior to another according as it succeeds in improving (or maintaining unimpaired) the fertility of the soil, or leads to soil deterioration as compared to the other. In order to study this effect, we may construct fertility indices by dividing the yield in the same field in different years by the yield in the basic year. Unfortunately owing to rotations having been started in different years in the present series of experiments, the basic year will differ for different rotations. This cannot, however, be helped.

The fertility indices for actual yields of cotton for Rotations 1, 2, 3, 6 and 8 with their standard errors are shown in Table XVII, and the analysis of variance in Table XVIII.

TABLE XVII.

Fertility indices for cotton (actual yields).

Year	1923-24	1924-25	1925-26	1926-27	1927-28	1928-29	1929-30	1930-31	Average
1. Cotton, groundnut	—	—	166·6±27·13	G	239·4±17·06	G	330·4±57·70	G	245·5±31·4
2. Cotton, *juar*, groundnut.	—	—	J	G	169·8±22·50	J	G	143·8±23·00	156·8±15·78
3. Cotton, cotton, *juar*, groundnut.	—	—	—	83·0±5·29	J	G	279·8±10·73	141·8±17·98	181·3±24·58
6. Cotton every year (control A).	—	113·2±18·53	78·8±6·69	105·2±21·51	250·2±34·93	111·2±10·52	185·8±8·76	198·2±22·69	147·5±11·87
8. Cotton every year (control B).	—	—	—	126·0±14·11	204·8±12·96	98·2±8·49	114·6±14·83	120·8±12·77	144·08±9·20

TABLE XVIII.

Analysis of Variance : fertility of indices for cotton (actual yields).

Rotation	Between years		Within years		Total		Ratio of variance	
	D. F.	Variance	D. F.	Variance	D. F.	Variance	Observed	5 per cent.
1	2	33675·05	12	11650·30	14	14795·93	2·88	3·89
2	1	1690·0	8	2591·0	9	2491·0	<1·0	··
3	2	42650·0	10	893·8	12	7853·3	47·4	4·10
6	6	18894·8	28	1928·6	34	4934·5	9·80	2·45
8	4	8583·0	20	824·2	24	2117·33	10·4	2·87

In the case of Rotation 1 there is an apparent increase in the fertility index from year to year, while the indices vary irregularly in other cases.

It will be noticed from Table XVIII that the seasonal effect is very pronounced, and some of the irregularities must be ascribed to this factor. It will, therefore, be desirable to work with the yields corrected for the seasonal effect. Doing this we obtain the fertility indices (corrected for the seasonal factor) given in Table XIX, and the corresponding analysis of variance given in Table XX.

TABLE XIX.

Fertility indices for cotton (yields corrected for seasonal effect).

Year	1924-25	1925-26	1926-27	1927-28	1928-29	1929-30	1930-31	Average
1. Cotton, groundnut	G	164·4±26·72	G	135·0±25·69	G	170·6±30·00	G	156·67±15·36
2. Cotton, *juar*, groundnut	—	*J*	G	79·6±10·71	*J*	G	90·8±14·63	85·2±8·74
3. Cotton, cotton, *juar*	—	—	85·0±9·85	—	G	146·6±7·25	107·8±17·16	117·5±9·81
6. Cotton every year (control A).	128·0±20·94	77·4±6·48	105·6±21·31	133·4±18·44	88·6±8·48	94·8±4·70	135·0±15·99	109·03±6·40
8. Cotton every year (control B).	—	—	129·8±15·68	110·4±7·10	80·4±7·39	62·2±5·95	92·8±9·39	95·12±6·22

TABLE XX.

Analysis of Variance for Fertility Indices for Cotton (yields corrected for seasonal effect).

Rotation	Between years		Within years		Total		Ratio of variance	
	D. F.	Variance	D. F.	Variance	D. F.	Variance	Observed	5 per cent.
1	2	1809·0	12	3791·2	14	3508·0	<1·0	..
2	1	313·6	8	821·0	9	764·62	<1·0	..
3	2	3937·0	10	713·0	12	1250·33	5·52	4·10
6	6	2716·9	28	1159·88	34	1434·6	2·35	2·45
8	4	3427·25	20	474·85	24	966·96	7·22	2·87

It will be noticed from Table XX that for Rotations 1, 2 and 6 the seasonal differences are no longer significant. In the case of Rotation 3 also it is so much reduced that the observed ratio of variances (5·52) is not much greater than the just appreciable (5 per cent.) ratio (4·10). The only exception is Rotation 8, for which the seasonal variation is definitely significant.

In Rotation 1 the corrected indices do not confirm the progressive improvement in fertility shown by the raw indices. The results with the raw indices must therefore be ascribed to the seasonal effect. Rotation 2 shows a lowered index of fertility (85·2) while Rotation 3 shows a small improvement (117·5), but neither of these effects are definitely significant.

'Control' Rotation 6 (cotton every year) also shows a small improvement (109·0) on the whole, which, however, is quite negligible in comparison with its standard error. It is clear, however, that Rotation 6 does not show any progressive lose of fertility. Control' Rotation 8 (cotton every year), on the other hand, shows unmistakable evidence of progressive soil deterioration. In fact with the exception of the year 1930-31, there is a steady decline in the fertility index (129·8, 110·4, 80·4 and 62·2) in successive years. As I have already remarked, this is also the one single case in which the seasonal effect is very definitely significant. The progressive deterioration of soil fertility in the case of Rotation 8 is thus clearly brought out.

SUMMARY OF ANALYSIS.

We may now summarise the results of the statistical analysis. The soil fertility levels of the different fields under different rotations were probably not equal.

Seasonal effects were also very strong, and masked the rotational effects in most cases. In control B (Rotation 8, cotton every year) there was distinct evidence of progressive exhaustion of the soil under successive crops of cotton. Such exhaustion was, however, not noticed in control A (Rotation 6, cotton every year), and this was probably due to the originally poor character of the field. Ignoring initial soil differences, Rotations 2 (cotton, *juar*, groundnut), 3 (cotton, cotton, *juar*, groundnut), and possibly 1 (cotton, groundnut) on the whole gave larger yields of cotton.

An attempt was made to eliminate the effect of seasons and of initial differences in soil fertility by constructing correcting indices. The corrected yields failed to show significant differences between the rotations, but brought out the progressive deterioration of the field under successive cotton crops in Rotation 8. The method of using correcting indices is, however, purely empirical in character, and the results cannot be considered conclusive.

Comparing the pooled results for different rotations it was found that the yields were always in favour of a cotton crop succeeding a crop of groundnut but not of *juar*. The balance of evidence is thus distinctly in favour of the view that a crop of groundnut (but not of *juar*) exerts a beneficial influence on a succeeding crop of cotton. This fact, however, cannot be established with scientific precision owing to defective planning of the experiments.

Plot design for rotational experiments.

In view of the importance of the question, a few suggestions are made on the design of rotation experiments. In order to reach valid results in rotational experiments, the plots must be arranged in such a way that it would be possible to eliminate (*a*) the soil differences, as well as (*b*) the effect of different seasons. A Latin Square (or Randomised Block) arrangement is essential for (*a*), while a complete cycle of years is necessary for (*b*). Finally (*c*) there must be a sufficient number of replications in order to attain the desired degree of precision.

A concrete illustration may make clear the principles involved in the construction of such designs. Let us consider the following 5 rotations :—

Rotation 1 : Cotton every year (C, C, C, C, C, C,..........................)

Rotation 2 : Cotton, groundnut alternately (C, G, C, G, C, G, C).

Rotation 3 : Cotton, *juar* alternately (C, *J*, C, *J*, C, *J*, C, *J*, C).

Rotation 4 : Cotton, groundnut, *juar* (C, G, *J*, C, G, *J*, C, G, *J*).

Rotation 5 : Cotton, *juar*, groundnut (C, *J*, G, C, J, G, C, *J*, G).

The rotation schemes for 6 years are shown in Fig. 1. In the seventh year all the plots will again receive cotton.

Rotations	Seasons						
	1	2	3	4	5	6	7
1	C	O	C	C	C	C	C
2	C	G	C	G	C	G	C
3	C	*J*	C	*J*	O	*J*	C
4	C	G	*J*	C	G	*J*	C
5	C	*J*	G	C	*J*	G	C

C = Cotton

G = Groundnut

J = *Juar*

1st Year

All cotton

2nd Year

J	G	C	G	*J*
C	*J*	G	*J*	G
G	C	G	*J*	*J*
G	*J*	*J*	C	G
J	C	*J*	G	C

3rd Year

C	*J*	C	C	G
C	G	*J*	C	C
J	C	C	G	C
C	C	G	C	*J*
G	C	C	*J*	C

4th Year

J	C	C	G	C
C	C	C	*J*	G
C	C	G	C	*J*
G	*J*	C	C	C
C	G	*J*	C	C

5th Year

C	G	C	C	*J*
C	*J*	G	C	C
G	C	C	*J*	C
C	C	*J*	C	G
J	C	C	G	C

6th Year

J	*J*	C	G	G
C	G	*J*	*J*	G
J	C	G	G	*J*
G	*J*	G	C	*J*
G	G	*J*	*J*	C

Fig. 1. A scheme for a six-year rotation experiment.

The accumulated effect of the rotations will be ready for analysis after the seventh year of the experiment. It will, however, be desirable to conduct the experiment over two (or more) complete cycles; with the present design, 13 years will be the desirable minimum period. The precision of the experiment can be considerably increased if two or more Latin Squares are laid out for the experiment with different random arrangements of the plots (but with the same sequence of rotations).

When possible an attempt may also be made to balance the seasonal effects by using a suitable number of Latin Squares simultaneously. Consider the following four rotations:—

(1) Cotton every year (C, C, C, C).

(2) Cotton, *juar* alternately (C, *J*, C, *J*, C).

(3) Cotton groundnut alternately (C, G, C, G, C).

(4) Cotton, *juar*, *juar*, groundnut (C, *J*, *J*, G, C).

It will be noticed that one whole cycle will be completed in four years. We may, therefore, use simultaneously four separate Latin Squares (each divided into 4×4 plots), each phase of the cycle being represented by one Latin Square. One set of randomized lay-out constructed by Mr. Subhendu Sekhar Bose of the Statistical Laboratory, Presidency College, Calcutta, is given in Fig. 2. It is possible, of course, to construct designs of the same type for other rotations, and we are prepared to supply suitable designs on receipt of detailed specifications.

Rotation	Seasons				
	1	2	3	4	5
1	C	C	C	C	C
2	C	*J*	C	*J*	C
3	C	G	C	G	C
4	C	*J*	*J*	G	C

C = Cotton

G = Groundnut

J = *Juar*

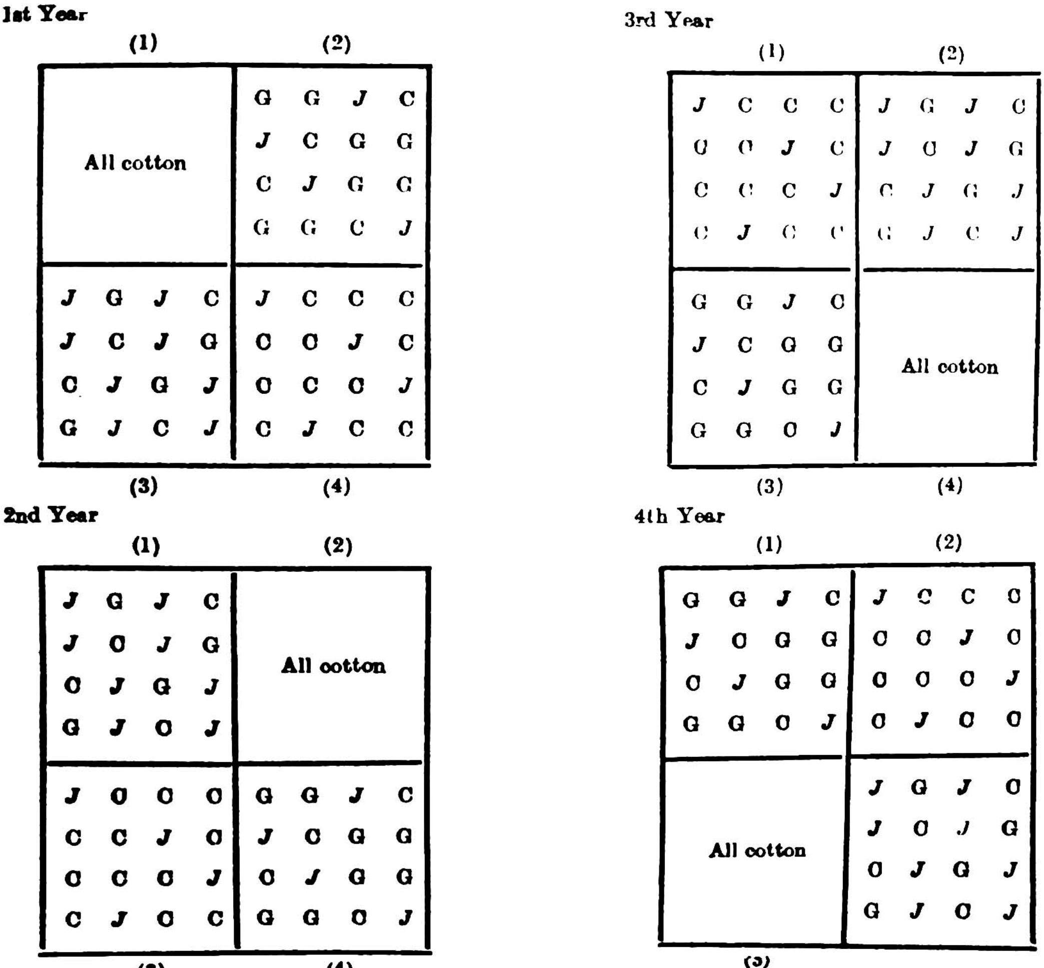

Fig. 2. A scheme for a four-year rotation experiment.