STUDIES IN CROP VARIATION.

IV. THE EXPERIMENTAL DETERMINATION OF THE VALUE OF TOP DRESSINGS WITH CEREALS.

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(With One Text-figure.)

I. Introduction.

The practice of applying nitrogenous fertilisers to cereal crops as a top dressing is one which has become firmly incorporated into normal farm routine.

The classic wheat experiment on Broadbalk field shows that to apply all the nitrogenous fertiliser at the time of drilling the seed in autumn leads to a diminution in crop when compared with the yield of a plot in which only a quarter of the nitrogenous fertiliser was applied in autumn.

Over the 49-year period 1878–1926, during which time the treatments of the plots have been uniform, the average yields are as follows:

Plot No.	Autumn dressing lb. of N.	Spring dressing lb. of N.	Average total grain in lb. per acre	Differences
15	86·0	—	1647	
7	21·5	64·5	1894	247
6	21·5	21·5	1313	581

The loss of crop due to corresponding loss in nitrogen leached out of the soil by winter rains is serious in spite of the fact that the 86 lb. of nitrogen applied gives a substantial margin over the quantity required by the plant to support a 1900 lb. crop (about 50 lb.). Comparison with plot 6 shows that the added single dressing of 43 lb. nitrogen on plot 7 gives an increase of 581 lb. of grain in this region of crop yield, so that the loss in yield due to autumn application of 64½ lb. of nitrogen amounts to approximately 16 lb. of nitrogen (28 per cent.) lost before the time of spring dressing. The 40 lb. per acre of nitrogen lost annually during the early years of the drainage experiment from the uncropped 1/1000 acre drain gauge suggest that the gross loss is possibly much heavier. Whilst therefore a spring application of nitrogen in some form is undoubtedly the most beneficial, there remains the important point as to whether the time of that application can be determined within

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reasonable limits in order to ensure the production of something approaching a maximum crop. The following field experiment was designed to investigate this point, and the detailed description which follows is published not as a solution of the problem but as showing what is hoped will prove a fruitful method of tackling such a question. An attempt has been made to view the problem as a whole and to put the investigation on a broad basis. The design of the experiment, instead of being only a matter of secondary importance, as has often been the case in field experiments, is in this instance paramount and has been determined by a detailed consideration of the nature of the problem, the accuracy deemed necessary, and the practical difficulties which had either to be allowed for or overcome. Such a contribution in the sphere of field experimental technique will, it is considered, be better presented in the form of a description of the experiment as a step in a specific experimental programme rather than as an abstract example of method.

II. PLAN OF EXPERIMENT.

1. *General.*

The site of the experiment was one of the typical "clay loam with flint" fields common in the district, and at the time was considered to be deficient in organic matter. The experimental crop was oats (Grey Winter) which marked the end of a long rotation of corn broken only once with a clover ley. The previous history of the field is shown below in tabular form.

Year	Crop	Type of manuring
1920–1	Potatoes	Dung and artificials
1921–2	Wheat	None
1922–3	Barley undersown	,,
1923–4	Clover	Basic slag and potash
1924–5	Wheat	Complete artificials

The seeding took place under favourable conditions and germination was fairly rapid. The crop was tillering before the winter set in and stood the winter well, showing a strong plant when the plot site was chosen on February 20, 1926. The whole field had been dressed with a mixture of artificial manures, of which the composition per acre was: sulphate of ammonia, ½ cwt.; superphosphate, 2 cwt.; muriate of potash, 1 cwt. Throughout the period of growth the plant suffered no check, but wind and rain in mid-July laid the crop badly. By cutting before the crop was too ripe the plots were cleanly harvested, and this operation probably did not contribute to the experimental error more than is normally the case. The order of lodging of the plots was on the whole definitely marked, the later and the heavy dressings of nitrogen starting first; those not receiving nitrogen were clearly less damaged.

The dates of operations and stages of development were as follows:

Operation or stage of development	Date
Sowing	October 9 and 10
Rows visible	November 15
50 % tillering (early dressing applied)...	March 15 and 16
Maximum shoots (late dressing applied)	June 5
Cut	July 28–August 7
Carted	August 17 and 18
Threshed	January 1927

2. *Experimental scheme.*

In planning this experiment, allowance had to be made for the fact that it was proposed to carry out similar trials in subsequent years, and consequently some convention with regard to the two dates of top dressing (designated for convenience "Early" and "Late") had to be arranged. A calendar basis would obviously be unsatisfactory, but if definite stages in the life cycle of the crop could be used, a measure of comparability could be assured. The two stages chosen were firstly the recommencement of growth in the spring as shown by the production of tillers, and secondly the time of maximum tiller development. The first stage ensures that the nitrogenous fertiliser can actually be used by the plant, and is not lost as leached nitrate at a time when the soil temperature is too low for plant growth; the second coincides within limits with the beginning of rapid development of the grain. Periodical counts of the number of shoots per metre row were made throughout the season on the basis of three random rows per plot. For the purpose of ascertaining maximum shoot number these were frequent but not extensive.

Attention was not confined either to one moderate application or to one form of nitrogen, there being applications 1 and 2 cwt. per acre of sulphate of ammonia and dressings equivalent in nitrogen (94·5 lb. and 189 lb.) of muriate of ammonia.

By confining the experiment to one quantity and to one kind of nitrogen only, a greater number of replicates could have been afforded in the space and with the labour available, but the circumstances would have been too special to have had much value, and nothing would have been known regarding the possible differential behaviour with respect to time of application of the two quantities of the two types of nitrogen.

Moreover, it is one of the advantages of the experimental method to be described that in carrying out such a comprehensive or survey experiment not only is extra information obtainable but the reduction in pure replications which it involves does not (within definable limits) reduce the accuracy of the experiment. This follows from the fact that in a systematically designed experiment every plot is of use in making every possible comparison, and the whole number of plots is available

	2 M EARLY	2 S LATE		2 S LATE			1 S EARLY
1 S EARLY	1 M EARLY	1 M LATE	1 S LATE	2 M EARLY	2 M LATE	1 M EARLY	1 M LATE
	2 M LATE		2 S EARLY		1 S LATE		2 S EARLY
2 S EARLY	2 M EARLY		1 M LATE		2 S EARLY	2 S LATE	2 M LATE
	1 S LATE	1 S EARLY	1 M EARLY	1 M LATE			1 S LATE
2 M LATE		2 S LATE		2 M EARLY		1 M EARLY	1 S EARLY
2 S EARLY	2 M LATE	1 S EARLY	2 M EARLY	2 S LATE	2 S EARLY	2 M EARLY	
		1 M LATE		1 M EARLY	2 M LATE		1 M LATE
2 S LATE	1 M EARLY		1 S LATE			1 S EARLY	1 S LATE
2 M EARLY	1 M EARLY	2 M LATE	2 S LATE	1 S EARLY			1 S LATE
1 S LATE			1 M LATE	1 M EARLY	2 S EARLY	2 M LATE	
1 S EARLY		2 S EARLY			2 M EARLY	2 S LATE	1 M LATE

Fig. 1. A complex experiment with winter oats. (Reproduced from the *Journal of the Ministry of Agriculture* by permission of the Controller of H.M. Stationery Office.)

for the estimation of the error applicable to any group of them. An amplification of this and subsequent points is given in the section devoted to the analysis of the data and method.

One of the largest contributory causes of error in field trials is the unavoidable heterogeneity of the soil. By special arrangement much of this disturbing element can be eliminated from the estimates both of the average yields and of the errors to which they are subject. In the particular case under consideration disturbance was further added to by the fact that it was found necessary to superimpose the 1/40 acre plots of which the experiment consisted on a series of 1/15 acre plots in the clover shift which had been heavily dressed with varying quantities of markedly different basic slags. For this reason instead of a fourfold replication an eightfold one was used. The results are thus a unique test of the success of the method in eliminating any heterogeneity of this kind.

Fig. 1 shows in diagrammatic form the lay-out of the experiment. The dimensions are not to scale. The following points are noteworthy and form the essence of the lay-out.

1. The 96 plots are grouped into eight blocks resembling window panes and within each block each treatment occurs once. The fact that there are four no-nitrogen plots in each block is due to a special reason.

2. Within each block the arrangement is arrived at by the process of drawing lots.

3. The dimensions of the blocks are arranged so as to make them as compact as possible. The correlation between fertility of adjacent sections of a field is high, and in this way the comparability of plots within a block is maintained at as high a level as possible. In this case the dimensions were 175 × 197 links, including paths (5 links) passing between all adjacent plots.

It has been generally recognised that the introduction of replication into agricultural experiments has made possible a greatly increased accuracy, and that such increased accuracy was urgently required if the results of experimental trials were to carry any weight in guiding farm practice. It has been realised much more slowly how very great is the increased precision required for the solution of practical problems; this conclusion has been forced upon workers both in variety and manurial trials by a realisation that the advantages of improved farming, while enormous in their effects upon the general revenue of the agricultural community, and large in relation to the economic return for the individual farmer's skill, are yet small when expressed as a percentage of the gross yield of the crop. In applying a manure the farmer is concerned not merely with the increased selling value of his crop, which may easily be brought up by 10 or 20 per cent., but with the balance left after the increased cost of growing it has been allowed for; and in this balance an advantage or loss of 5 per cent. represents a very considerable item. It is probable, therefore, that the advantages of direct experimentation in the field will not be fully open to exploitation for the benefit of agriculture, until it becomes possible to carry out field experiments with confidence that the standard error of the values obtained will not much exceed 1 per cent.

The main advance in recent agronomic progress has been due to increased replication; nevertheless it is evident that many replicated experiments have yielded very disappointing results. This is partly due to an insufficient realisation of the extent to which replication may with advantage be practised, but in large part also to the fact that the satisfactory design of replicated experiments involves other considerations, practical and theoretical, to which adequate attention has very seldom been paid. These may be considered under three heads: (i) the geometrical arrangements of the plots in the field, so as to minimise the errors due to soil heterogeneity, (ii) the systematic choice of the combinations of treatments to be studied, so that every plot yield may be available to throw light upon every question which it is desired to answer, (iii) the provision by the field arrangement of a valid system for the estimation of the standard error of the results, or of the precision to be attached to them. These considerations may be illustrated by the discussion of the top-dressing experiment under consideration; in this discussion we must seek for the reasons, in so far as such reasons can be assigned *a priori*, for the exceptionally high precision actually attained.

To obtain the maximum precision in the comparison to be made between sulphate and muriate it is important that corresponding to every plot receiving sulphate there shall be a plot, similarly treated in respect of quantity and time of application, in which the sulphate is replaced by muriate. Similar considerations apply to the comparison of early with late application, and to the comparison of single with double quantity. These requirements are satisfied by making up the manurial treatments in all possible combinations, a system which has the additional advantage that any interaction which may exist between the effects of the three different factors upon yield may also be detected with the same precision. Thus, in testing whether the differential effect due to the second dose is greater with the sulphate than with the muriate, or whether it is greater in the early than in the late application, our comparisons will be based upon the means of 32 plots, corresponding each to each in other particulars. The remaining two-factor action, representing the comparison between sulphate and muriate in the advantage, if any, of early dressing, and the three-factor action, representing the comparison of this effect in the single and the double quantities, may be made likewise with a precision appropriate to the comparison of the means of 32 plots. In order that the same accuracy may apply to the comparison between the plots receiving none, with the plots receiving one and two doses, the former must also be given 32 plots, making a total of 96. Every plot is therefore made to add to the precision of the conclusions on every point examined; regarded as an experiment of 12 treatments in eightfold replication, comparisons should be available on all different questions, but since there is no agricultural distinction to be drawn between the sets of 4 plots receiving no top dressing, the number of agriculturally relevant questions to be answered is reduced to 8; it is an important point in the system of combinations employed that each of these 8 questions will be answered with a precision appropriate to the means of 32 plots. The experiment thus gains in efficiency not merely from its size, but also from its complexity.

A further advantage of combining several factors in the same experiment lies in the circumstance that the action of each factor is examined not merely in one particular set of circumstances, but in four different sets. The conclusions to be drawn as to the action of each factor are thus given a wider inductive basis than would be the case with a single factor experiment of equal precision. This advantage may be summarised by saying that an experiment of this type combines the advantages of wide exploration with those of precision.

The geometrical arrangement of the plots with a view to the elimination of as much as possible of the variance in fertility of the area used, is a most important consideration, to which many writers have paid attention. The problem of the reduction of error by skilful arrangement is found, however, to be intimately involved in the problem of obtaining from the results a valid estimate of the errors remaining. The statistical procedure known as the analysis of variance brings to light the fact that of different experiments represented by assigning the same physical plots of land differently to the chosen treatments, and using the same statistical procedure for the estimation of error, those experiments which are in reality the most accurate will appear to be least so, and *vice versa*. Because each element of field heterogeneity must produce its effect either in the real errors, or in the differences between replicates upon which the estimate of error is based. The experimenter, therefore, who wishes to decrease his real errors, and at the same time obtain a valid estimate of them, will be obliged to make his methods of statistical estimation conform to the field situation, a precaution obviously necessary on theoretical grounds, which has been very greatly overlooked. In practice we can in fact eliminate in the field the important elements of soil heterogeneity represented by the differences between whole blocks of plots, by the simple method of putting one replicate of each treatment into each block. The differences between the blocks as wholes is thus completely eliminated from the comparisons between treatments, and a parallel elimination can be made (Fisher, 1925, p. 224) in the estimation of error. The errors which remain to disturb our comparisons are those due to fertility differences between plots of the same block, and in order that these may be estimated with validity the only adequate precaution is to arrange the different treatments in the same block wholly at random.

The experiment, then, is of the general type known as "randomised blocks," there being in this case eight blocks, each containing 12 plots, the treatments of which are assigned by pure chance. The coherence between field arrangement and laboratory calculations, to the necessity of which attention has been called above, may be followed in the next section.

III. Yields and Analysis.

For calculations the yields of grain and straw are best set out as in the following table, wherein to avoid superfluous decimal places the grain yields are given in eighths and the straw yields in halves of a pound, these being the units of weighing.

The marginal totals show at once that, while there are considerable differences in the fertility of the eight blocks of land used, the difference between the treatments is very small, especially in the yield of grain, of an order which could only be detected in a very precise experiment. The arithmetical analysis will be designed to separate the components of the observed variation due to the different blocks of land, due to each item in the differences in the treatments, and due to the residual errors by which the results obtained are effected.

A simple preliminary, which serves both to guide and to interpret the calculations based on the yields, is to partition off the total number of degrees of freedom available into parts representing the different causes of variation, the effects of which can be separately evaluated. The total of 96 plots will yield 95 independent comparisons, and these 95 degrees of freedom would have been partitioned, had 12 different treatments been used, into

7 differences between different blocks of land,
11 differences between different treatments,
77 differential responses to treatments in different blocks.
95

Owing to the identity of the treatment of the four plots receiving no top dressing in each block, we have in fact only eight different treatments, and only 56 degrees of freedom representing differential response; the remaining 24 degrees of freedom represent the differences among the undressed plots on each block, each block yielding three such comparisons. The partition required is therefore

7 differences between different blocks of land,
8 differences between different treatments,
24 differences between plots similarly treated in the same block,
56 differential responses to treatments in different blocks.
95

Table I. *Grain.*

Block treatment	I	II	III	IV	V	VI	VII	VIII	Total
0	491	634	604	732	629	677	551	650	4968
0	524	668	599	690	632	676	636	644	5069
0	545	666	502	710	671	703	506	717	5020
0	577	679	689	660	622	637	670	678	5212
1 *SE*	620	646	681	644	706	615	552	726	5190
1 *SL*	644	745	542	711	705	637	543	646	5173
1 *ME*	523	713	686	688	692	612	635	748	5297
1 *ML*	601	693	685	714	699	697	701	746	5536
2 *SE*	664	693	666	516	656	663	657	683	5198
2 *SL*	514	637	697	710	633	595	697	712	5195
2 *ME*	550	708	663	673	671	626	655	671	5217
2 *ML*	521	661	594	730	625	644	745	747	5267
Total	6774	8143	7608	8178	7941	7782	7548	8368	62342

Table II. *Straw.*

Block treatment	I	II	III	IV	V	VI	VII	VIII	Total
0	166	244	204	299	220	288	201	252	1874
0	192	281	208	288	231	291	226	257	1974
0	187	243	198	310	267	243	181	314	1943
0	197	333	276	279	226	273	281	244	2109
1 *SE*	242	321	261	317	255	381	216	295	2238
1 *SL*	267	382	201	316	280	285	200	309	2240
1 *ME*	215	330	298	381	300	294	256	284	2358
1 *ML*	212	292	265	255	238	309	283	324	2178
2 *SE*	322	370	284	323	232	393	351	363	2638
2 *SL*	200	261	259	361	234	258	306	376	2255
2 *ME*	260	318	266	340	362	400	276	385	2607
2 *ML*	203	275	207	331	229	266	276	328	2115
Total	2663	3650	2927	3800	3074	3631	3053	3731	26529

The variation in yield both of grain and straw will be analysed into corresponding portions by a similar partition of the sums of squares of the deviations from the general mean. Equally the co-variation of grain with straw may be analysed by partitioning the sums of the products of the deviations. The large groups of 24 and 56 degrees of freedom represent residual errors not eliminated by the method of experimentation, and therefore provide estimates of corresponding weight of the errors to which our results are subject. The 24 refer only to the error variation of the undressed plots, while the 56 are principally affected by the plots receiving some kind of top-dressing.

The sum of the squares of the deviations of the block totals from their mean provides a measure of the differences between blocks; this will be divided by 12, the number of plots in the block, and by a further factor to reduce to a basis of pounds per plot, namely 64 for grain, 4 for straw, and 16 for the product. The results are shown as the first line of Table IV.

The eight degrees of freedom representing manurial response may, with advantage, be treated individually; thus, taking for example the contrast of Late versus Early application, we find the 32 plots dressed late yielded 269 more units of grain and 1053 units less of straw than the 32 plots dressed early. The squares and products of these differences divided by 64, the number of plots in the comparison, and by the further factors necessary to reduce to pounds of produce, give the corresponding contribution of the one degree of freedom for "time of application" to the total of the eight degrees for manurial treatments in Table IV. In dealing with quantity the same method may be employed for the contrast of double versus single dressings, but if so the remaining contrast of no dressing versus the mean of the single and double dressings requires a divisor of 48 instead of 64, since on taking the mean we have somewhat diminished the sampling errors. The sum of these two contributors may be equally and symmetrically obtained from the deviations of the three totals each of 32 plots from the mean of the three, by squaring, adding and dividing by 32. The totals thus obtained for the eight manurial degrees of freedom are shown in Table IV; it will be useful in addition to show the actual differences of these eight comparisons separately with their proper signs (Table III).

Table III.

	Grain	Straw
Late *minus* early	+269	−1053
Muriate *minus* sulphate	+561	−113
Single *minus* double	+319	−601
$ML+SE-ME-SL$	+309	−291
$M2+S1-M1-S2$	+379	−229
$E2+L1-E1-L2$	+175	+697
$ML1+ME2+SL2+SE1-SL1-SE2-ML2-ME1$	+203	−73
½ (single + double) *minus* undressed	+767·5	+1414·5

It should be observed in passing that with the exception of the large effect ascribable to the first dressing, and to the interaction of quantity and time of application the effect upon the grain is in the six other cases of opposite sign to the effect upon the straw.

The analysis of variance in Table IV is completed by calculating the amounts ascribed to the 24 degrees of freedom representing the variation of the undressed plots in the same block. The squares and products of the deviations of each of these plots from the mean of the four are therefore added, and reduced to pounds per plots. The amounts ascribable to the remaining 56 degrees of freedom are then immediately obtainable by subtraction.

For each of the four causes of variation into which the total has been divided a correlation between grain and straw may at once be calculated simply by dividing the sum of the products by the geometric mean of the two sums of squares. These correlations are shown in the last column of Table IV. The values found for the blocks and for the treatments being based on only a few degrees of freedom, are of course liable to large sampling errors, and cannot in fact be taken as significantly different from the remaining two better established correlations. If, however, we confine attention to the eight treatments which received single or double dressings, the correlation for the seven comparisons among them is − 0·468, which is now significantly different from all of the others. This fact will have an important bearing in the interpretation of the results and serves to illustrate a principle of some importance in the use of the comparatively precise types of experiments now possible.

In order to test the significance of each apparent effect, the sums of squares and products of Table IV are each divided by the corresponding degrees of freedom; this shows at once which effects have a larger share of the total variation than that assigned to random causes, and thus forms a basis for testing their significance; the mean squares and products are shown in Table V.

Table IV.

	Degrees of freedom	Sum of squares: Grain	Sum of squares: Straw	Sum of products	Correlation
Blocks	7	2,286·4	27,556·8	+6,793·7	+0·8559
Treatments	8	387·0	18,667·1	+ 989·4	+0·3681
Errors	24	773·2	5,491·2	+1,526·7	+0·7409
	56	2,508·8	18,556·3	+3,723·4	+0·5457
Total	95	5,955·4	70,271·4	+13,033·2	+0·6371

Table V.

	Degrees of freedom	Mean square Grain	Mean square Straw	Mean product
Blocks	7	326·6	3,936·7	970·5
Treatments	8	48·4	2,333·4	123·7
Errors	24	32·22	288·0	63·61
	56	44·80	331·4	66·49
	80	41·02	300·6	65·63

The two independent estimates of error do not differ appreciably in the case of straw, so that the values of the variance derived from 80 degrees of freedom may with confidence be adopted; this is 300·6 and its square root 17·84 may be taken as the standard error in pounds of straw for a single plot. The standard error for the total of 32 plots is thus 98·1 lb., or 2·218 per cent.; while that for the difference between two such totals is 138·7 lb. or 277 units of half a pound. Reference to Table III shows that the advantage of early over late dressings, the advantage of double over single dressing, and the differential advantage of applying the double dressing early are all significant, in addition, of course, to the advantage of the dressed over the undressed plots.

In the case of grain the two estimates of error show an interesting apparent discrepancy which may be used to illustrate the method of testing doubtfully significant effects. From the two values of the mean square is calculated a quantity, z, defined as half the difference of their natural logarithms, we have

$\log_e$	4·480	1·4996
$\log_e$	3·222	1·1700
Difference		0·3296
z		0·1648

The question whether so large a value of z will often occur by chance, when comparing a value derived from 56 with one derived from 24 degrees of freedom may be resolved at once from the table of the 5 per cent. points of the z distribution (Fisher, 1925, p. 210) which shows that in this case the 5 per cent. point lies between 0·2749 and 0·3425. The discrepancy is therefore quite insignificant, and as in the case of straw, the value derived from the whole 80 degrees of freedom may be used with confidence.

This value 41·02 shows that the effects of the different blocks of land used is very distinct, but that little effect upon grain yield has been produced by the different manurial treatments. The standard error in grain yield of a single plot is only 6·405 lb., and that of the difference between two totals of 32 plots is therefore 51·24 lb. or 410 units of 2 oz. each. Of the seven comparisons between treated plots only one, that of muriate versus sulphate exceeds this value, and that to an insufficient extent to be judged significant. The comparison of dressed with undressed plots has a standard error of 355 units, and the observed difference of 767·5 is therefore significant.

The significant response in the case of grain is therefore confined to the quantity of nitrogenous top-dressing, the effects of kind and date of application being inappreciable even with the low standard error attained. The quantitative effects may be summarised as in Table VI.

Table VI.

	Quantity of top dressing			Standard error
	None	Single	Double	
Grain, bushels per acre	75·4	78·9	77·7	1·08
,, per cent.	97·5	102·0	100·5	1·39
Straw, cwt. per acre	44·1	50·3	53·7	1·10
,, per cent.	89·3	101·9	108·7	2·22

The figures for straw show in addition certain differential responses involving quantity and time of application, but no effects in the four comparisons involving sulphate versus muriate; the significant effects are therefore summarised in Table VII.

Table VII.

	Single early	Double early	Single late	Double late
Straw, cwt. per acre	51·3	58·6	49·3	48·8
,, per cent.	104·0	118·6	99·9	98·9

The advantage shown by the double dressing is thus confined to the early application; at this time the second dose yields 14·6 per cent. increase, nearly as much as the increase of 14·7 per cent. ascribable to the first dose. In the late application either the single or the double dressing may be said to give an increase of about 10 per cent.

IV. Discussion.

Since in the design of the experiment care was taken through the random arrangement of the plots within blocks, to ensure that the estimate of error should afford a reliable measure of the actual errors to which the comparisons made are subject, the extremely low standard errors obtained in Table VI call for some explanations. This is the more important since all experimenters will desire to obtain a similar accuracy in tests involving questions of practical profit or loss. The main factors in the success of the present trial are clearly three: (i) the adequate use of replication, namely in eightfold in place of the triplicates and quadruplicates usually employed, (ii) the choice of combinations of treatments in such a way that each plot yield recorded contributes to the accuracy of all the comparisons desired, (iii) the elimination of the effects of soil heterogeneity by the method of arrangement adopted in the field. It is worth while to emphasise that only when weight is given to all three of these considerations can high accuracy be expected from field trials.

It is to be noted that when attention is given to the above points the conclusions from the results are drawn without any complex statistical analysis by simple arithmetical additions and subtractions. The only tests of significance required are those of which the theory is now fully understood, and for which adequate tables are available.

The yields of grain and straw obtained from all plots are remarkably heavy. Nevertheless, the early nitrogenous dressings produced a considerable increase of about 7·3 cwt. of straw to the acre for each cwt. of sulphate of ammonia or its equivalent in muriate. A large part of this increase was undoubtedly due to increased tiller formation, and in such a heavy crop it would be surprising if it should be reflected proportionately in an increased yield of grain. Indeed the additional yield in grain from either the single or the double dressings is only about 3 bushels to the acre. We may conclude that much of the additional tiller formation was superfluous in the sense of not leading to additional ears. With the late dressings in June the condition limiting the effect of the top dressing had become much more stringent; no additional yield of straw was produced by the second cwt. of manure, and no additional grain by either the single or the double dressing. This again fits with the view that such late dressed nitrogen as was taken up by the plant, was utilised only in additional and abortive tillers.

The correlation between grain and straw found in Table IV indicates that in the differences between different treatments, though not in the larger differences between blocks of land, some factors were at work acting antagonistically as between grain and straw. Thus the differences in grain yield on the treated plots, though individually insignificant, yet in relation to the straw yields of the same treatments show a significantly subnormal correlation. The same conclusion is suggested, though not so clearly demonstrated, by the low grain-straw correlation in the differential responses of the different treatments on the different blocks of land. The values of Table III show that this effect is not confined to any one manurial contrast but emerges in considering the aggregate of all. It is not improbable that we have here an indirect effect of the laying of the crop, which has interfered in other ways remarkably little with the success of the experiment, but which may well have hindered grain maturation somewhat more on plots having the greatest abundance of straw. If this is the case the straw yields will afford the better basis for estimating the effects of the manurial treatments on plant nutrition, while the laying of the crop and the small response in additional grain, represent a sporadic risk of loss to which heavy crops are particularly exposed.

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