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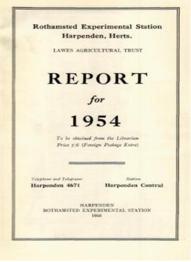

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UPTAKE OF NUTRIENTS FROM LEAF SPRAYS BY AGRICULTURAL CROPS

By

G. N. Thorne

Introduction

Interest in the application of fertilizers in sprays has increased in recent years because of the development of concentrated highly soluble fertilizers, and because the increasing use of machinery for spraying insecticides, weed-killers, etc., and for overhead irrigation, facilitates the application of nutrients in sprays. The effects of nutrient sprays are frequently ascribed to nutrient uptake by the leaves; for example such a claim is made by Secrett (1949) to explain the beneficial results obtained from the irrigation of a cauliflower crop with water containing 1 part in 20,000 of KNO_3. In an experiment on irrigated sugar beet, in which 12 inches of irrigation water were applied during the season, the application of nitrogen in the water caused a greater increase in the yield of tops than application to the soil at sowing (Results of field experiments for 1949, Rothamsted). However, in this experiment and in Secrett's irrigations the amount of water applied was so great that most of the contained nutrient must have fallen on the soil, and not been retained by the leaves, so that the difference between solid and spray application of fertilizer was probably not due to leaf absorption, but to the sustained supply of nutrients throughout the season, resulting from the repeated irrigations. Work was started at Rothamsted in 1950 to determine whether plants can absorb appreciable quantities of nutrients from leaf sprays, and to investigate the conditions that affect the amounts so absorbed.

Pot Experiments

Pot experiments were done in which the soil was protected so that the spray could not reach the roots (Thorne, 1954). Spraying barley, Brussels sprouts, French beans, tomato and sugar beet daily for several weeks with a solution containing nitrogen, phosphorus and potassium increased the content of all three nutrients and dry weight of plants of all the species. Increase in nutrient content occurred whether nutrient supply to the roots was high or low, and was approximately proportional to the concentration of nutrient in the spray and the frequency of spraying. Previously, Lewis (1936) had found that the phosphorus content, but not the nitrogen or potassium contents, of lettuces growing in a phosphorus-deficient soil was increased by spraying the leaves daily for 5 weeks with a solution containing nitrogen, phosphorus and potassium.

These experiments established that sprays containing several nutrients could increase the nutrient content of plants by as much as 100 per cent, and might in some circumstances cause similar increases in dry weight. They did not prove, however, that nitrogen, phosphorus and potassium were all absorbed by leaves, because absorption of one nutrient by the leaves might have increased uptake of others by the roots. In order to distinguish the effects of individual nutrients, sprays supplying nitrogen, phosphorus and potassium separately, and in all combinations, were tested on sugar beet (Thorne, 1955). All three nutrients were absorbed through the leaves, and uptake of any one of them was unaffected by the presence of others in the spray. Spraying with nitrogen-containing sprays increased the absorption of phosphorus and potassium by the roots from the soil, and potassium in sprays increased the uptake of phosphorus from the soil.

Nitrogen, but not phosphorus or potassium, fertilizer added to the soil increased the leaf area of sugar beet, and hence also the quantity of nitrogen retained and absorbed by the leaves from an ammonium nitrate spray (Thorne, 1955). None of the nutrients applied to the soil affected the percentage of the nitrogen retained on the leaf that entered the plant. Rodney (1952) showed that apple leaves absorb nitrogen equally easily from sprays of urea, calcium nitrate or ammonium sulphate, and the same result was found for sugar beet (Thorne, 1954). Urea is absorbed very quickly by the leaves of apple, and probably also other species (Cook and Boynton, 1952; Hinsvark *et al.*, 1953). In 2 hours the lower surface of young apple leaves absorbed 60 per cent of the applied urea and the upper surface 13 per cent; after 24 hours the corresponding figures were 80 and 20 per cent. Urea uptake by the lower surface during 2 hours was increased by high leaf nitrogen, unaffected by reducing the carbohydrate in the leaf by shading, and reduced by adding sucrose to the urea spray.

The amount of phosphorus retained and absorbed by leaves of sugar beet from a sodium phosphate spray was increased by nitrogen fertilizer added to the soil, and the percentage absorbed was also apparently slightly increased by nitrogen fertilizer, but unaffected by phosphorus or potassium (Thorne, 1955). Phosphorus uptake by the roots of swedes grown in a very high phosphorus nutrient solution was reduced when phosphorus was applied to the leaves (p. 66). The uptake of phosphorus from a variety of compounds supplied in sprays has been studied by Silberstein and Wittwer (1951), who found that the growth of tomato, maize and French-beans was increased by ortho-phosphoric acid and potassium and ammonium phosphates, but magnesium phosphate and most organic phosphates had little effect. Autoradiographs of whole plants of tomato, maize and French-bean, made a few hours after applying radio-active phosphorus to the leaves, showed that phosphorus is absorbed and translocated to other parts of the plant very rapidly (Silberstein and Wittwer, 1951; Wittwer and Lundahl, 1951). Absorption of ^{32}P by swede leaves increased for 2–3 days after a single application, and then remained constant for another 10 days at about 50 per cent of the amount applied (p. 67). Trebling the concentration of the solution applied to the leaves increased the percentage absorbed slightly, but significantly.

Potassium uptake by sugar-beet leaves from KCl sprays was increased by nitrogen applied to the soil in the same way as was nitrogen and phosphorus uptake. The percentage of the applied potassium absorbed by the leaves appeared to be slightly increased by nitrogen added to the soil, and reduced by potassium. The

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latter effect may be due to reduced uptake by the roots of plants with a high supply of potassium from the soil when sprayed with potassium, because there was no accumulation of unabsorbed potassium on the surface of the leaves (*cf.* phosphorus uptake by swedes).

The quantity of nutrient remaining on the surface of sprayed leaves of sugar beet and removed by washing before harvest was small, showing that most of the nutrient retained by the leaves from sprays was absorbed. Therefore the percentage recoveries of nutrients from sprays were greater than those obtained from fertilizer applied to the soil at sowing (Thorne, 1955). Usually a slightly greater proportion of nutrient applied in sprays than of nutrient applied to the soil remained in the tops. The dry weight increases per unit of nutrient absorbed through the roots were greater than for nutrient absorbed through the leaves. Both these differences between nutrients applied to leaves and soil may be related to the later uptake from sprays; fertilizer nutrients were all applied to the soil at sowing, and those in the spray were supplied continuously throughout the growing season.

The mechanism of leaf absorption is not understood. Nutrients must be able to pass through the cuticle, because urea is absorbed by both surfaces of the hypostomatous apple leaf (Rodney, 1952; Cook and Boynton, 1952). Boynton (1954) claims that absorption also occurs through the stomata, but Fogg (1947) considers this unlikely on theoretical grounds. There is a continuous path of hydrophilic pectic substance from discontinuities in the cutin covering McIntosh apple leaves to the vascular bundle sheaths, along which water-soluble substances could pass (Roberts *et al.*, 1948). Absorption continues, however, long after the leaf is apparently dry, and spraying with water after a phosphate spray had dried did not increase phosphorus uptake by swede leaves (p. 67).

It can be concluded from pot experiments that nitrogen, phosphorus and potassium can all be absorbed by leaves from sprays and that most of the nutrient retained on the leaf is probably absorbed, often within a few days of application. Therefore recoveries in the plant of nutrients applied in sprays are normally greater than of nutrients applied to the soil. In spite of this, the effects on growth of nutrients applied in sprays were smaller than those of nutrients applied to the soil, but this difference would not necessarily occur in pots or in the field if fertilizers were applied simultaneously to soil and leaves.

Field Experiments

Nutrients supplied in sprays will only be absorbed by the leaves of field crops if the volume of solution applied per acre is sufficiently small for most of it to be retained by the leaves and not fall on the soil. Because of this limitation on the volume of spray solution, the quantity of nutrient that can be applied in a single spraying is restricted by the solubility of the fertilizers and the danger of scorching the leaves. Nitrogen is the best major nutrient for application by this method, because, as both urea and ammonium nitrate are highly soluble and rich in nitrogen, dilute solutions contain a relatively high concentration of nitrogen. Urea usually scorches less than ammonium nitrate.

Nitrogen uptake by sugar-beet plants from six sprays of 3 per cent ammonium nitrate or an equivalent urea solution, applied at 100 gal./acre in September, was twice that obtained from similar solutions applied to the soil between the rows (Report of Rothamsted Experimental Station for 1952, p. 67). Seventy per cent of the nitrogen applied in leaf sprays, whether as ammonium nitrate or urea, was recovered in the plant, and 30 per cent was converted into leaf protein. The distribution in the plant was the same for nitrogen absorbed through leaves or roots. In another experiment nitrogen uptake from four 3·4 per cent urea sprays, applied at 100 gal./acre or from one spray of 54·7 per cent urea applied at 25 gal./acre, did not differ significantly, although there was some scorching by the more concentrated spray (Report of Rothamsted Experimental Station for 1953, p. 70). Spraying winter wheat at ear emergence with 3 per cent NH_4NO_3 at 100 gal./acre increased the yield and nitrogen content of grain and straw to the same extent as applying the same solution to the soil at the same time (Report of Rothamsted Experimental Station for 1953, p. 70). Nitrogen applied as urea sprays also had the same effect as soil dressings of urea or other nitrogenous fertilizers on yield and nitrogen content of grass–clover leys, Italian ryegrass (Low and Armitage, 1954) and cereals when given in spring or ear-emergence application (Jealott's Hill, 1953). Urea solutions ranging in concentration from 11 to 44 per cent were used as sprays and applied at 20 gal./acre. Soil dressings and urea sprays have been shown to be equally effective methods of nitrogen application to tomatoes (Montelaro *et al.*, 1952), maize (Foy *et al.*, 1953) and sugar cane (Hawaiian Sugar Planters' Association, 1951). Urea sprays are frequently applied to apple trees, and give responses equal to, or better than, those obtained from soil dressings (Fisher 1952). Tolhurst and Bould (1952) have shown that nitrogen applied to apple trees as urea sprays does not kill the clover in the cover crop, as do soil dressings, and that trees grown in a non-leguminous sward benefit from urea sprays, whereas all the nitrogen in a soil dressing is utilized by the grass.

Spray application of phosphorus, which is easily fixed in the soil, might be an economical method of using the element, but phosphorus appears to have been applied in sprays much less frequently than nitrogen. This may be because annual agricultural crops require phosphorus early in the season when there is only a small leaf area to retain the spray, and because many phosphorus compounds have a low solubility. Silberstein and Wittwer (1951) report an experiment in which 2·7 lb. P_2O_5 per acre applied in four sprays of ortho-phosphoric or glycero-phosphoric acid increased the early yield of tomatoes more than did 135 lb. P_2O_5 per acre applied to the soil as superphosphate before transplanting. However, the total yield was significantly increased only by the soil dressing. Sugar cane is reported to respond well to 8 lb. P_2O_5 per acre applied as a superphosphate solution (Hawaiian Sugar Planters' Association, 1951).

Examples of spray application of potassium are also scarce, although the results that have been reported indicate that the method may be useful. The potash content of a crop of lucerne was increased 35 per cent by the application of 65 lb. K_2O per acre in four potassium sulphate sprays, and equivalent soil dressings gave only one-third this increase (Report of Rothamsted Experimental

Station for 1953, p. 70). The potash content of the crop was already high, and neither leaf nor soil application caused any increase in yield. Tropical crops might benefit from potash application in sprays, because many tropical soils are low in potassium and do not respond well to soil dressings. The yield of sugar cane and potassium per cent of dry weight of the sheaths were the same 5 months after receiving 19 lb. K_2O per acre as a spray as after 200 lb. K_2O applied to the soil (Hawaiian Sugar Planters' Association, 1951). The potassium spray was a 28·5 per cent solution of muriate of potash applied from the air at 10 gal./acre.

Nutrients can be applied in sprays with each other, with pesticides, herbicides, etc., or with trace elements. Several commercial highly soluble mixed fertilizers have been developed for application in solution to leaves or soil, and some have been used experimentally (Gillern, 1950; Arvan and Mowry, 1954; Pirone, 1952). The concentration of salts in a mixed nutrient spray is limited by their solubility and the danger of scorching, so that several applications are required to supply the same quantity of one nutrient as can be applied alone in a single spraying or as a soil dressing. When nutrients are added to fungicidal or insecticidal sprays the phytotoxicity may be increased. According to Hamilton *et al.* (1943), lime added to the spray reduced the injury to apple foliage caused by spraying with sodium or potassium nitrate or ammonium sulphate mixed with wettable sulphur and lead arsenate. Urea caused less damage than other forms of nitrogen when mixed with insecticides. Vegetable crops were damaged by sprays containing ammonium nitrate and arsenicals unless lime was also added, but urea was safe with a number of insecticides and fungicides (Isaacs and Hester, 1954). It is suggested that ammonium nitrate increases and lime decreases the solubility of the arsenates. A 51 per cent solution of ammonium nitrate or a 40 per cent solution of urea was safely applied to winter wheat in April, either alone or mixed with 2-4D (p. 67). Micronutrients can be mixed with major nutrients in sprays or applied alone, and the small quantities required can be easily supplied in a single dilute spray. Trace-element deficiencies are frequently due to soil conditions making the element unavailable to the plant, and are therefore often cured more easily by sprays than by soil application, e.g., manganese deficiency in peas and beetroot (Lewis, 1939; Wallace and Ogilvie, 1941) and boron deficiency in turnips (MacLachlan, 1944).

In field experiments the effects of nutrient sprays are usually of the same order as for soil dressings, and rarely more than two or three times greater. Therefore, spray application does not result in a great saving of fertilizer, but may be preferable to soil application when: (1) soil conditions or a competitive crop make nutrients from soil dressings unavailable; (2) an accurately timed response to fertilizer is required, e.g., a change in the composition of a crop late in the season; (3) routine applications of insecticidal or herbicidal sprays, to which nutrients can be added, are made; (4) the growth of the crop prevents application of fertilizer to the soil but permits it to the leaves from a high-clearance sprayer or helicopter. If crops are to absorb nutrients applied in sprays through their leaves there must be sufficient leaf surface to retain the spray. This limits the usefulness of the application of nutrients in sprays to annual

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agricultural crops, because those most in need of fertilizer, i.e., young or starved crops, have only a small leaf area. Application of sprays is liable to be more expensive than traditional methods of fertilizer distribution, and therefore not economically justifiable, even when a saving in fertilizer results. Thus, although it is now well established that fertilizers applied in leaf sprays can be absorbed by crops and in some circumstances are more effective than fertilizers applied to the soil, the method is not likely to become very widespread. Apart from these practical considerations, nutrient absorption through leaves may prove very useful in theoretical studies on plant nutrition.

References

ARVAN, P. G. & MOWRY, D. T. (1954). High analysis water soluble plant food formulations. *Agric. Chemic.* **9** (3), 47.

BOYNTON, D. (1954). Nutrition by foliar application. *Annu. Rev. Pl. Physiol.* **4**, 31.

COOK, J. A. & BOYNTON, D. (1952). Some factors affecting the absorption of urea by McIntosh apple leaves. *Proc. Amer. Soc. hort. Sci.* **59**, 82.

FISHER, E. G. (1952). The principles underlying foliage applications of urea for nitrogen fertilization of the McIntosh apple. *Ibid.* 91.

FOGG, G. E. (1947). Quantitative studies on the wetting of leaves by water. *Proc. Roy. Soc., B*, **134**, 503.

FOY, C. D., MONTENEGRO, G. & BARBER, S. A. (1953). Foliar feeding of corn with urea nitrogen. *Proc. Soil Sci. Soc. Amer.* **17**, 387.

GILLERN, C. (1950). Untersuchungen über die Wirkung des Laubdüngemittels " Assimilan " auf das Pflanzenwachstum. *Bodenkultur*, **4**, 233.

HAMILTON, J. M., PALMITER, D. H. & ANDERSON, L. C. (1943). Preliminary tests with uramon in foliage sprays as a means of regulating the nitrogen supply of apple trees. *Proc. Amer. Soc. hort. Sci.* **42**, 123.

HAWAIIAN SUGAR PLANTERS' ASSOCIATION (1951). Cultural practices. *Rep. Hawaiian Sug. Exp. Sta. for 1951*, p. 8.

HINSVARK, O. N., WITTWER, S. H. & TUKEY, H. B. (1953). The metabolism of foliar-applied urea. I. Relative rates of $C^{14}O_2$ production by certain vegetable plants treated with labeled urea. *Plant Physiol.* **28**, 70.

ISAACS, R. L. & HESTER, J. B. (1953). Plant nutrients, foliar application to vegetable crops. *J. agric. Food Chem.* **1**, 239.

JEALOTT'S HILL RESEARCH STATION (1953). *Guide Exp. Jealott's H.*, p. 50.

LEWIS, A. H. (1939). Manganese deficiencies in crops. I. Spraying pea crops with solutions of manganese salts to eliminate Marsh Spot. *Emp. J. exp. Agric.* **7**, 150.

LEWIS, D. (1936). A note on the absorption of solutes by leaves. *J. Pomol.* **14**, 391.

LOW, A. J. & ARMITAGE, E. R. (1954). Foliar application of nitrogen on grassland. *Agriculture, Lond.* **61**, 368.

MACLACHLAN, J. D. (1944). Control of water-core of turnips by spraying with borax. *Sci. Agric.* **24**, 327.

MONTELARO, J., HALL, C. B. & JAMISON, F. S. (1952). Studies on the nitrogen nutrition of tomatoes with foliar sprays. *Proc. Amer. Soc. hort. Sci.* **59**, 361.

PIRONE, P. P. (1952). Feeding plants through the leaves. *Gdn J. N. Y. Bot. Gdn* **2**, 45. (*Hort. Abstr.* **23**, 1482.)

ROBERTS, E. A., SOUTHWICK, M.D., & PALMITER, D. H. (1948). A micro-chemical examination of McIntosh apple leaves showing relationship of cell wall constituents to penetration of spray solutions. *Plant Physiol.* **23**, 557.

RODNEY, D. R. (1952). The entrance of nitrogen compounds through the epidermis of apple leaves. *Proc. Amer. Soc. hort. Sci.* **59**, 99.

ROTHAMSTED EXPERIMENTAL STATION (1951). *Results Fld. Exp. for 1949, Rothamst. exp. Sta.*

SECRETT, F. A. (1949). The use and abuse of artificial irrigation on horticultural crops. *J. R. hort. Soc.* **74**, 282.

SILBERSTEIN, O. & WITTWER, S. H. (1951). Foliar application of phosphatic nutrients to vegetable crops. *Proc. Amer. Soc. hort. Sci.* **58**, 179.

N

THORNE, G. N. (1954). Absorption of nitrogen, phosphorus and potassium from nutrient sprays by leaves. *J. exp. Bot.* **5**, 37.

THORNE, G. N. (1955). Interactions of nitrogen, phosphorus and potassium supplied in leaf sprays or in fertilizer added to the soil. *J. exp. Bot.* **6**, 20.

TOLHURST, J. A. H. & BOULD, C. (1953). Nutrient placement in relation to fruit tree nutrition. IV. Experiments with urea sprays on foliage, 1952. *Rep. agric. hort. Res. Sta., Bristol, for 1952*, p. 55.

WALLACE, T. & OGILVIE, L. (1942). Manganese deficiency of agricultural and horticultural crops. Summary of Investigations, Season 1941. *Rep. agric. hort. Res. Sta., Bristol, for 1941*, p. 45.

WITTWER, S. H. & LUNDAHL, W. S. (1951). Autoradiography as an aid in determining the gross absorption and utilization of foliar-applied nutrients. *Plant Physiol.* **26**, 792.