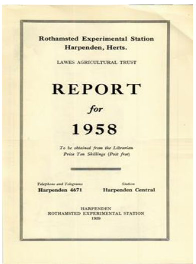
# Report for 1958

*Full Table of Content*




## Special Reviews

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# SOME ASPECTS OF SOIL MINERALOGY

BY

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According to Robinson (1949) "soil may be conveniently considered as being composed of a relatively inert framework of unweathered minerals, together with the so-called clay–humus complex, consisting mainly of the products of the chemical weathering of silicates and with humus, which is the product of the decay of plant and animal residues in the soil". The mineral matter of soils consists of particles of all sizes which, for the purposes of describing the mechanical composition, are conventionally divided into four grades: coarse sand from 2 to 0·2 mm.; fine sand from 0·2 to 0·02 (or 0·05) mm.; silt from 0·02 (0·05) to 0·002 mm.; and clay below 0·002 mm. The sand and silt fractions may be ordinarily regarded as the "relatively inert framework", while the clay is the more reactive part of the soil and is the main seat of the property of base-exchange as well as being largely responsible for the mechanical properties. Primary mineral grains, such as quartz, feldspars, micas, amphiboles, pyroxenes, iron oxides and various accessories, normally constitute the bulk of the sands and silts, although occasionally secondary products of weathering, including concretionary material, may be present. The clay fraction may contain grains of quartz and other resistant primary minerals, but most of it consists of material of secondary origin in the colloidal state which has been formed by the processes of weathering of primary minerals, either in the present environment or during previous cycles of weathering and sedimentation.

Methods for identifying the minerals in soils follow the lines normally used in studies in sedimentary petrography. Because of their amenability to study by the petrological microscope, the coarser material in soils received most attention by earlier workers in soil mineralogy, and much of that work was concerned with identifying the minerals in the fine sand fractions to correlate drifts with geological formations with a view to parent material classification (Hendrick and Ogg, 1916; Hendrick and Newlands, 1923, 1925; Hart, 1929a, b). The constitution of the clay fraction was largely ignored, because suitable techniques for its study were lacking. The applicability of X-ray diffraction to the problem of determining the constitution of fine-grained materials was demonstrated by Hadding (1923) and Rinne (1924), and using this method Hendricks and Fry (1930) and Kelley *et al.* (1931), working independently, showed that the colloidal fractions separated from some selected soils in the U.S.A. contained crystalline particles comparable with those of the layer lattice silicates montmorillonite–beidellite and halloysite. Since then much work has been done on the occurrence of clay minerals in soils, and other techniques employed for their characterization include differential thermal analyses, cation exchange reactions, electron microscopy and infra-red spectrometry.

*Pedogenic weathering*

Not many detailed studies have been made of the changes undergone by rocks and minerals in the course of disintegration and decomposition into clay. It is now realized that all the classical soil-forming factors (parent material, climate, time, topography and biotic agencies) have their influence on the processes of weathering, and consequently on the minerals present in soil colloids, and to assess the importance of the different factors the weathering products of different rock types must be compared under similar environments, and *vice versa*.

Several studies of rock weathering of this kind have been made at Rothamsted. One area studied was the Malvern Hills in the west of England, where the suite of rocks shows great variation from acidic rocks (granite) to highly basic rocks rich either in biotite (biotitite) or in hornblende (appinite): furthermore, there is no glacial or other drift to introduce ambiguities in the relationship of bedrock and soil (Stephen, 1952a, b). The mineralogical composition of the soils was determined by the constitution of the underlying rocks, both as regards the coarser " inherited " particles and the clays. In the sands, quartz and feldspar were the principal minerals in the granite-derived soils, whereas in the soils derived from the basic rocks amphiboles, epidote-clinozoisite and iron oxides occurred in fairly large amounts; the soil derived from the biotitite also contained characteristic yellowish brown glistening flakes of vermiculite. Illite (dioctahedral mica) * was dominant in the clays of the granite-derived soils, and trioctahedral chlorite–vermiculite in those derived from the basic rocks; the presence of these minerals was directly related to the trend of alteration of the primary minerals in the different rock types. The illite appears to be derived exclusively from the breakdown of feldspar in which abundant white mica is developed as hydrothermal inclusions. The operation of the weathering sequence (biotite, hornblende) $\longrightarrow$ chlorite $\longrightarrow$ vermiculite appears to be the conditioning factor leading to the development of the soil clays derived from the basic rocks. Pseudomorphing of original biotite by chlorite in the biotitite, and the development of finely crystalline secondary chlorite at the expense of hornblende in the appinite, was observed in thin sections of the weathered rocks, and further weathering of the chlorite from either source through intermediate stages of mixed chlorite–vermiculite produces vermiculite in the soils. The occurrence in the clays of illite and chlorite, which are early members of the layer lattice silicates in the sequence of weathering proposed by Jackson *et al.* (1948), and the presence of much unweathered (though readily weatherable) minerals in the sand fractions, leads to the conclusion that the soils are at an early stage of development.

The association of acid and basic rocks, as described above, is

* The terms tri- and dioctahedral were proposed by Stevens (1946), the former to designate layer lattice minerals in which all three octahedral positions are occupied, and the latter for those in which one in three octahedral positions is vacant.

common in many regions of igneous intrusion and metamorphism, and a comparative study of two profiles from Ghana, occurring only a few miles apart under similar environments, on two such contrasted rock types (a feldspar–quartz–schist and a hornblende–garnet–gneiss) has shown that, even under the more extreme climatic conditions there, the nature of the parent rock was strongly reflected in the constitution and also the morphology of the derived soils (Stephen, 1953). The acid schist gives a grey quartzose sandy soil containing kaolin–montmorillonite clay, whereas the soil derived from the basic gneiss has the characteristics of a typical tropical black earth (regur) with almost exclusively montmorillonite clay. The more complete weathering of the soils, compared with those on the Malvern Hills, is indicated by the lack of ferromagnesian minerals (amphiboles, pyroxenes) and feldspars in the surface horizons, although these are abundant constituents of the parent rocks.

The degree of crystallinity of rocks may also affect the products of weathering (Muir, 1951). In a soil developed from a holocrystalline olivine-basalt in Syria, the clay was dominantly kaolin, whereas a merocrystalline olivine-basalt with over 70 per cent glass in the ground mass altered to montmorillonite. The two also differed in chemical composition, particularly in the Ca/Mg and Ca/Sr ratios in their exchange-complex.

The probability of drainage conditions influencing the clay minerals in soils was indicated by Nagelschmidt *et al.* (1940), working on Indian soils, and the combined influence of drainage and parent material has been established by Mitchell (1955) for some Scottish soils. Soils developed on drift derived from granite and various metamorphic and sedimentary rocks (quartz–schist, quartzite, Dalradian slates, Old Red Sandstone, etc.) contain illite as the major clay mineral, whereas in those developed on drift from basic igneous source rocks vermiculite or montmorillonite is dominant. The influence of drainage is pronounced in these latter soils, vermiculite tending to prevail in the brown earths with free drainage, and montmorillonite in the gley soils. The same relationship between the production of vermiculite or montmorillonite and drainage conditions in soils derived from basic rocks was also reported by Butler (1953) for soils overlying serpentine in the Lizard area of Cornwall, and by McAleese and Mitchell (1958) for soils derived from basaltic parent material in Northern Ireland.

The great influence of the parent material on the products of weathering is evident in the studies mentioned above, which are mainly confined to temperate regions; but where weathering is intense and prolonged, as under tropical and subtropical conditions, its influence may be greatly lessened or even eliminated. For example, in some parts of Tanganyika, where wet and dry seasons with high temperatures alternate, both acid and basic gneisses give rise to red earths with dominantly kaolinitic clays (Anderson, 1957; Muir *et al.*, 1957). Except where these soils are shallow, only minor amounts of feldspars, ferromagnesian and other primary minerals are present, and it appears that they weather directly to kaolinite, mica and iron oxides; consequently, as stated by Muir *et al.*, " it is only by an examination of the resistant heavy minerals that an indication of the probable source rocks is obtained ".

Weathering of individual minerals has been much studied; much of this work has concerned the micas, as, in addition to being widely distributed in soils, they are potential sources of potassium available to plants. From these studies the process of vermiculitization in the weathering of primary biotite (trioctahedral mica) appears to be common. The vermiculite is formed either *via* mixed-layer biotite–vermiculite intermediate products (Wager, 1945; Walker, 1949; Butler, 1953, 1954) or *via* mixed-layer biotite–chlorite and chlorite–vermiculite products (Stephen, 1952a; Butler, 1953). The most pronounced chemical changes occurring during the weathering of biotite to the expanded-lattice mineral are: loss of potash and magnesia, gain of silica and water, almost complete oxidation of iron and a large increase in cation-exchange capacity. Fewer studies have been made on the weathering of the dioctahedral mica muscovite. A comparative study of muscovite from adamellite and the overlying soil in Cornwall showed that, although structural changes were slight and flakes from both environments gave visually identical X-ray patterns, the loss on ignition from the soil muscovite was greater than from the fresh mineral, and the potash content had decreased (Butler, 1953). The excess of water and deficiency in potash in hydrous micas compared with normal micas can be explained on the basis of substitution of oxonium ions ($H_3O^+$) for potassium in the interlayer positions (Brown and Norrish, 1952).

The occurrence of a mineral which appears to be the dioctahedral analogue of vermiculite was described by Brown (1953, 1954a) in the clays of some gleyed soils developed on Carboniferous till in Lancashire. It is apparently the weathering product of an aluminous mica, as it is dominant in the upper more highly weathered layers, where it replaces dioctahedral hydrous mica, the chief clay component in the lower layers. A similar antipathetic relation with depth between mica and vermiculite occurs in some soils from Anglesey (Muir, 1958), e.g., in the Treuddyn series, a brown earth of low base status developed in drift of Millstone Grit and Mona Complex origin, and in the Dyfnan series, a non-calcareous gley soil derived from drift from Carboniferous shale and limestone.

| | % $K_2O$ in clay | % mica in clay | % vermiculite in clay |
|---|---|---|---|
| *Treuddyn series* | | | |
| 0–5 inches ... ... | 1·59 | 20 | 45 |
| 28–36 inches ... ... | 4·34 | 65 | Nil |
| *Dyfnan series* | | | |
| 0–7 inches ... ... | 0·70 | Trace | 75 |
| 14–23 inches ... ... | 2·71 | 60 | 15 |

The increase in vermiculite at the expense of mica in the surface horizons, together with a decrease in the potash content, suggests that the vermiculite originates by loss of potassium from the mica.

That the degree of alteration of the mica lattice may be important in agronomic practices has been demonstrated by Brown (1954b) for some Irish soil clays. The clay minerals present in the soils were illite (mica), vermiculite, chlorite, kaolin and a material provisionally called " degrading illite ". All the soils that, in field experiments, fix potash contained " degrading illite ", whereas the others did not, and the " degrading illite " may either fix potassium or be related to the actual cause of fixation.

*Study of the detrital minerals*

The mineralogical examination of the sands and silts is greatly facilitated by dividing them into fractions according to specific gravity. This is done by separation in a liquid of high specific gravity, e.g., bromoform (S.G. 2.90). The heavy fraction (S.G. > 2.90) includes the ferromagnesian and related minerals, iron oxides, and various stable accessory minerals such as zircon, tourmaline, rutile, anatase and garnet. Although in immature soils derived from igneous and metamorphic rocks rich in ferromagnesian minerals the amount of " heavy residue " may be 50 per cent or greater, in sediments and derived soils it is often less than 1 per cent, but may contain a wide variety of mineral species, 15–20 being common. These minerals are particularly suitable for purposes of correlation and differentiation, because distinctive associations of minerals are characteristic of different rock types and stratigraphic units. Undoubtedly the most important roles of heavy mineral analyses in pedological studies are in determining the sedentary nature (or otherwise) and the degree of uniformity of the materials comprising the solum, and thus in deciding how far vertical variations reflect pedogenic processes or are geologic in character caused by parent material or depositional differences.

Often a cursory examination of the residues will determine whether or not a soil is derived *in toto* from the underlying formation, as shown by Stephen *et al.* (1956) in a study of tropical black clays with gilgai in Kenya. The soils occur on the Athi Plains to the east of Nairobi, and are underlain by volcanic rocks of trachytic affinities. On the east the plains are bounded by hills of Basement Complex, which contains a wide variety of metamorphic rock types. An examination of the heavy residues of the sands from the soils showed that they could not be entirely derived from the underlying volcanic rocks, as minerals occurring in the lavas and species such as sillimanite, kyanite and staurolite were present in all horizons. The latter are characteristic of metamorphic rocks, and their presence suggested that Basement Complex material had been deposited on the soils possibly by wind transportation during dry Interpluvial periods. These additions then became incorporated in the soils by the churning action resulting from their shrinking and cracking properties.

Studies of " chalk heath " soils on the South Downs and of soils overlying serpentine in Cornwall by Perrin (1956) and Coombe and Frost (1956), respectively, showed that the mineralogical composition of the soils is inconsistent with derivation from the underlying rocks. On the basis of particle-size distribution analyses, they postulated substantial loessial accessions to the soils. Perrin further points out that deposits of a well-graded nature with a maximum particle-size distribution in the silt grade (0·04–0·03 mm.), also considered to be loess-like in character, occur overlying Chalk on the Berkshire Downs, the Carboniferous limestone in Derbyshire and the Clay-with-flints on the Chilterns. Where undisturbed by recent erosion, the superficial layers of both plateau and valley drifts on

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the Chilterns are rich in silt and overlie more clayey subsoil horizons; the non-clay fraction of these subsoil horizons may also be considerably coarser in texture than in the surface layers (Avery, 1958). Although the silty character of the surface soils and the increased clay content of the subsoil could be attributed to pedogenic processes—such as the physical disintegration of sand grains *in situ* to yield silt-sized particles by a mechanism such as frost shattering combined with clay-eluviation from or clay-decomposition in the A-horizons—mineralogical studies indicate that parent material differences are also involved (Stephen, 1957; Loveday, 1958). Soils studied in detail included profiles of the Batcombe series, as mapped by the Soil Survey of England and Wales, which is developed over Clay-with-flints that probably consists largely of the weathered remains of Chalk and Eocene sediments redistributed by ice-action or solifluxion. In these profiles, occurring on level or gently sloping plateau sites where the drift is thick, thin sections show that some physical disintegration of sand grains has taken place and also provide evidence of clay migration and deposition in the heavier-textured B-horizons. In all the profiles studied, however, the coarse silt (0·05–0·02 mm.), and, to a lesser extent, the fine sand (0·2–0·05 mm.) of the surface layers contain heavy residues of a different mineralogical character, and therefore different origin, from that of the subsoil horizons. Non-opaque heavy minerals common to all horizons are zircon, rutile, tourmaline, kyanite and staurolite, but the surface horizons contain a more varied suite, including epidote-clinozoisite, garnet, chlorite and green hornblende, which are rare or absent in the substrata. The mineralogical evidence in conjunction with particle-size distribution studies strongly suggests a loessial origin for a major portion of the silt, and the added wind-blown materials seem to have been incorporated with the underlying drift by solifluxion either during or after their deposition. These profiles have therefore developed in materials of different geologic origin and character and the pedogenic processes have further accentuated the differences.

As well as the fairly widely separated loess-like deposits discussed above, undoubted loess of considerable thickness at Pegwell Bay in Kent has been described by Pitcher, Shearman and Pugh (1954). Such deposits may, therefore, be more widespread than was formerly supposed and they may constitute or contribute to the upper layers of soils over considerable areas in Southern England. One of the areas at present being investigated is the Mendip Hills in Somerset, where it is uncertain whether the soils overlying the Carboniferous limestone are residual or whether they are partly derived from superficial deposits of different origin. These soils have maximum particle-size distributions in the range 0·06–0·02 mm., which has led to the suggestion that they have developed in part in a loessial cover overlying the limestone (Findlay and Clayden, 1958). The insoluble residues from the limestones, however, have a very similar mechanical composition, so it appears that the resolution of the problem will depend on mineralogical evidence, using criteria similar to those advocated by Smithson (1953) to recognise residual soils on Carboniferous limestone in North Wales. After a mineralogical examination of the residues from the limestone the criteria suggested were that the light fraction of the soils should be dominated by quartz euhedra and chert rather than detrital quartz grains, and that the heavy fraction should be small in amount and poor in mineral species. The cover in North Wales is strongly influenced by mixed drift of northern origin, and the limestone may have contributed little to the constitution of the overlying soils but acts rather as " a foster-parent that has imparted to the profile the characteristics of a limestone soil ".

Although normally constituting 95 per cent or more of the sands and silts of soils, the light minerals (S.G. $< 2 \cdot 90$) do not usually receive as much attention as the heavy minerals. In many soils the light fraction is dominated by quartz and contains only few other mineral species, thus making the assemblages less valuable than the heavy residues for purposes of correlation. A study of the light minerals, however, should not be neglected, as the separates often possess features worth attention. Various forms of silica occurring in soils have been described by Smithson (1956), who, besides drawing attention to varieties of quartz and chalcedony, described and depicted characteristically shaped grains of opaline silica occurring in the silts of various British soils. These originate from organic matter, being components of grass leaves, and he suggested that a study of such phytoliths might provide information about the former vegetation and soil conditions of the sites where they occur. Phytoliths derived from *Nardus stricta* have unmistakably characteristic forms, but the shapes of others can only be assigned to tribes of grasses (Smithson, 1958). The presence of phytoliths in palaeosols in Illinois has been noted by Beavers and Stephen (1958), indicating the possibility that they could be used to determine the presence and location of buried A-horizons. The opal phytoliths in some of the palaeosols had been transformed to chalcedony.

An unusual form of chalcedony in soils developed on Clay-with-flints and allied deposits has been reported by Brown and Ollier (1957). The grains, apparently of inorganic origin, occur in a variety of forms ranging from bundles of parallel rods arranged in tabular form to grains with a botryoidal or honeycombed appearance. As silica is considered to be more mobile under tropical conditions, a warmer climate of the past may have promoted their formation. Some support for this hypothesis is given by a consideration of the morphology of the plateau drifts (Avery, 1958). A characteristic feature of these is the incorporation of " relic " soil materials of a braunlehm character with red mottling (rubefication), which according to Kubiëna (1956) occurs in strongly alternating wet–dry regimes of the tropics.

Feldspars also occur in the light fractions of all but the most highly weathered soils and, as specific types of feldspar are typical of different groups of igneous and metamorphic rocks, a study of the variety present may be useful in determining the source of soil materials derived from such rocks (e.g., Muir and Stephen, 1957). As sodic plagioclases are more resistant to weathering than the calcic plagioclases, Graham (1949) has suggested that the Na/Ca ratios of the sands and silts could be used to assess the degree of weathering undergone by soils; and Hawkins and Graham (1950), studying silt separates from the A-horizons of some Missouri soils, showed that

https://doi.org/10.23637/ERADOC-1-91 

the percentages of potash feldspar and plagioclase were in direct proportion to the fertility levels measured by field tests. The relation between the feldspar content and the agronomic potential of soils has also been demonstrated by other workers (e.g., Leenheer, 1950a, b; Jeffries *et al.*, 1953; Jeffries *et al.*, 1956). Other minerals that frequently occur in the light separates are weathered micas, glauconite, calcite and gypsum; these are diagnostic of either derivation from particular types of source rocks or of characteristic weathering regimes.

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# THE USE OF INSECTICIDAL SEED DRESSINGS

By

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Jameson, Thomas and Woodward (1947) showed that the chlorinated hydrocarbon insecticide $\gamma$-BHC applied as a seed dressing at about 0·02 mg./seed could protect the young cereal plant from wireworm attack. This was a most important step in insect pest control of agricultural crops, for it has led to widespread use of insecticide seed dressings against many insect pests, mainly soil insects, including, in Britain, wireworms (*Agriotes* spp.), flea beetles (*Phyllotreta* spp.), wheat-bulb fly (*Leptohylemyia coarctata* Fall.), and onion fly (*Delia antiqua* Meig.). The minute amounts of insecticide used, sometimes as little as 1 oz./acre, avoid undesirable effects such as destroying beneficial soil insects and the accumulation of residues liable to harm the plant or affect its flavour and food value. Cost is small, especially as no extra machinery or labour is needed to apply the insecticide in the field.

At about the time that the chlorinated hydrocarbon insecticides, $\gamma$-BHC, dieldrin, aldrin and heptachlor were being developed as seed dressings against soil insects, some organic phosphorus compounds taken up by roots and seed were shown to move throughout the plant and to kill insects feeding on aerial parts of the plant by their "systemic" action. (Schrader, 1951; Ivy, Iglinsky and Rainwater, 1950; Ripper, Greenslade and Hartley, 1950; Jancke, 1951; David and Gardiner, 1951, 1955.) Some systemic phosphorus insecticides, notably demeton and demeton-methyl, have since proved especially valuable as aerial sprays against aphids (Way, Smith and Potter, 1954; Way, Bardner, Aitkenhead and Van Baer, 1958; Broadbent, Burt and Heathcote, 1956; Hull, 1958), but until recently their use as seed dressings has not been examined in detail with field crops. The systemic phosphorus insecticides yet tested have not been very effective against soil insects (Bardner, 1958; Walker, 1958); conversely, except for $\gamma$-BHC (Starnes, 1950; Shapiro, 1951; Ehrenhardt, 1954; Bradbury and Whitaker, 1956; Jameson, 1958), the chlorinated hydrocarbons have had little systemic activity against insects attacking aerial parts of the plant. Thus, they may be conveniently considered separately. All work on insecticide seed dressings cannot be covered in this review and as seed dressing with chlorinated hydrocarbons is now well established in practice, it is appropriate to discuss mainly their limitations which have led to the recent work at Rothamsted on mode of action and on methods of application. Phosphorus insecticide seed dressings have been used only experimentally except with cotton; results will therefore be given mainly to show where they are likely to prove useful.

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## Chlorinated Hydrocarbon Insecticides

### *Wireworm control*

Since it was first demonstrated that $\gamma$-BHC seed dressing could protect young cereals from wireworm attack, much work has been done on wireworm control by $\gamma$-BHC, aldrin, dieldrin and heptachlor seed dressings especially in North America. Some of this is reviewed by Lilly (1956), Potter, Healy and Raw (1956) and Raw and Potter (1958). Seed dressings have usually protected various seedling crops in the year of application, but there is conflicting evidence about their ability to lower the wireworm population. Potter, Healy and Raw (1956) and Raw and Potter (1958) have made a special study of this problem. In one experiment a seed dressing of 1·2 oz. $\gamma$-BHC/acre on wheat sown in November 1947 was compared with soil treatments where the insecticide was combine drilled at 6 oz. $\gamma$-BHC and broadcast at 1 lb. $\gamma$-BHC/acre. Grain yields in 1948 were respectively 24·0, 24·8 and 30·6 cwt./acre compared with 8·9 in untreated plots. The plots were redrilled with wheat in the autumn of 1948 without further insecticide treatment, and in 1949 yielded 24·2, 37·3 and 39·6 cwt./acre, the yield of the untreated being 28·4. The seed dressing therefore gave a good response in yield, but less than the soil treatments, and unlike these it had no effect on the subsequent crop. The second-year wireworm populations (numbers per plot, square root transformation) were: untreated, 3·30; seed dressing, 3·73; combine-drill, 2·20; broadcast, 1·33, showing that the seed dressing did not kill the wireworms. Presumably it deters them from feeding during early stages of growth when the young plant is especially susceptible, and this would decrease losses of crop when the infestation is small. With large infestations, however, attack at a later stage of growth when the deterrent effect has worn off and when the plant would normally be able to withstand moderate damage, could be harmful, and this may explain why a $\gamma$-BHC seed dressing has sometimes failed to protect a crop against large wireworm populations (Dogger and Lilly, 1949; Kulash, 1953). There are, however, further difficulties in our understanding of how seed dressings act against wireworms, for a seed dressing sometimes kills wireworms—for example, in experiments by Lange, Carlson and Leach (1949), 70–95 per cent of wireworms in the immediate area of the treated seed were killed, and the total population was reduced by about 50 per cent. These, and similar results of Starks and Lilly (1955), were obtained in experiments with late-sown crops, when the wireworms were immediately attracted to the ungerminated or newly germinated seed, in contrast to the conditions studied by Potter, Healy and Raw, in which the crop was sown about 4 months before the wireworms became active; by then the growing seedling would have long since exhausted the seed, and the wireworms would attack the shoot. Therefore, wireworms attacking the ungerminated or newly germinated seed may be either deterred (Long and Lilly, 1958) or killed by contact with the insecticide seed dressing, whereas in attacking the older plant they are unlikely to be killed, but may be deterred by systemic action of insecticide translocated to the shoot. This confirms the general conclusion that seed dressings as used at present against wireworms become less effective as the plants age (Kulash and Munroe, 1955); also, that they must be regarded as methods of obtaining temporary protection and note as a means of destroying the wireworm population in the field (Lange, Carlson and Leach, 1949). It seems certain, however, that seed dressings are not yet being used to the best advantage against wireworms; for example, it would be valuable to know more about their mode of action and to study methods of increasing the dose of insecticide on the seed to levels approaching those which have been successfully applied by combine-drill or as a broadcast treatment.

*Mode of action of seed dressings against certain Diptera*

A wireworm may spend 5 years in the soil before pupating, and populations of overlapping generations can persist many years feeding on the underground parts of many plant species. By contrast, the larvae of soil-inhabiting species of Anthomyidae and Chloropidae (Diptera) normally pupate within 2–8 weeks of hatching; they are mostly specific in their choice of plant hosts, and they usually appear only after the host has been planted. Unlike wireworms, they would soon die if deterred by a seed dressing, not only from lack of alternative wild hosts, but also because they attack the plant as newly hatched larvae which cannot survive without food. It seems their control ought to be simpler than that of wireworms, but in practice the effectiveness of the seed dressings differs greatly with different insect species. A dieldrin seed dressing, for example, can almost completely protect the young onion crop from damage by the larval onion fly, *Delia antiqua* Meig.; it will kill the larva of the closely related wheat-bulb fly, *Leptohylemyia coarctata* Fall., but does not prevent the plant from being damaged; finally, it usually has little or no effect on the larval frit fly, *Oscinella frit* L. Chloropidae.

Way (1950a, 1959b) studied the mode of action of the seed dressings in an attempt to find the circumstances that effect their action against the three species. The simplest and most effective way in which a seed dressing can act is by direct contact with the insect before it attacks the plant. For this to happen, the larva must pass close to the treated seed; therefore, much depends on the position of the eggs and on the behaviour of the newly hatched larva.

Onion-fly eggs are laid on the soil surface close to the plant, but even when the seed was sown 1 inch deep, most of the larvae crawled down to enter the plant at the base of the bulb close to the position of the treated seed. The normal behaviour of newly hatched onion-fly larvae seems to ensure that almost all are killed by contact action before they can damage the plant. This was confirmed by preliminary experiments which showed the onion seedlings, replanted after removal of the dieldrin-treated seed, were no longer protected from onion-fly attack (Way 1959a).

Frit-fly eggs are laid both on the plant and in the soil. Larvae hatching from the former can enter the oat or wheat shoot from within the ensheathing coleoptile and sometimes above soil level. In these circumstances, kill by direct contact with the seed dressing seems unlikely. Larvae hatching from eggs in the soil normally reach and enter the shoot above the seed at, or just below, soil level and thus are unlikely to meet the insecticide unless the seed is shallow sown (Way 1959b). Experimental results have confirmed these conclusions: when dieldrin-dressed wheat seed was sown at three depths—just below the soil surface, at ¼ inch and at 1 inch, the percentages of shoots damaged by frit larvae were 17, 29 and 41 respectively for treated, and 40, 47 and 50 for equivalent untreated control plants. The mean numbers of larvae per plant were 0·3, 0·6 and 0·7 for treated seed and 1·0 for all sowing depths of the untreated. Larvae from eggs in the plant probably formed the majority of the survivors of the shallow-sown treatments. Unfortunately, it is not normally practicable to sow oats or wheat less than about 1 inch deep; hence, the lack of protection from dieldrin seed dressings in practice.

The wheat-bulb fly is unusual because its eggs are laid in August and September well before the host plant, winter wheat, is drilled. The eggs are distributed in the soil by cultivations to a depth of 8 inches or more, and eventually hatch in the following February–March. The newly hatched larvae move upwards, and most reach the surface soil, where they search for the young wheat plant. Therefore, irrespective of the position of the eggs, they mostly behave like onion and frit-fly larvae and reach the plant from near the soil surface. The shoot is entered at a depth of about ¼–1 inch, suggesting that, as with frit-fly larvae, contact action is unlikely unless the seed is shallow sown. This was confirmed by experiments with dieldrin seed dressings, where the calculated kill, probably by direct contact, varied from 0 per cent for a 3 inch sowing depth to 45 per cent at ½ inch (Way 1959a). Experiments in which seedlings were replanted and infested after removing the treated seed, confirmed that the latter was needed to protect the plant from attack.

Thus the contact action of the seed dressing may depend on at least three biological factors: the behaviour of the newly hatched larva (onion, frit and wheat-bulb fly), the position of the seed (frit and wheat-bulb fly) and the position of the egg (frit fly).

Apart from direct contact with the treated seed, the larva may be affected outside the plant by fumigant action and by insecticide picked up by tips of roots and shoots as they emerge from the germinating seed. More important, however, is the possibility that chlorinated hydrocarbon insecticides can act systemically. $\gamma$-BHC is taken up by the plant, and it has already been suggested that wireworms are deterred by insecticide translocated from the seed to the underground parts of the shoot. Furthermore, Gough and Woods (1954) found that larvae of wheat-bulb fly may die after feeding inside wheat shoots growing from dieldrin-treated seed. Experiments in which larvae died after feeding on pieces of shoot, no part of which could have come into contact with the seed dressing, show that the kill is by systemic action (Way, 1959a). This property has made dieldrin, aldrin and heptachlor seed dressings the recommended control measure for wheat-bulb fly, for although the larva usually destroys the first shoot, it is killed before destroying any more. The action of $\gamma$-BHC seed dressing is less clear; $\gamma$-BHC appears to be absorbed and lost by the plant more readily than the other chlorinated hydrocarbons. In the very young seedling, therefore, the higher concentration in the plant, and perhaps inherently greater toxicity, ensures that the wheat-bulb fly larva is usually either killed or deterred before it causes serious damage. The insecticide is then quickly lost, perhaps mainly by volatilization (Bradbury and Whitaker, 1956) at a stage when dieldrin, for example, is still present in lethal concentration in the shoot.

It is surprising that, although systemic action is particularly important for wheat-bulb-fly control and probably in protection from wireworm damage, there is little evidence that either frit- or onion-fly larvae are affected in this way by chlorinated hydrocarbon seed dressings. For example, in experiments with frit fly using dieldrin-dressed seed, the number of dead larvae found in treated plants and the proportion of larvae which survived to become pupae were the same as in untreated plants (Way, 1959b). Systemic action may depend on a delicate balance between uptake and loss of insecticide that is influenced especially by temperature; this would increase loss from dilution by plant growth and by volatilization in late May and June, when frit- and onion-fly larvae are hatching, above that in the colder weather of March to early April when wheat-bulb-fly larvae and wireworms are active.

*The importance of placement of insecticide around the seed*

Way (1959a) showed that, although dieldrin and aldrin need to be placed in contact with either the shoot, roots or seed of the wheat seedling to act systemically against wheat-bulb fly, contact between the insecticide and the seed seemed particularly important. For example, when wheat seeds were planted together in pairs, one dead and one alive, with either the dead or the live seed dressed with dieldrin, contact action killed as many larvae whether the live or dead seed had been treated, whereas systemic action killed a calculated 50 per cent of the larvae when the live seed was treated and only 18 per cent when the dead seed was treated. The value of applying the insecticide to the seed was also convincingly shown by Bardner (1959a), in field trials when aldrin, dieldrin and heptachlor dressings at 3 oz. active ingredient/acre controlled wheat-bulb fly better than aldrin or dieldrin combine drilled at 24 oz./acre. Further, in the control of the aphid, *Myzus persicae* Sulz. on potatoes, Burt (1959) showed that the effect of spot treatments of the systemic phosphorus insecticide "Thimet" lessened as the insecticide was placed at increasing distance from the "seed" tuber. Seed dressings should therefore be valuable when systemic action is important, and also, as in onion-fly control, when seed treatment concentrates the insecticide where the larva is likely to meet it before attacking the plant. This does not necessarily mean that seed treatment is better for systemic action than other methods of soil application, at any rate where persistence is needed. For example, Burt (see above, p. 128) has shown that "Thimet" combined with the fertilizer protected potatoes from aphids better, and for longer, than the same amount placed under the "seed" tuber. This is probably because lasting protection by systemic phosphorus insecticides depends on their continued uptake by the roots, the absorbing region of which may not only grow beyond the area of the treated seed (Way and Needham, 1957) but also becomes concentrated where the fertilizer is placed (Cooke, 1954).

Seed dressings have lacked persistence partly because the dose of insecticide has been limited to what would adhere as a dry dust to the seed. Bardner (see above, p. 130) has recently studied methods of applying larger doses using different " stickers " and " carriers " to enhance both initial and persistent effects. A methyl cellulose sticker for increasing the dose of dieldrin, aldrin and heptachlor has already given promising results in wheat-bulb-fly control (Bardner, 1959; Way, 1959a). Unfortunately, insecticides, especially $\gamma$-BHC and many phosphorus insecticides, are likely to be more phytotoxic as seed dressings at high rates than when applied in other ways, but there is preliminary evidence (p. 130 above) that carriers, such as activated charcoal, and stickers, such as polyvinyl acetate, can release the insecticide comparatively slowly, thereby lessening phytotoxicity and enhancing persistence of systemic action.

## Systemic Phosphorus Insecticides

Laboratory work on systemic phosphorus insecticides has mainly demonstrated their uptake and translocation to aerial parts of the plant where they kill various insects. Early work by Andersson and Ossiannilsson (1951) and Ashdown and Cordner (1952) indicated that crops might be protected from aphids by schradan and demeton seed dressings. Using a demeton seed dressing on spring-sown field beans (*Vicia faba*), Way and Needham (1957) found that, although the insecticide protected the seedling shoot from damage by adult pea and bean weevil (*Sitona lineatus* L.), it had little effect on the bean aphid (*Aphis fabae* Scop.) which colonizes the crop 2–4 months after the seed is sown. The aphid was controlled by demeton dust applied to the seed drill at sowing time, but the dose of active ingredient needed was about 180 times more than that required by a suitably timed demeton aerial spray. In an experiment with potatoes, demeton dust put in the planting hole around the " seed " tuber at rates of 0·125–0·25 gm. of active ingredient/tuber, killed the aphid *Myzus persicae* Sulz. for 40–60 days after planting, whereas 0·5–1 gm. per tuber was needed to protect the plant for more than 112 days. Way and Needham concluded that seed dressings of systemic phosphorus insecticides should be valuable for protecting the young plant shoot soon after germination, especially as an aerial spray is not only difficult to apply at the right time but is wasteful and does not persist in the small, rapidly growing shoot.

The young plant is particularly susceptible to viruses; therefore, the initial protection and persistence provided by a systemic insecticide may be useful in preventing early virus transmission by insects. In this connection Burt (see above, p. 128) showed that " Thimet " and " Rogor " at 0·31 and 0·35 gm. active ingredient/potato seed tuber put in the planting hole kept the crop almost completely free from aphids throughout the period when they usually infest it. The rates, like those of demeton used by Way and Needham, were high, but less insecticide might still give the necessary initial protection. Dunning (see above, p. 194) also obtained promising results with seed dressings of " Thimet ", " Disyston " and " Rogor " on sugar beet. These chemicals not only controlled

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aphids but also lessened the spread of aphid-transmitted yellows virus in the young plants.

Although demeton as a seed dressing may be slightly better than "Thimet" and "Disyston" against aphids (Reynolds, Fukuto, Metcalf and March, 1957), the last-named chemicals are less specific, and as seed dressings they protect the aerial parts of some young crops from various species of Aleyrodidae, Thysanoptera, Diptera, Lepidoptera and Coleoptera as well as Aphidae. (Reynolds, Fukuto, Metcalf and March, 1957; Parencia, Davis and Cowan, 1957; Dunning (see above, p. 194)). Disadvantages of the systemic phosphorus insecticides are that they can be phytotoxic and they are poisonous to mammals and birds. Evidence so far (Reynolds, Fukuto, Metcalf and March, 1957; Burt (see above, p. 129)) showed that dangerous residues can be avoided in some food plants, and the main problem is the handling of such poisonous chemicals as "Thimet", "Disyston" and demeton as concentrated seed dressings during and after their application to the seed. In this respect "Rogor" is apparently less dangerous and is an advance towards the ideal of the safe systemic phosphorus insecticide which, as a seed dressing, should have many uses in agriculture.

## Conclusion

This review has dealt mainly with some of the biological factors that are important in the action of insecticide seed dressings. Little has been said about some other factors that need to be considered before seed dressings can be used to the best advantage, and so that what has been discussed can be put in proper perspective, the main ones are listed below under three main headings. It will be seen that many of the factors are likely to interact.

### (1) *The relationship between the seed dressing and the seed*

Something has been said about the special value and limitations of applying insecticides direct to the seed and also about methods of varying the dose, but the safety margin between the dose which is insecticidal and that which is phytotoxic is especially important, because seed dressings are more likely to harm the young plant than are other methods of soil application.

### (2) *The fate of the insecticide in the soil and in the plant*

This will influence the immediate and lasting effects of insecticides against insects in the soil and on the plant, and is also relevant to the problem of harmful residues. Soil factors include the spread of insecticide through the soil and its rate of disappearance, especially in relation to soil type and root distribution. Plant factors include rate and period of uptake as well as distribution and disappearance of the insecticide in the plant in relation to plant species and age. Little is known about soil problems, and few plant studies relate directly to the action of seed dressings. They are not discussed in this review.

### (3) *The relationship between the insect and the insecticide in the soil and plant*

This involves inherent resistance of the insect, the reaction of the insect to the insecticide and the behaviour of the insect in relation to the plant and to the position of the treated seed. Except for inherent resistance, these problems are discussed in the review.

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