

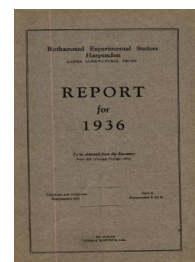
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## Crops, Plant Growth, Plant Products and Action of Manures

### Rothamsted Research

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## SCIENTIFIC PAPERS

(Published 1936, and in the Press)

### PLANT GROWTH, PLANT PRODUCTS, AND ACTION OF MANURES.

(Departments of Bacteriology, Botany, Chemistry, Fermentation, Physics, Plant Pathology, Sections of Biochemistry and Field Experiments, and the Imperial College Staff.)

#### (a) PLANT GROWTH

- I. E. J. RUSSELL. "*The Story of Rothamsted.*" Agricultural Progress, 1937, Vol. XIV, pp. 1-13.
- II. E. J. RUSSELL. "*The Culture of the Soya Bean in England.*" Journal of the Ministry of Agriculture, 1936, Vol. XLIII, pp. 24-30.
- III. E. J. RUSSELL. "*Les travaux de la Station Experimentale de Rothamsted.*" Lecture given May 1935 at l'Institut Superieure de l'Agronomie, Lisbon.
- IV. E. J. RUSSELL. "*Fünfzig Jahre Dauerfeldversuche in der Versuchstation Woburn, einer Abteilung der Versuchstation in Rothamsted.*" Landwirtschaftliche Jahrbücher, 1937, Vol. LXXXIV, pp. 161-312.
- V. D. J. WATSON. "*The Effect of Applying a Nitrogenous Fertiliser to Wheat at Different Stages of Growth.*" Journal of Agricultural Science, 1936, Vol. XXVI, pp. 391-414.

The effect of applying a nitrogenous fertiliser to wheat at seven different times and three rates, was studied in pot culture. The later the time of application the smaller was the increase in the yield of total dry matter and of straw. The increase in the yield of grain, on the other hand, was constant for the first six times of application, the last of which was made on May 25, but a later application made after ear emergence produced no increase.

Analysis of the grain yield showed that early application produced its effect by increasing the number of ears per plant. Later applications caused a smaller increase in ear number, but also increased the number of grains per ear and 1000-corn weight. There was no evidence of a critical time for tiller formation such as has been postulated by Doughty and Engledow.

The increase in total nitrogen uptake was equal for all times of application, but the ratio of nitrogen in grain to nitrogen in straw and chaff was greater, the later the time of application.

- VI. F. J. RICHARDS and W. G. TEMPLEMAN. "*Physiological Studies in Plant Nutrition. iv. Nitrogen Metabolism in Relation to Nutrient Deficiency and Age in Leaves of Barley.*" Annals of Botany, 1936, Vol. L, pp. 367-402.

Barley was grown in sand culture under four nutrient treatments, i.e. complete nutrients and deficiency of nitrogen, of phosphorus, and of potassium. On eight selected dates the successive individual leaves were separately grouped, dried immediately, and subsequently analysed for certain nitrogen fractions.

Differences in composition of the successive leaves at the time of their emergence were found, together with differences in the changes occurring as the leaves aged. In general, total nitrogen and most of the estimated fractions rose to a maximum about the period of Leaves 2-4, and thereafter declined to a minimum at Leaf 8 or 9, the last leaves again showing a rise. Nitrogen content fell continuously with leaf age in the earlier leaves, but in later ones rose for some time after expansion. The relation between nitrogen supply and ageing of the leaf is discussed.

Differences in nitrogen level induced by deficiency of that element are very marked, but there is little indication of departure from the usual protein cycle, and the observed fractions bear much the same relations to one another as in high-nitrogen plants.

Under phosphorus deficiency large differences are found. Protein is reduced even in early stages of the leaf history, and rapidly declines with the age of the leaf. The most marked characteristic of phosphorus deficiency is a greatly increased amide concentration. Clearly there is a check in protein synthesis beyond the stage of the production of asparagine.

The main effects of potassium deficiency on the various fractions are (1) a very rapid disappearance of protein with advancing leaf age although at the time of emergence these leaves have a normal protein content; (2) a marked increase in amino and amide-nitrogen, and (3) accumulation of nitrate in later leaves. The very different types of plants obtainable under varied conditions of potassium deficiency are stressed. The hypothesis that potassium plays an essential part in protein synthesis is examined, and an alternative view that appears to be more in accord with the known facts is presented.

VII. W. E. BRENCHELEY. "*The Essential Nature of Certain Minor Elements for Plant Nutrition.*" Botanical Review, 1936, Vol. II, pp. 173-196.

Much of the extensive literature on the rôle of minor elements deals with toxic and fungicidal aspects. The present review discusses recent work on the effect of some sixteen elements on plant growth. Small amounts of boron and manganese are essential to the growth and health of many, if not all, species of plants. Copper and zinc are necessary in many cases, though it is uncertain at present whether this need is universal. For other minor elements, only isolated cases of improvement have as yet been established. The possibility that specific elements are necessary for specific plants may have scientific and economic consequences.

VIII. E. A. ROWE. "*A Study of Heart-rot of Young Sugar Beet Plants Grown in Culture Solutions.*" Annals of Botany, 1936, Vol. L, pp. 735-746.

The fact that boron is an essential element for the healthy growth of sugar beet is confirmed. Some of the plants were grown with or without boron throughout the experiment, and others received it for a limited period only, either at the outset or at a later stage of development.

In the absence of boron the first tissues to degenerate are the apical meristem of the shoot, together with the youngest leaves and the newly developed cambia of the beet. Cells of the vascular rings in process of differentiating, and sporadic groups of parenchyma cells adjacent to conducting elements are also sensitive to the deficiency. Hypertrophy of the cambial cells, and also of the adjacent parenchyma cells, together with complete disintegration of the phloem, characterizes the later stages of heart-rot disease. It is suggested that plugging of the sieve-tubes is the first indication that the tissue is suffering from boron-deficiency.

Recovery in boron starved plants, as a result of the addition of boron, involves the activation of axillary buds at the top of the beet, each of which develops its own independent system of secondary vascular rings. The secondary vascular zones in the beet are downward continuations of the vascular supply of the leaves and the influence of any factor adversely affecting the leaves is very quickly reflected in the corresponding vascular rings of the beet. Since the root-tip does not degenerate, but merely ceases to grow in the absence of boron from the nutrient solution, either the requirements of this meristem, or the conditions obtaining in it must be different from those of the shoot-apex.

IX. W. E. BRENCHELEY. "*The Resistance of Plants to Poisons and Alkalies.*" 3rd. Congrès International de Pathologie comparée à Athenes, 1936, pp. 3-23.

When plants are attacked by poisons, either through the roots or by vapours or sprays, the consequence is either death, or a check to the normal processes of growth. Different plant species and even comparable individuals of one species vary in their response to the same poison.

Nutrient salts are toxic if supplied too lavishly, mixtures usually being less toxic than the individual salts. Other inorganic substances, as copper, arsenic, lead, zinc, manganese, etc., are poisonous in much smaller quantities. Organic compounds, as hydrocyanic acid, and various gases and sprays are also toxic, and the degree of resistance of plants to their action is of great economic importance.

The degree of resistance varies with the nature as well as the quantity of poison, and with individuals within a species. The stage of development of a plant, its relative weakness or strength, environmental conditions of light, temperature, moisture and food supply all affect resistance. But the marked differences in resistance between certain species can often be exploited by using poisons that suppress harmful plant growths without appreciably injuring the main crop. Such knowledge has already saved agriculturists much money, and research on the differential use of toxic substances, and on mitigating damage due to poisons in the soil will open further possibilities.

- X. W. E. BRENCHELEY AND K. WARINGTON. "*The Weed Seed Population of Arable Soil. III. The Re-establishment of Weed Species after Reduction by Fallowing.*" *Journal of Ecology*, 1936, Vol. XXIV, pp. 479-501.

Delay in cultivation after harvest allows some weed species, already developed, to continue seed production, and others have time to germinate and reach the seeding stage. The numbers of extra seeds thus produced may be greater than those destroyed by fallowing, so that the reducing effect of the operation is entirely nullified.

The first wheat crop after one year's fallowing is often heavy, and competition with the weeds is increased. Some species fail to reassert themselves, but others are able to withstand the competition and can replenish their stores of seed in the soil by the time the first wheat crop is harvested. A few species vary in their response, either remaining at a low level or re-establishing themselves quickly after fallowing, and in some cases, notably *Alopecurus agrestis* and *Stellaria media*, they may be much more plentiful after three years under crop than they were before fallowing began. The varying rate of re-establishment produces a definite change in the balance of the weed flora. Though *Papaver rhoeas* was only reduced to about half its original number by fallowing it has failed to increase appreciably, and is no longer a dominant feature.

After prolonged fallowing, (four years) re-establishment of species follows the same lines as after a shorter period, but the number of buried seeds is reduced more drastically and their return to the original numbers is delayed. The period of natural dormancy of most species on Broadbalk ranged from four to nine years, but for a few species may exceed ten years.

*Bartsia odontites* showed very strongly marked periodicity of germination, as every seedling appeared between February and June, the majority appearing early in the year.

Relatively few abnormal seedlings have been observed in over 600,000 which germinated. A few albinos occurred in *Alopecurus agrestis* and *Papaver rhoeas*, and also a number of tricotyledonous seedlings belonging to seven species, chiefly *Papaver spp.*, *Alchemilla arvensis* and *Veronica hederifolia*.

- XI. F. M. L. SHEFFIELD. "*The Early Development of the Cotton Fibre.*" *The Empire Cotton Growing Review*, 1936, Vol. XIII, pp. 277-285.

A detailed cytological examination, with illustrations, is given of the development of the fibre from primordial cells in the epidermis from the date of the opening of the flower. Emphasis is laid on the variability from cell to cell in a single seed, and from seed to seed within a single boll.

#### (b) PLANT PRODUCTS.

- XII. A. G. NORMAN. "*The Composition of Forage Crops. I. Rye Grass, (Western Wolds).*" *Biochemical Journal*, 1936, Vol. III, pp. 1354-1362.

The composition of fortnightly cuts of rye grass was studied, particular attention being given to the structural constituents. The contents of cellulose and lignin increased rapidly as maturity approached and the percentage of xylan in the cellulose also increased with age. The polyuronide hemicelluloses,

as judged by furfuraldehyde yield, did not exhibit any regular increase and were slightly lower in the mature grass than the young grass. A water-soluble fructosan or laevan, was found in considerable amounts in the younger samples, reaching a peak of over 37 per cent. As maturity was reached the fructosan content fell rapidly. The fructosan on isolation was unusually easily hydrolysed. Losses in hay making were of the order of 10 per cent., mostly accounted for by loss of this water-soluble constituent.

- XIII. A. G. NORMAN. "*The Composition of some Vegetable Fibres, with particular reference to Jute.*" *Biochemical Journal*, 1936, Vol. XXX, pp. 831-838.

Vegetable fibres of many types fall into two well-defined groups, according as the cellulose of the fibre is low or high in xylan. The first group, low in xylan, includes the high grade fibres such as flax, ramie and Italian hemp. The second group, high in xylan, consists of fibres of the coarser type, such as jute, manilla hemp and sisal, all of which contain also appreciable amounts of lignin and encrusting hemicelluloses. No direct relationship between quality and xylan content was found in a wide range of jute samples. The resistance or susceptibility of isolated cellulose to such treatments as boiling with dilute alkalis cannot be deduced from the xylan content, owing to the presence of varying amounts of easily extractable hexosan.

- XIV. A. G. NORMAN. "*The Association of Xylan with Cellulose in certain Structural Celluloses.*" *Biochemical Journal*, 1936, Vol. XXX, pp. 2054-2072.

The cellulose of most plants and woods differs from that of cotton in containing associated polysaccharides, known as cellulosans, which are tenaciously retained as an integral part of the cellulose aggregate. Heat-drying produces some change in the properties of both components of such a cellulose, which is manifest in an increased availability to extracting and hydrolysing agents. The effect of heat treatment may be observed repeatedly on the same sample and must involve breakage of the cellulose chains, though the xylan fraction is affected to a much greater extent. Preparations of the water-soluble material produced as a result of heat-treatment are mixtures which can be partially separated to give a portion of higher xylan content. Some oxidation undoubtedly occurs, and uronic groupings are present.

The xylan may be removed from celluloses by treatment with either acid or alkali, but a concurrent loss of hexosan material takes place in all cases. In acid hydrolysis there is no apparent break in the continuity of the reaction. The reducing value of dilute acid extracts indicates that the material removed is not completely hydrolysed to reducing sugars. Continued boiling with alkali removes hexosan at a greater rate than xylan, and in effecting the same total loss a higher concentration of alkali in a short period extracts more xylan than a lower concentration for a longer period. Plant celluloses show considerable differences of behaviour towards hydrolytic and extracting agents and reveal distinct individualities.

By solution and reprecipitation of a cereal cellulose, the organised molecular structure may be destroyed, and the xylan, which was initially extracted only to a small extent by water and dilute alkali, becomes almost completely soluble. No equivalent change occurs in the properties of the hexosan material.

These observations support the view that the cellulosan fraction of the cellulosic aggregate of plant materials and woods is oriented and participates in the micellae, being retained by secondary valency forces identical with those which obtain between parallel cellulose chains in pure cotton cellulose.

- XV. A. NOWOTNÓWNA. "*The Distribution of Mannan in some Gymnosperms.*" *Biochemical Journal*, 1936, Vol. XXX, pp. 2177-2184.

Conditions suitable for the determination of mannan in woods and wood pulps are discussed. The precipitation of mannose as the phenylhydrazone is not quantitative in low concentrations, but over a limiting value almost complete recovery may be obtained.

The major part of the mannan in softwoods is associated with the cellulose. Considerable variation in the proportion of mannan to xylan is found. Mannan may be removed from the cellulose by dilute acid hydrolysis along with the xylan. At the same time there is some loss of hexosan. The mannan and xylan are affected to different extents on treatment of the cellulose with alkali.

- XVI. M. F. NORMAN. "*The Oxidation of Amino-Acids by Hypochlorite I. Glycine.*" *Biochemical Journal*, 1936, Vol. XXX, pp. 484-496.

Glycine is rapidly oxidised by hypochlorite. At least five times as much chlorine as glycine must be present for completion of the reaction, in which circumstance 1 mg. glycine uses 4.26 mg. chlorine, equivalent to 9 atoms of chlorine per mol. of glycine. The rate of oxidation is most rapid between the limits of acid and alkali concentrations of 0.05 m. mol. per 100 ml. Outside these limits the reaction is greatly retarded. As oxidation proceeds the mixture becomes more acid, the optimum pH range being 7-9. The oxidation of possible intermediates was tested, from which it was established that the probable route of reaction is through the formation of HCN, CO<sub>2</sub>, and water, the HCN then hydrolysing to formic acid and ammonia, both of which are further oxidised to CO<sub>2</sub>, water and gaseous N. Quantitative recovery of carbon dioxide was obtained.

- XVII. C. N. ACHARYA. "*Structure in Relation to Chromic Oxidation of Nitrogenous Substances.*" *Biochemical Journal*, 1936, Vol. XXX, pp. 1026-1032.

The nature of the products obtained by chromic oxidation of nitrogenous substances varies with the structure of the compound. Compounds in which the nitrogen atoms are attached to different carbon atoms, with the exception of hydroxylamine and hydrazine derivatives, yield full recovery of nitrogen in the form of ammonia accompanied by small quantities of nitrate; those having two or three nitrogen atoms attached to the same carbon atom lose a portion of the total nitrogen in the form of nitrous oxide. Hydroxylamine derivatives are converted into nitrous oxide and nitrate, while hydrazine derivatives yield mainly elementary nitrogen; in both cases, the amount of ammonia formed is inappreciable.

An improved wet combustion apparatus has been described which includes the analysis of gaseous products and is applicable to the determination of nitrogen in all types of organic compounds.

- XVIII. R. K. SCHOFIELD AND G. W. SCOTT BLAIR. "*The Relationship between Viscosity, Elasticity and Plastic Strength of a Soft Material as Illustrated by some Mechanical Properties of Flour Dough. IV. The Separate Contributions of Gluten and Starch.*" *Proceedings of the Royal Society of London, A*, 1937, Vol. CLX, pp. 87-94.

These experiments support the view that in a flour dough the gluten forms an elastic network which dominates the mechanical behaviour. When a cylinder of dough is first stretched some of the links in the network are ruptured, since it will not return to its original length. Enough remain unbroken, however, for a continuity of structure to be preserved until the cylinder has been extended to five or six times its original length. The "work-hardening" of dough is thus accounted for. The elastic network is not completely built up until some time after the dough is mixed. Its strength is greatly reduced by drastic remixing of the dough but is largely recovered on further standing. The addition of hydrochloric acid in slight excess of the acid binding capacity destroys the strength of the network. This shows that the electrostatic attraction between oppositely charged groups in neighbouring molecules is an important factor in the strength of the gluten network.

The upward bend of the reloading curve up to the point where flow (i.e. the rupture of further links) occurs is probably mainly due to the irregularity of assembly of the elastic members, but may also indicate that individual chains are approaching the limit to which they can be extended.

The evidence suggests that the starch paste penetrating the gluten network has a "yield value" so that there is elastic hysteresis even when the cycle is carried out slowly enough to avoid elastic after-effect.

- XIX. R. K. SCHOFIELD AND G. W. SCOTT BLAIR. "*Über die grundlegenden mechanischen Eigenschaften des Mehlteiges.*" *Kolloid-Zeitschrift*, 1937, Vol. LXXIX, pp. 148-154.

A résumé of work on the viscosity and shear modulus of flour doughs is given. Study of such fundamental properties is essential for an understanding of the behaviour of doughs, either as purely physical systems or in their relation to the bread-making industry.

The starch paste penetrating the gluten network has a "yield value" in consequence of which there is elastic hysteresis even when the cycle is carried out slowly enough to avoid elastic after-effect. It has been found, moreover, to be thixotropic, the breakdown of the gel which forms on standing being exhibited in an "elastic fatigue." The effect is complicated by a rise in the elastic modulus due, presumably, to the establishment of new linkages in the gluten network.

Through the action of the starch, the mechanical properties of the dough are more influenced by age and moisture content when measured at low than at high stresses. The elastic recovery of dough cylinders extended only 20 per cent. in a given time varies both with the age and moisture content of the dough and with the nature of the flour.

No plastic flow occurs during elastic recovery. The presence of a "plastic after-effect" would invalidate the method used to evaluate the viscosity and rigidity-modulus.

- XX. P. HALTON AND G. W. SCOTT BLAIR. "*A Study of Some Physical Properties of Flour Doughs in Relation to their Bread-Making Qualities.*" *Journal of Physical Chemistry*, 1936, Vol. XL, pp. 561-580.

Methods described in earlier papers for measuring the viscosity and rigidity modulus of flour doughs have been extended and developed.

The physical properties of dough are markedly affected by excessive handling hence the methods used have to be carefully controlled.

Viscosity and modulus measured under standard conditions of stress and strain both decrease with increasing water content or with increasing age of the dough.

Good bread-making quality is associated with a relatively high viscosity and low modulus; the relaxation time, i.e., viscosity-modulus ratio, therefore, appears to be the chief single criterion of quality.

Yeast in small amounts has little effect on viscosity or modulus, and its importance in bread-making appears to be entirely due to its gas-producing activities.

Preliminary work indicates that tensile strength is a major factor in determining the extensibility and gas-holding properties of a dough.

Stickiness is an independent property which can be roughly measured. Its principal importance lies in its effect on the handling properties of the dough.

The investigations have disclosed relationships between the physical properties of flour doughs and their bread-making qualities, and their development should increase our knowledge of the nature of flour quality.

- XXI. P. HALTON AND G. W. SCOTT BLAIR. "*The Relationship between Conditions Governing Rupture and Flow in Flour Doughs.*" *Journal of Physical Chemistry*, 1936, Vol. XL, pp. 811-819.

The shortness (i.e. ease of tearing) of flour doughs is closely paralleled by the rate at which viscosity falls with increasing stress (structural viscosity). A perfect correlation is not obtained, partly because neither property can be determined with great accuracy. The effect on structural viscosity of certain substances (fats, amino-acids, etc.) known to alter the shortness of dough has been measured, and the nature of the processes involved discussed. The significance of shortness in terms of heterogeneity of dough, and its relation to tensile strength and ductility are tentatively discussed.

- XXII. P. HALTON AND G. W. SCOTT BLAIR. "*A Study of some Physical Properties of Flour Doughs in Relation to their Bread-Making Qualities.*" *Cereal Chemistry*, 1937, Vol. XIV, pp. 201-219.

The baking quality of a flour has been found to depend on the physical properties of the dough and a picture is given of the mechanism of dough behaviour during fermentation based on these physical properties. Viscosity and elasticity modulus are of chief importance, and methods of measuring these in absolute units have been devised. The viscosity and elasticity modulus are not constants but depend on the magnitude of the stress and strain to which the dough is subjected. They also vary with the water content, age, and temperature of the dough.

The baking quality of a flour depends primarily on the spring and shortness of the doughs. The spring of dough depends on the relationship between viscosity and elasticity modulus, the higher the viscosity/elasticity modulus ratio the better the spring. Shortness in doughs is connected with structural viscosity in the rate at which viscosity falls under increasing stress.

- XXIII. G. W. SCOTT BLAIR AND P. POTEL. "*A Preliminary Study of the Physical Significance of Certain Properties Measured by the Chopin Extensimeter for testing Flour Doughs.*" *Cereal Chemistry*, 1937, Vol. XIV, pp. 257-262.

A preliminary analysis of the physical properties of dough measured by the Chopin extensimeter indicates that water absorption capacity and a complex function of viscosity and modulus are the principal factors involved. Under the conditions of the test, the former is directly related to viscosity, and the latter depends on a complex mixture of "spring" and shortness which has been only partially resolved.

The increasing use of the Chopin instrument as a criterion of wheat and flour quality independent of any baking test, emphasises the importance of a wider understanding of the nature of the factors measured.

- XXIV. HUGH NICOL. "*The Two Ends of Straw.*" *Agricultural History*, 1936, Vol. X, pp. 3-13.

Most published analyses of straw relate to the entire stem, and thus show only average values. The first demonstration of differences in chemical composition of the upper and lower ends of straw, and in some other parts of stems was made by James F. W. Johnston for cereals and bamboo and was published in 1842; his differential analyses of barley straw remained unique for nearly a century. Johnston's pupil, John P. Norton, performed more detailed analyses of oat straw (1847). The work of Pierre, on wheat straw, published in 1863 and 1866, is probably the most elaborate series of analyses of a plant species ever performed. In the present paper it is suggested that Pierre's work bears upon the hypothesis of regressive or downward migration of plant nutrients, put forward recently by Professor Deleanu of Bukarest.

The early work on differences of composition along the stem appears to have been forgotten in spite of its practical value (see Papers XCII, XCIII).

(c) ACTION OF MANURES.

- XXV. J. CALDWELL AND H. L. RICHARDSON. "*The Growth of Clover in the Presence of Ammonium Sulphate.*" *Journal of Agricultural Science*, 1936, Vol. XXVI, pp. 263-267.

In pot experiments with alsike and red clovers, fortnightly dressings of ammonium sulphate applied in solution at rates up to 1 gm. per pot did not injure the plants. The total amount of ammonium sulphate applied to the alsike was relatively enormous, of the order of 24 tons per acre. Soil and plant analyses showed that although abundant ammonia and nitrate (including water-soluble ammonia) were present in the soil there was little extra nitrogen in the treated plants. It was concluded that the adverse effect of ammonium sulphate on clovers in grassland was due not to the toxicity of ammonium ion but to competition with the extra growth of grass produced.

- XXVI. E. M. CROWTHER AND R. G. WARREN. "*Report on Field Experiments in England and Pot Culture and Laboratory Work at Rothamsted.*" Appendix I to Fourteenth Interim Report of Permanent Committee on Basic Slag, Ministry of Agriculture, 1936.

A series of pot culture experiments on eleven slags using repeatedly-cut perennial rye grass was continued for a second season. Only the heavier dressings of the more soluble slags had appreciable effects on the crops. In total dry matter and in total phosphoric acid uptake the results followed the citric acid solubilities of the slags, about 60 per cent. of the added citric acid-soluble phosphoric acid being taken up by the crops.

In a repeated mowing experiment on neutral grassland continued for five seasons about 30-40 per cent. of the phosphoric acid added in high-soluble slag or superphosphate was recovered in the herbage, but less than 10 per cent. was recovered from low-soluble slag and mineral phosphate.

- xxvii. E. M. CROWTHER (with D. N. McARTHUR). "*Report on Scottish Field Experiments in 1935.*" Appendix II, Fourteenth Interim Report of Permanent Committee on Basic Slag, Ministry of Agriculture, 1936.

A series of seven 48-plot field experiments was carried out to compare single and double dressings of four kinds of basic slag and also of ground limestone. The relative effects of high- and low-soluble slags followed their citric acid solubilities, but of two new medium-soluble slags one was better and the other worse than would be judged from their citric acid solubilities. Second year residual effects on oats were very small and were shown only by the two more soluble slags which had given the best immediate results.

## STATISTICAL METHODS AND RESULTS

(Department of Statistics)

### (a) DESIGN OF EXPERIMENTS

- xxviii. F. YATES "*Incomplete Randomized Blocks.*" *Annals of Eugenics* 1936, Vol. VII, pp. 121-140.

The paper describes a general method of arranging replicated experiments in randomized blocks when the number of treatments to be compared is greater than the number of experimental units in a block. This new type of arrangement, for which the name of symmetrical incomplete randomized blocks is proposed, is such that every two treatments occur together in a block the same number of times. This restriction enables estimates of the treatment effects and of the experimental error to be obtained expeditiously by the ordinary procedure of the analysis of variance. Estimates of block differences can also be obtained if required. The special case in which the blocks are formed of pairs of experimental units is capable of specially simple treatment. The method of symmetrical incomplete randomized blocks is likely to be of most use in cases in which the experimental material naturally divides itself into groups, such as litters of experimental animals, containing numbers less than the number of treatments that it is desired to test, especially if the differences between these natural groups are of interest.

The necessary formulae are presented and their application illustrated by numerical examples, one based on the numbers of local lesions produced by a virus on half leaves of susceptible plants, the other on the scores of rats in a discrimination test. The minimum number of replications required for different numbers of treatments and block sizes is discussed, and actual arrangements are given for the cases likely to be of general utility. A short discussion of the relative efficiency of an arrangement of this type and an arrangement in ordinary randomized blocks is also included.

- xxix. M. M. BARNARD. "*An Enumeration of the Confounded Arrangements in the  $2 \times 2 \times 2$  Factorial Designs.*" Supplement to the Journal of the Royal Statistical Society, 1936, Vol. III, pp. 195-202.

The structure of the  $2^n$  factorial system is described, and the various possible types of confounding are enumerated for designs involving up to six factors.

- xxx. F. YATES. "*A Further Note on the Arrangement of Variety Trials: Quasi-Latin Squares.*" *Annals of Eugenics*, 1937, Vol. VII, pp. 319-331.

The principles of quasi-factorial design are extended so as to enable varietal trials involving a number of varieties which is a perfect square (not  $6^2$  or some other numbers, however) to be arranged in the field so that differences between rows and between columns are eliminated from the varietal comparisons. It is proposed to call this type of arrangement an arrangement in quasi-Latin squares, from the analogy with ordinary Latin square design.

As a numerical example a quasi-Latin square design for twenty-five varieties is superimposed on the uniformity trial on oranges which was used in a previous paper to illustrate quasi-factorial designs in randomized blocks. A gain in efficiency over an arrangement in ordinary randomized blocks of 91 per cent. resulted, the corresponding gain in a quasi-factorial design in randomized blocks (two groupings) being 41 per cent.

Various other possible applications of the quasi-Latin square principle are briefly discussed.