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THE EFFECT OF THE USE OF HERBICIDES FOR
THE CONTROL OF WEEDS ON THE ENVIRONMENT

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Bonnet, a French vine grower, observed the phytocidal effects of Bordeaux Mixture, and in 1896 demonstrated the use of copper sulphate as a selective weed-killer for the destruction of *Sinapis arvensis* in cereal crops. Since then many other inorganic chemicals have been used to kill weeds. However, it was the relatively recent development of the auxin-type herbicides in the mid 1940s that launched the herbicide industry on its meteoric career. Today, well over 150 organic chemicals are listed as herbicides, and in use not only on farms for crop protection, but also for total weed control on industrial sites, rail roads and road sides, aquatic weed control in irrigation channels, rivers and lakes, for brush control in rangeland, in forestry, and even as a weapon in the Vietnam war. Such widespread use in increasing quantities must surely result in the eventual dissemination of herbicides, or their degradation products, in nearly all sectors of the environment.

In recent years there has been much controversy and concern regarding the highly persistent organochlorine insecticides. The detection of the insecticide DDT in the fat of Antarctic seals and penguins, and in the ice of Alaskan glaciers, and in the fat of fish all over the world, though an extreme example, indicates that the pollution of the environment by pesticides on a global scale is a real threat (Cole 1969). This has focussed attention on pesticides in general, and the possible side-effects from their use. Although pesticides are designed to combat a particular pest, they are rarely specific, and affect to a greater or lesser degree, other 'non-target' organisms. The introduction of these highly active chemicals into the environment could therefore conceivably interfere with the complex interactions within natural ecosystems, and upset the 'balance of nature'. This paper reviews some of the side-effects that already have resulted, or may result, from the use of herbicides.

In crop production, herbicides are either applied directly to the soil, or to the aerial parts of plants. In either case, a large proportion of the applied herbicide eventually finds its way into the soil. Soil ecosystems are extremely complex, and the balance between the many and varied populations of soil micro-organisms, are of fundamental importance in maintaining the biological cycling processes on which soil fertility is dependent. What then would be the effect of adding a potentially toxic substance to the soil? Herbicides vary widely in chemical composition from simple inorganic salts such as sodium chlorate, to complex organic compounds, such as monuron. Yet, it is surprising, that in general most of the herbicides that

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have been studied, when tested at concentrations equivalent to recommended doses for weed control, have had no lasting effect on the soil microflora (Fryer & Evans 1968). While this may be an indication of the adaptability of these organisms, it must be conceded that our knowledge in this area is still fragmentary. A few examples will help to illustrate the intricacies involved. Certain types of soil microorganisms produce metabolites which have strong antibiotic properties. It seems highly probable that these substances may depress the activity of other soil microorganisms, thereby giving the antibiotic producer an advantage. One way in which this may be affected has been demonstrated by Naito and his co-workers (Naito 1958 ; Naito & Tani 1955, 1956a & b ; Naito *et al.* 1957). They have demonstrated that the three fungi *Gleosporium olivarum*, *G. kaki* and *Schizophyllum commune*, when grown in media containing 2,4-D, MCPA or 2,4,5-T, produce an antibiotic metabolite, which is active against a range of other fungi. The antibiotic is not produced by the fungus in the absence of the herbicide.

Another interesting observation is that of Westlake (1955), who found that barley plants sprayed with 2,4-D showed a temporary increase in the number of bacteria in the thin film of soil surrounding the roots (rhizosphere). This appears to be caused by an increase in the outflow of bacterial nutrients from the roots, related possibly, to a change in membrane permeability in the root cells of the plant brought about by the herbicide. Or, consider the effects of phenoxyacetic herbicides on *Azotobacter*, an important group of nitrogen-fixing organisms. These effects seem to be dependent on soil conditions and method of application. Vindard *et al.* (1952) have shown that MCPA at 2 Kg/hectare has no effect on *Azotobacter* in a lime-rich soil, but in a soil poorer in lime, MCPA applied in liquid form considerably reduces colonies of *Azotobacter*, while application in powder form has no effect. There are also reports, that *Azotobacter* can be stimulated at low concentrations (Vindard 1952 ; Nair *et al.* 1957). Also, species differ in their sensitivity, *A. chroococum* being about ten times more sensitive than *A. agile*. *A. agile* also has the ability to acquire tolerance, as subculturing three times allowed good growth in 5000 ppm, which at first was markedly inhibiting (Colmer 1953a & b).

These side-effects resulted in no more than a temporary upset in the ecological balance, and, on the whole, herbicides at normal field rates have had no lasting effects on soil bacteria and fungi. However, the subtle nature of the changes, and the difficulties involved in their investigation, not the least of which is an incomplete understanding of soil ecology, focus attention on the need for greater concern and research in this field.

Contact herbicides are used extensively for the pre-harvest desiccation of crops such as peas, field beans, potatoes and cotton, to facilitate mechanical harvesting. Wilkinson (1969) has demonstrated that herbicide residues on the desiccated plant material alters the patterns of colonization of the moribund plant tissues by fungi. Her results showed that diquat residues on desiccated field beans reduced the ability of *Trichoderma viride* to compete with *Fusarium culmorum*. This enabled *F. culmorum* to become established on the plant debris, and was a complete reversal of the situation on unsprayed plants which were colonized by *T. viride*. Similar results have been obtained of the suppression of *T. viride* in favour of *F. culmorum* on potato haulm treated with diquat at rates comparable to those used for pre-harvest desiccation. Paraquat and MCPA also caused similar changes in the outcome of

competition for a substrate (Wilkinson & Lucas 1969). These indirect effects of herbicide use on the patterns of microbial colonization of crop residues are of practical significance, in that *T. viride* which is suppressed is well-known for its antagonism towards other fungi, including pathogens, and *F. culmorum* which is favoured is a pathogen of cereals. Furthermore, diquat is used for desiccating potato haulm, and cereals frequently follow potatoes in a rotation.

Some pathogens, are also known to survive saprophytically in tissues of plants which they have parasitized, to invade subsequent crops. For example, *Ophiobolus graminis* which causes Take-all Disease in wheat and barley is carried over in infected stubble. Its survival is inversely related to the activity of other micro-organisms in the stubble. Herbicides which affect micro-organisms differentially may alter the rate at which the plant debris is decomposed, and thus indirectly affect the survival of pathogens within them.

The large-scale introduction of chemical methods of weed control have led to reductions in soil cultivations. The ultimate goal in this direction is to develop a no-tillage or minimum-tillage system of crop husbandry. In this system the soil is not tilled at all, no seed bed is prepared and the seed is drilled directly into the stubble which has been killed by herbicides. The introduction of herbicides such as diquat and paraquat—they give a rapid kill of weeds by contact action but no residual effects on crops sown soon after—have enabled the development of such a system. The elimination or reduction of mechanical cultivation (together with the protection of the soil surface by the weed debris) results in increased rainfall acceptance, reduced run-off, reduced wind and water erosion. The elimination of the deleterious effect of cultivation on soil aggregation, is probably the greatest agronomic benefit from this technique. These changes in the physical environment of soil organisms must necessarily influence their ecology. Brooks & Dawson (1968) have shown that winter wheat, drilled directly into stubble or pasture killed with paraquat, is less severely affected by Take-all Disease (*O. graminis*), than wheat drilled after cultivation. Their investigations revealed that paraquat does not have a direct effect on *O. graminis*. The reduction of disease is associated with factors resulting from the no-tillage technique, which limit the rate of spread of the fungus in the undisturbed soil. On the other hand the undisturbed mulch could increase certain insect problems. Shear (1968) reports that in several instances army worm damage has increased on corn direct-drilled into rye mulches.

Pest incidence also appears to be influenced by herbicide use. Aphid infestations increased on oats sprayed with 2,4-D amine (Adams & Drew 1965). The activity of three coccinellid predators of aphids was reduced by 2,4-D amine. This probably accounts for the increase in the aphid population. Aphids have also been shown to reproduce more rapidly on broad beans treated with 2,4-D (Muzik 1970). It is well established that 2,4-D brings about changes in the biochemical composition of treated plants and the greater acceptability of treated plants to pests may well be influenced by these changes. Ishii & Hirano (1963) found that the growth of rice stem borer (*Chilo suppressalis*) on 2,4-D treated rice plants was more rapid than on untreated plants. The mere addition of 2,4-D to the diet of borers did not improve borer growth. It was concluded that the growth increases of the larvae were due to an increased nitrogen content of the treated rice plants, rather than to a direct effect of the chemical itself.

The outstanding selectivity of some herbicides is changing the patterns of arable cropping. It has become possible to dispense with crop rotation as an aid to weed control. Sequence of four or five cereal crops in successive years are common in the United Kingdom. The use of atrazine has allowed maize to be grown year after year in Canada. The build-up and spread of pests and diseases in these vast monocultures is not unpredictable.

The continued use of herbicides with a similar spectrum of activity have been shown to bring about changes in the composition of the weed flora. The original susceptible weed flora may be gradually replaced by resistant weeds. Linser (1951) reported that seed obtained from weeds that survived 2,4-D treatment, produced plants twice as resistant to 2,4-D as the previous generation had been. In Hawaii, Hanson (1956) reported that *Erechtites hieracifolia* which had previously been controlled in sugar-cane plantations by applications of 2,4-D has developed resistant strains. In sugar cane, rice and temperate cereals, susceptible species have been replaced with grasses after the repeated use of phenoxy acids (Kasasian 1971). The repeated use of triazines have also led to the build-up of *Cyperus* spp. The trend towards perennial weeds is to be seen in many parts of the world where chemicals have replaced traditional methods. Unless these perennial weeds are at least kept under control until efficient eradictory methods are developed there is a threat of replacing the 'easily-killed' weeds with 'difficult to kill' weeds.

Another aspect of the resistant weed problem is that sometimes there is a close taxonomic relationship between the crop and the resistant weeds. The grass weeds in the cereals and the chenopodiaceous weeds in sugar beet are examples. The importance of these associations from a crop protection point of view has not received sufficient consideration.

In step with the increase in perennials is a decline in the numbers and diversity of annual weeds easily controlled by herbicides. Wix (1968) reports the reduction of charlock (*Sinapis arvensis*) in arable areas in Britain because of the use of herbicides. This, he says has made it difficult for bees to maintain themselves during the hungry gap between the spring and summer flora. The use of herbicides on road sides, hedgerows and headlands have further reduced wild flowers and aggravated the position. It is likely that the changes in the weed flora would have an impact on other insects as well, and possibly upset the pest-predator-parasite balance.

The foregoing, though not an exhaustive review of the side-effects caused by herbicides, is sufficient to illustrate their potential for bringing about ecological changes. There is little doubt that herbicides have an important role in crop production. Herbicide usage has had an influence on many individual aspects of crop growing procedures, and on the crop environment as well. Herbicide use is likely to expand, and new techniques based on herbicide use speedily adopted. It is, therefore, all the more urgent to develop a multi-disciplinary approach in evaluating new weed control techniques, bearing in mind their inter-actions with other cultural operations, environmental factors, pests and diseases.

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