

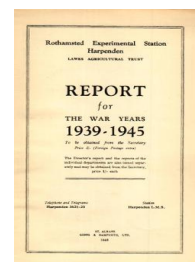
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Crop Physiology Department

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SECTION OF CROP PHYSIOLOGY

By D. J. WATSON

FIELD EXPERIMENTS

The Section has continued to act as a link between the farm and the laboratories, and has been responsible for the preparation of detailed plans of field experiments, and the general supervision, from the laboratory side, of the conduct of the experiments. The problems investigated in the field experiments are discussed on page 233.

New summaries have been prepared (1, 2, 3) of the results of the Broadbalk, Hoosfield and Barnfield classical experiments, including the data accumulated since the last account of the experiments was published in 1905, and the results of the many statistical investigations made on the data in recent years.

PROBLEMS ARISING FROM THE WAR

(a) *Damage to crops by war gases and by incendiary action*

On the outbreak of war, the possibility of damage to growing crops by enemy action had to be faced. Deliberate attack on crops seemed improbable, but it was thought that serious losses might occur in the course of operations against other objectives. Of the possible methods of attack, the one most likely to cause damage over large areas was considered to be the spraying of the persistent vesicant gases, mustard gas and lewisite, from aircraft. Accordingly an investigation was begun in 1940 in collaboration with the Chemical Defence Research Station, Porton, on the effect of these substances on the more important agricultural crops. In connection with this work, Sir John Russell and D. J. Watson served on the Crop Sub-Committee of the Chemical Board of the Ministry of Supply.

The objects of the work were :

- (1) to discover the immediate visible effects of mustard-gas and lewisite spray on growing plants, for the purpose of diagnosing the presence of contamination ;
- (2) to measure the loss of yield caused by contamination at different stages of growth ;
- (3) to determine how long toxic effects, which would render crops unsafe for use as food, persist after contamination ;
- (4) to work out appropriate methods of treating contaminated crops, and of utilising or disposing of the produce.

A series of field experiments was carried out in 1940, in which mustard-gas and lewisite spray, simulating in drop size and concentration the spray from high-flying aircraft, was deposited on a variety of crops at different stages of growth. Observations were made on the immediate effects of contamination and on the effects on subsequent growth and yield. The toxicity of the contaminated plants at intervals after spraying was determined by feeding experiments with rabbits. The results varied greatly with the crop, ranging from complete destruction to the absence of any permanent injury. Mustard gas usually caused only localised injury at the site of contact with spray drops, and toxic effects were of short duration

except when the temperature was very low. Lewisite readily penetrated into plant tissues, and caused more extensive scorching of the foliage. It tended to spread along the vascular tissue, and in this way caused necrosis in underground parts of the plant, such as potato tubers and the storage root of sugar beet. Affected tissues were shown to have a high arsenic content and were permanently toxic.

Mustard-gas vapour caused proliferation of the tissue of the above-ground portion of the storage root of sugar beet, producing tumour-like growths similar in appearance to those caused by the bacterial disease "crown-gall." It also affected the apical buds of potato stems, leading to deformation of the leaves subsequently produced.

The germination of wheat and barley grain from contaminated crops was only slightly affected. Pot experiments in 1941 showed that such grain could safely be used for seed, and with very few exceptions produced plants which were normal in growth and yield. It was also found that potato tubers affected by internal necrosis caused by contamination of the growing crop with lewisite were suitable for use as seed: they gave a slightly higher yield than tubers from an uncontaminated crop grown from the same stock of seed, probably because the destruction of the haulms by lewisite had reduced the spread of leaf-roll infection. Although the necrotic tissue in these tubers was toxic to rabbits, only a small part of the volume of each tuber was affected, and the tubers were fed, either raw or boiled, to pigs, as part of a balanced ration without causing ill effects.

A summary of the results and recommendations was issued to Agricultural Advisory Officers and Civil Defence authorities in 1941 (7).

The problem of how to deal with grain stored in bulk, in the event of its becoming contaminated by a gas-bomb burst, was raised by the Ministry of Food, and an investigation was made of the particular case of barley and malt, large stocks of which are held at maltings (8, 9). It was suggested that the contaminants might be removed by volatilisation, by heating the grain in a malting kiln. An experimental kiln was constructed to provide conditions of temperature and ventilation similar to those used in a malting kiln. It was found that heat treatment followed by a period of storage was successful in removing all but a trace of mustard gas from both malt and barley, and fully restored the ability of the barley to germinate. The method failed when the contaminant was lewisite.

Precautions also had to be taken during the war against loss of standing corn crops by fire, started either by incendiary bombs aimed at built-up areas, or possibly by agents specially designed for igniting crops. Warnings to farmers were broadcast on nights when fire hazard was thought to be especially great, owing to favourable weather conditions. In the summer of 1941 experiments were undertaken at the request of the Ministry of Home Security to investigate the change in water content of cereal straws during ripening and its relation to weather factors, and to determine the critical water content at which ripening straw becomes inflammable, with the object of assessing the fire-hazard accurately from a knowledge of the progress of ripening and the weather forecast.

The season was very unfavourable for the work, for there was frequent rain during July and August, and the corn harvest was much delayed. Laboratory tests showed that wheat and barley straws become inflammable, in the sense that a flame is propagated indefinitely along the straw, when the water content falls below about 30 per cent. As it was found that the water content of the straw, especially near to the ground, when the grain was fit for harvest, was not greatly below and sometimes much above 30 per cent., it was concluded that the danger from fire had been over-estimated. This was confirmed by direct tests on field crops and the work was not continued.

(b) The storage of potatoes in clamps

At the beginning of the war, potatoes became one of our most important staple crops, and production was greatly increased by expanding the acreage grown. The proportion of the harvested crop which becomes available for human consumption depends on how much is lost during storage, and it was soon found that the wastage was high, especially as potatoes had to be held in storage until much later in the season than in peace time, owing to the cutting-off of supplies of imported new potatoes. It was recognised that the main causes of loss of weight during clamp storage were tuber diseases (especially blight), frost damage, loss of water and loss of dry matter by respiration and sprouting, but there was little information on the relative magnitudes of the losses due to different causes or on the rate of increase of wastage with time of storage. In 1942 the Agricultural Research Council set up a Conference on potato wastage to discuss these problems and arrange for experimental work on the causes of wastage, and its prevention. The Section was concerned with part of this work, in collaboration with the Biochemical Section, the Plant Pathology Department and members of the staff of the Midland Agricultural College.

In 1942 and 1943 experimental clamps divided into weighed sections were set up. At monthly intervals from January to July one section of each clamp was opened, the weights of sound tubers remaining and of sprouts, damaged tubers and debris were determined, and an examination of the rotted tubers was made to identify the pathogens causing rotting. It was found that the losses due to evaporation and respiration greatly exceeded the sprouting loss. The loss of weight increased slowly until April, and then much more rapidly during May and June: it was greatly increased in clamps from which the soil cover was removed in April.

Estimations of dry matter, sugars, starch, total nitrogen and ascorbic acid were made on samples taken at each occasion of opening the clamps. It was found that the major part of the change of fresh weight during storage was due to water loss. About 16 per cent. of the dry matter was also lost from the tubers by early July, almost entirely at the expense of starch, and 5 per cent. was recovered in the sprouts. The additional fresh weight lost in the clamp from which the soil cover was removed in April consisted entirely of water. Sugar content fluctuated, apparently in accordance with temperature changes, until the onset of sprouting when it tended to rise. Total nitrogen content per cent. of dry matter varied little: by the end of July about 10 per cent. of the

nitrogen originally present in the tubers had passed into the sprouts. Ascorbic acid rose to a maximum at the time when sprouting began, subsequently falling to very low values at the end of the storage period.

A study of the micro-climate of a potato clamp was begun; continuous records of the temperature at various points in the potatoes and in the clamp coverings were obtained, and analyses of the internal atmosphere were made at intervals. Both temperature and CO₂ records gave evidence that in some conditions there was mass flow of air through the soil cover of the clamp caused by wind pressure on the clamp face.

A search was made for volatile chemical substances which would inhibit the sprouting of potatoes, without damaging or tainting the tissues of the tuber. Loss of weight and deterioration of quality due to sprouting after prolonged storage might be reduced by the use of such substances in clamps. Some 50 compounds were tested and a number gave promising results in laboratory tests, but attempts to use them in clamps met with little success, possibly because the permeability of the clamp covers to wind, noted above, prevented the maintenance of an effective concentration of vapour.

PHYSIOLOGICAL STUDIES

Studies on the growth of field crops have been in progress for several years, with the object of relating variations in yield to physiological attributes of the crop, particularly net assimilation rate and leaf area. The work continued in 1939 with studies of the effect of varying nutrient supply over a wide range, using material from the classical experiments, and of the effects of sodium and potassium salts on the growth of sugar beet in 1942 and 1943. Pressure of work on the more urgent problems already discussed has delayed the statistical analysis of the large amount of data collected, but this is now being completed. The results showed that differences in dry-matter accumulation in a range of crops, seasons and nutritional conditions were usually the result of variation in leaf area; variation in net assimilation rate played a minor part. It follows that a knowledge of the internal factors which affect leaf growth and determine leaf size is essential for the further analysis of agricultural yield.

Work on one aspect of this problem was begun in 1944, on excised stem tips of rye embryos, grown in sterile culture in darkness (6). This form of culture makes possible a study of the chemical factors concerned in leaf growth, independently of their effect on root growth. It was found that limited growth of the first leaf occurred, by extension of previously formed cells, if sucrose and mineral salts were supplied. A large number of substances, known or claimed to have growth-promoting effects on plant tissues were tested, but none of these increased the growth of the first leaf, and some had inhibiting effects.

During 1945 work has been done, in collaboration with the Botanical Department, on the effect of sodium salts on sugar beet at varying levels of potassium supply in sand culture, and in collaboration with the Plant Pathology Department, on the effect of infection with Yellow's virus on the growth of sugar beet in field conditions.

PUBLICATIONS

SCIENTIFIC PAPERS

1. RUSSELL, E. J. and WATSON, D. J. 1939. *The Rothamsted field experiments on barley, 1852-1937, Pt. III. The composition and quality of the barley grain.* Emp. J. Exp. Agric., **7**, 193-220.
2. RUSSELL, E. J. and WATSON, D. J. 1940. *The Rothamsted field experiments on the growth of wheat.* Imp. Bur. Soil Sci., Tech. Commun. **40**.
3. WATSON, D. J. and RUSSELL, E. J. 1943-5. *The Rothamsted experiments on mangolds, 1876-1940.*
Part I. 1943. *The effect of manures on the yield of roots.* Emp. J. Exp. Agric., **11**, 49-64.
Part II. 1943. *Effect of manures on the growth of the plant.* *ibid.* **11**, 65-77.
Part III. 1945. *Causes of variation of yield.* *ibid.* **13**, 61-79.
WATSON, D. J. 1946.
Part IV. *The composition of the mangolds grown on Barnfield.* *ibid.* **14**, 49-70.

The above three papers are critical summaries of the results of three of the classical experiments, started by Lawes and Gilbert, and still continuing. The last previous account of these experiments was given by A. D. Hall in 1905 in his "Book of the Rothamsted Experiments," and the present papers bring this up to date. They also include, for comparison, discussions of the results of similar experiments at Woburn, and of experiments carried out by modern methods at Rothamsted and other centres in recent years.

Much of the information is drawn from papers published during the past 25 years on the results of statistical investigations of the data from the classical experiments, but the results of studies on other aspects of the data, hitherto unpublished, are also included.

The following are among the many topics discussed: the effect of manurial treatment on the growth and yield of the crop, including comparisons of different forms of nitrogenous fertiliser, the effect of farmyard manure and rape cake, the effect of potassium and sodium salts and their interaction with nitrogenous fertilisers; seasonal variation of yield, and its relation to soil deterioration, weather conditions, plant population, and date of sowing; seasonal variation in the response to fertilisers, and its relation to yield and to weather factors; the effect of manurial treatment on the composition of the harvested crop; seasonal variation in composition and the influence of climatic conditions; the effect of fallowing on crop yield and weed infestation; diseases and pests; the effect of cultivation treatments on crop yield.

4. WATSON, D. J. and NORMAN, A. G. 1939. *Photosynthesis in the ear of barley, and the movement of nitrogen into the ear.* J. Agric. Sci., **29**, 321-46.

Experiments were made in 1936 and 1937 on barley plants grown in pot culture, to determine the effect of shading the ear or the shoot after ear emergence on dry weight and nitrogen content.

It was found that after ear emergence the ear and the shoot (leaves and stem) make approximately equal contributions to the assimilation of the whole plant. In the 1936 experiment 28 per cent. of the final dry weight of the ear was accounted for by assimilation in the ear itself, and in the 1937 experiment, 19 per cent. These are minimum estimates, for assimilation must have been proceeding in the ears during emergence, before the shading treatments were applied. The results agree well with similar estimates of the extent of assimilation in the ear made on wheat by other workers.

The effects of shading on the amount of nitrogen present in the plant at harvest were somewhat variable, but they were always small compared with the effects on dry weight. Shading tended to reduce the amount of nitrogen in the ear, but as the dry weight of the ear was reduced to a much greater extent, nitrogen as percentage of dry matter in the ear was increased. It is concluded from this result that translocation of nitrogen compounds to the ear is not closely dependent on the amount of the concurrent increase in dry

weight of the ear. It appears that the approximate constancy of nitrogen percentage in the ear and grain throughout development is a consequence of the particular conditions prevailing during normal growth in the field.

The experiments showed that 20 to 30 per cent. of the dry weight of the whole plant was added after ear emergence, suggesting that climatic conditions during this late stage of growth is of considerable importance in determining the final yield.

5. WATSON, D. J. 1939. *Field experiments on the effect of applying a nitrogenous fertiliser to wheat at different stages of growth.* J. Agric. Sci., **29**, 379-98.

An account is given of the results of two series of field experiments carried out at Rothamsted and Woburn in the years 1926 to 1936 on the effect of nitrogenous fertilisers on wheat. In the first series a comparison was made of the effects of early (March) and late (May) top-dressings, and in the second series a range of times of application from sowing to the end of May were tested.

At Rothamsted, the increases of yield of grain produced by the nitrogenous fertiliser were small and rarely significant, but they were greater at Woburn. On the average of all experiments, the effect of the fertiliser on yield of grain was independent of the time of application. In individual years, variation in effectiveness between times of application was found, and this was correlated with the amount of rain falling in a short period after the time of application. At Woburn, the effectiveness of the fertiliser decreased with increase in the amount of rain falling immediately after the application of the fertiliser, but at Rothamsted the effects were less clear and appeared to be in the opposite direction.

The effects on straw yield were relatively greater, and more consistent, than those on grain yield. A greater increase of straw yield was produced by early top-dressing (January-March) than by application at the time of sowing, and the increase declined steadily the later the time of top-dressing. Shoot height was increased by the nitrogenous fertiliser, and varied with time of application in a similar manner to straw yield.

An analysis of the yield of grain in terms of ear number, number of grains per ear and 1,000-corn weight gave results which varied greatly from year to year. The widely held view that early applications of nitrogen increase the yield of grain by increasing the number of ears, while late applications mainly affect ear size, was not confirmed in the field experiments, though it has previously been found to be true for pot cultures.

The effect of the nitrogenous fertiliser on the quality of the grain as measured by its nitrogen content and 1,000-corn weight also varied with the season. The 1,000-corn weight was usually depressed by the nitrogenous fertiliser whatever the time of application.

The nitrogenous fertiliser increased the susceptibility of the crop to lodging, and early top-dressings had a greater effect than late top-dressings.

The usual practice of applying the nitrogenous fertiliser as a top-dressing in February or March is justifiable on the grounds of convenience, and because applications of nitrogen at this time give as great an increase in the yield of grain as later spring top-dressings, and a greater increase of straw yield. But in circumstances where a high yield of straw is not particularly desirable, it would be advantageous to delay the top-dressing until May, and so to minimise the risk of lodging. Applications at the time of sowing appear to have no special advantage.

TECHNICAL PAPERS

6. DE ROPP, R. S. 1945. *Studies in the physiology of leaf growth. I. The effects of various accessory growth factors on the growth of the first leaf of isolated stem tips of rye.* Ann. Bot., **9**, 369-81.

Excised stem tips of rye were grown in sterile culture in darkness. It was found that on a medium containing 2 per cent. sucrose and mineral salts, growth was confined to the first leaf. The growth of this leaf was less than in excised whole embryos or in intact grains. In the absence of mineral salts growth was much reduced, and when sucrose was withheld no growth occurred. Occasionally, for reasons not yet understood, some of the stem-tips regenerated roots and when this happened, the entire growing point began to develop, and produced leaves normal in size and form.

Extracts of rye-grain, sprouted or unsprouted, of rye endosperm or of dried yeast added to the culture medium had no effect on the growth of the first leaf. American workers have claimed that a diffusate obtained from peas increases the growth of immature leaves grown in synthetic media, but this was not confirmed.

The following vitamins and other substances which have, or are claimed to have, effects on the growth of plant tissues, were also tested: thiamin, nicotinic acid, calcium pantothenate, pyridoxine, biotin, ascorbic acid, vitamins E and K, indole acetic and naphthalene acetic acids, and the purine derivatives, adenine, guanine, uric acid and caffeine. None of these increased the growth of the first leaf in stem-tip cultures, but some had inhibiting effects at the higher concentrations tested.

7. ANON. 1941. *Contamination of crops by war gases : effects and treatment*. Min. Agric. Fish., Tech. Commun., 4.

A short account is given of the different types of war gases and of the methods available for their dispersal. The effects of these gases on agricultural crops are discussed. The most probable method of contamination, and the one likely to have most serious effects, was considered to be by the persistent vesicant gases, mustard gas and lewisite, sprayed from aircraft. A detailed description is given in tabular form of the immediate visible effects of contamination with mustard gas or lewisite on common agricultural crops at different stages of growth, and of the effect on subsequent growth and yield.

It is pointed out that toxicity arising from contamination with mustard gas is rapidly removed by weathering, but crops contaminated with lewisite may continue to be poisonous for long periods of time. The conditions of contamination with lewisite which would render a crop unsafe for use as food are noted.

The procedure to be followed in handling and disposing of contaminated crops is described.

8. WATSON, D. J. and WILLIAMS, C. 1943. *The salvage and decontamination of barley contaminated with persistent war gases*. J. Inst. Brewing, 49, 303-6.
9. WATSON, D. J. and WILLIAMS, C. 1944. *The salvage and decontamination of malt contaminated with persistent war gases*. J. Inst. Brewing, 50, 292-4.

These two papers discuss the probable effects of a gas-bomb bursting in a stored bulk of barley or malt, and suggest a procedure to be followed in salvaging and disposing of the contaminated grain. It is shown that contamination is likely to be restricted to a very thin surface layer of the bulk of grain. If this is removed by careful shovelling, the underlying grain can be recovered uncontaminated. If the contaminant is mustard gas, the heavily contaminated grain in the surface layer can be decontaminated by heat treatment in a malting kiln, in conditions determined by experiments which are described, followed by a period of storage with good ventilation. After this treatment the grain is no longer toxic and the ability of barley to germinate is restored. Grain heavily contaminated with lewisite cannot be decontaminated by this method, and should be destroyed.