# SESSION 5

## ALTERNATIVE APPROACHES

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INVITED PAPERS 5-1 to 5-4

SESSION 5

# WEED CONTROL PRACTICE ON AN ORGANIC FARM

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ABSTRACT

Concern about the long-term effects of pesticides on the environment has generated increasing interest in farming practices which use reduced or no pesticide inputs. This paper describes the "organic" way of controlling weeds as practiced on a large farm (1650 acres) in Wiltshire. Basic principles such as preventing annuals from seeding, timeliness of operations, attention to detail and working with, rather than against, Nature, are considered in relation to control of annual and perennial weeds in cereals, grass and root crops.

## INTRODUCTION

I really feel most embarrassed to find myself on the same platform as these learned gentlemen and to be addressing an audience with whom, I suspect, I have very little in common - as far as farming practices go at any rate! We have been hearing about alternative approaches to weed control largely because of such things as "herbicide resistance" and "the impact of agrochemicals on the environment". What I have to present is the organic way of controlling weeds on the large farm (ours is 1650 acres, now all converted), which means using no chemicals of any sort. In common with other organic farmers and growers we are doing this because of a very real fear that no one knows what we are doing by applying all these poisons - and they are poisons, whatever we like to dress them up as - to our land and crops. The word environment is the 'in' word just now - but just because we use it does not mean that we are any nearer understanding the long term effect these chemicals may have on our soils, our plants, our animals, and ultimately on our own lives. Barely a week passes without some instance of poisoning being reported, and when you couple this with the story of the thalidomide tragedy, and Rachel Carson's exposure of the DDT story of bio-magnification, you must, in all conscience, begin to wonder whether all is well on our farms today under the present system of farming.

I warned you that we would probably not exactly be in accord on the subject before us this morning! However, I have been asked to speak on the organic farmers approach to weed control, and while it is difficult to separate any one activity on an organic farm from another, because the whole process is interdependent and because what you do (or perhaps, don't do) one year may well be the cause of your problems in the years ahead, there are some basic principles that we have to observe and obey if we want weed-free crops.

You may well be excused for thinking that all organic farmers crops are sure to be smothered in weeds. One has only to look around the countryside in early summer to see the strips left by the sprayers. These misses will be full of weeds - weed grasses, charlock, poppies or wild oats, - or a mixture of all of them! If a field, you will say, that has been sprayed continuously for ten years can be so infested where the sprayer misses, then obviously the organic grower, the man whose whole field is unsprayed, must have whole fields like these strips. Gentlemen, the P.R. boys of the agro-chemical industry are the best in the world! They have persuaded - I thought of saying conned, but I would like some lunch! - they have persuaded the farming fraternity that you cannot grow good clean crops without chemicals. I hope you will believe me when I say that this is rubbish. We have many visitors to our farm at Rushall and the predominant remark when they have been round is "Amazing - I wouldn't have thought it possible". This is borne out by an incident that occurred a few years ago. We erected a sign saying "no chemical fertilizers or sprays since 1972" in a field of Maris Wigeon winter wheat. This caused one I.C.I. salesman to stop and investigate (if he is here today I hope I have got it right - it was reported to me by our Mill Manager). Having looked at the crop he went into the Mill and asked what the sign meant. When our Mill Manager told him it meant exactly what it said his comment was "I just don't believe it". Incidentally, the field yielded 2 ton 7 cwts to the acre.

WEED CONTROL PRINCIPLES

So how do we control weeds in our cereal crops - and indeed in all our crops? After listening to so much technical, scientific talk on the subject, what I have to say may well sound old fashioned and obsolete. Nevertheless it works, and did work for many hundreds of years before the advent of chemicals. The underlying principles are simple:

1. Do not allow annuals to seed.
2. Timeliness of operations.
3. Constant attention to detail.
4. Work with, rather than against, Nature.

I accept that these are not earth shattering revelations, but if they are applied, clean crops can still be grown. I will deal first with cereals and explain how we apply these principles to wheat, oats and barley.

Quite obviously, not allowing annuals to seed means having no annuals in the crop as any present will have seeded by harvest. Hoeing cereals on a large acreage is not practical. To eliminate annuals we employ the "weed strike" or "false seed bed" technique. This means preparing the ground for planting some 10-14 days before drilling actually takes place. With normal weather conditions and a little bit of luck, all the weed seeds in the top 2" or so will start into growth ideally to the white string stage when they are very vulnerable, and the subsequent mechanical actions of drilling and harrowing will eliminate the majority of the weeds and volunteer cereals. Following this procedure usually results in the surviving level of weed infestation not being sufficient to depress the crop's yield. This is what I believe and it is borne out by the preliminary results of an ADAS monitoring project currently being done at Rushall. Some, and I would not disagree with them, say that a certain level of weeds is indeed advantageous to the ecology of a field and, if one accepts this, it raises the question, in another way, of whether a completely "clean" crop is in some way harmful to the local ecological systems. However, this is outside my terms of reference.

The second principle, timeliness, is in my view one of the most critical. It is so easy to get excited when all about you are planting earlier and earlier. The temptation to follow suit is sometimes almost irresistable. I think most farmers would agree that, provided you don't miss an opportunity in farming, Nature will atone for her aberrations. On the other hand, if you fail to take advantage of the opportunities offered, you will in all probability lose out. This applies very much in organic farming. By timeliness I mean such things as waiting for a weed strike, delaying the start of drilling until mid-October, cutting thistles in July when they will be sure to die, ploughing for spring crops in February rather than November or December and many more besides. I have already explained the weed strike principle. The date of drilling is also critical. By not drilling before mid-October you can effect a very good control over black grass, which can be a serious problem on our heavy land. This is a far cheaper control measure than planting early and spraying. As my farm Manager so aptly puts it "If you plant in September, you must spray in November."

We have been talking about annuals, but as we all know, there are perennials as well, notably couch (of both sorts) docks, nettles and thistles. In our system we seek to control these by means of the bastard fallow. Before going into that I ought briefly to outline our rotation. We are trying to establish a simple 8 year rotation consisting of 3 years long ley, 2 years winter wheat, (the second undersown red clover/Italian ryegrass) hay, winter wheat, winter oats (undersown long ley). With so many winter crops, any couch or docks have ample opportunity to multiply and so we find it essential, once in eight years, to have a bastard fallow, something which modern farmers and their advisers seldom contemplate. In the last year of the long ley we take hay from the field and then immediately break it up. Thus, we have the three normally driest months - July, August and September - to work the ground to kill off the ley and any perennial weeds that may be there. This is really the only opportunity we have of doing this and it is vital to the maintenance of clean fields. The experts tell us that we lose a certain amount of organic nitrogen every time we cultivate a field in this way, but we feel it is a price we have to pay to maintain the cleanliness of the farm.

The principle of constant attention to detail really means the farmers presence. The old adage that the best fertiliser is the farmers foot is so very true of organic farming. For instance, harrowing a field today may mean a clean crop because the following week may be wet. By the time it has dried enough to work the weeds will have gained too strong a hold to be dealt with by surface cultivations. The same applies to topping a ley. The annuals may be stopped from seeding today whereas next week may be too late.

It appears that there might well be another way of ensuring a clean crop of spring barley. Recently, one of our fields was planted by my Manager when I wasn't looking. The field was previously kale, grazed by the sheep in early spring and destined to be sown to spring barley. My idea was that we should go through the usual routine, plough, work down to a seed bed, leave for 10-14 days for a weed strike and then plant. My manager, who is now a great enthusiast for our system of farming, heard the weather forecast one night and decided that it he didn't get it in the next day, he might not get it in at all. So he set to and ploughed, disced and planted it and the job was done before I knew anything about it. I told him in no uncertain terms that he had gone completely against all our principles and that the crop would be completely smothered in weeds and would be hopeless etc. etc. In the event, I have had to eat my words as the final crop was weed free and yielded well. However, we may have stumbled onto something important. Perhaps early planting with a slightly higher seed rate may effectively smother the weeds that would otherwise smother the crop. We shall have to experiment again.

This reminds me that we are trying to achieve a smothering effect already. One way is to grow tall varieties of wheat. Maris Wigeon, is and always has been, our main standby and last year we invested in a new narrow spacing drill - 4 1/4" against the old 7". We need plenty of straw, for bedding or for feed, and because we use no bag nitrogen we have no fear of serious lodging by using the taller varieties. With the narrower drill we feel that we spread the plants more evenly over the soil. Hitherto, incidentally, I had always felt that a narrow drill would clog, but now that we are fully organic and our fields are clean, this is no longer a problem!

Let us turn now to our root crops. Having given you our rotation you may be surprised to hear that we do grow roots as they didn't figure in the rotation. The explanation is that we only grow some 50-60 acres of roots as cattle and sheep fodder. As this is way below 1/8 of our arable land they are grown where they are needed, and do not go right round the farm. I have to be honest and say that "where needed" could also be interpreted as where the foxes and pheasants need some cover. We grow kale, clean swedes and mangolds and again, if I may say so, you could be forgiven for thinking that our crops would be hidden by fat hen, charlock, and the like when you see some chemical farmers efforts in this direction. I say some because this year I have been most impressed by the cleanliness of the potato crop. I have seen some really splendid looking fields of spuds which were so level and clean you could play snooker on them. But to return to our roots. We grow these on land that has been dunged the previous autumn. Usually this is following a second crop of winter wheat. The straw is baled or chopped and cultivated in, dung spread, worked into the surface and the field left to green up over the winter. It is important in our system not to leave a field in bare fallow over winter. The weeds that grow over the autumn and winter lock up nutrients that would otherwise tend to be leached out. When we plough in the Spring these nutrients become available to the chosen crop. Having ploughed in March or April we work the land to achieve a seed bed by 10 days or a fortnight before we want to plant. Then by shaving or harrowing we can destroy the weeds and hope for a clean crop. You will see that this doesn't really entail any more work than the chemical farmer has to do, it just has to be timed correctly.

Using this system, we grow some 4 or 5 acres of mangolds. They are planted somewhere about the middle of May and clamped in early November. These are eaten by the housed cattle after the swedes have all gone, from about March until the grass comes. Cattle really enjoy mangolds at that time of year, often preferring them to their cake. A yard full of cattle eating mangolds sounds just like a room full of kids eating apples! We also grow about 20 to 25 acres of clean swedes, precision drilled and mechanically lifted with an old beet harvester. These are fed chopped, with rolled oats, to the young calves and whole to the older ones and the outliers. Lastly kale which is, of course, the easiest to grow as, once well established, it tends to defeat the weeds.

I would not want you to think that we never get any weeds in our roots - we do. But provided we have done the basics right it is quite easy to deal with the rest with a gang of boys or girls in the holidays.

Our grass leys are the easiest to manage as there is virtually nothing you can do except prevent the annuals from seeding. Any wild oats from the preceding crop that happen to germinate are either eaten or decapitated, and so do not build up in numbers. One of the reasons for the really disgraceful fields of wild oats one sees around the countryside is surely the abuse of sound farming principles by people trying to grow continuous corn. A ley system, a mixed system, is the time honoured way of keeping your farm clean as during its time under ley the more persistent annuals like wild oats and sterile brome are prevented from seeding and those that do grow are finished for ever.

SOME ECONOMIC ASPECTS OF ORGANIC FARMING

There are one or two points which are always raised in discussions about organic farming and it is worth touching on these briefly. The first is - "How can you make organic farming pay?"" We base our system on wheat and stock. The wheat is for flour which we grind ourselves and bake some, and the stock being beef, sheep and horses. Some typical returns are shown in Table 1. These figures for wheat were prepared by ADAS from the 1983 and 1984 harvests and give you an idea of the comparison between our system and our neighbours on similar land, but using chemicals.

TABLE 1

Average costs and returns for wheat in 1983 and 1984.

| | £/ha CONVENTIONAL | £/ha ORGANIC |
|---|---|---|
| Seed | 40.60 | 48.80 |
| Cultivation Costs | 65.38 | 75.72 |
| Harvesting Costs | 58.00 | 58.00 |
| Fertiliser | 118.28 | Nil |
| Sprays | 96.43 | Nil |
| Total Costs | 378.69 | 182.52 |
| Average Yield | 7.4 t/ha | 4.4 t/ha |
| Returns at standard prices * | 838.60 | 528.00 |
| Returns at organic premium price (£160/t) | N/A | 704.00 |
| Flour (£200/t) | | 880.00 |
| Margin @ standard prices * | 439.90 | 345.50 |
| @ premium price | N/A | 521.50 |
| @ flour price | N/A | 697.48 |

* Where a variety is suitable for milling it is presumed to have been sold as such.

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Of course, we cannot grow wheat continuously on our system, but contrary to popular opinion, the stock show a very satisfactory return. As I said earlier, on an organic farm one must look at the whole rather than at individual enterprises as they are so interdependent. The leys build up the fertility for the corn, and the corn break enables us to keep the land free of perennials.

The second point is "It's all very well for you but if everyone tried to do it there would not be a premium and then we could not survive". From farmers, this is fair comment, but from the agricultural economists it is somewhat hollow. They are forever telling us first to find our markets and then produce for those markets. Now that we have done so (successfully as I like to think), they seem to find that wrong. But to farmers who seriously ask the question I would say this: All the main farm commodity prices are controlled (rigged if you like) by the Government or the CAP or both. Last season a 3.5 ton/acre crop of feed wheat sold into intervention for six months and then exported onto the world market cost some taxpayer or other £105/acre. We organic farmers get no subsidies for selling wheat. Give us the £105/acre and we would happily forego our premium. In effect, what I am saying is that chemical farmers are kept in business by the taxpayer who could do the same for organic farming if they so wished.

In conclusion, I will return to the subject of weeds. As one gets older I find that the borderline between weeds and wild flowers shifts quite rapidly. As a young man I was as lethal with sprays as the 'best' of the modern farmers. But age brings tolerance and I would like to hope that when you see some of the beautiful wild flowers on our farms, they will remind you, as they have reminded me, that it is so easy to destroy, so difficult to create.

# ALLELOPATHY : A VIABLE STRATEGY FOR WEED CONTROL?

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## ABSTRACT

Allelopathy produces a variety of impacts in agricultural and natural ecosystems including influences on plant succession, patterning of plants, inhibition of nitrogen fixation and nitrification, and chemical inhibition of seed germination and decay. The major challenges to weed scientists are to minimize the negative impacts of weed allelopathy on crop growth and yield, and to exploit allelochemicals as additional crop protection strategies. Secondary plant products, microbial products, or their synthetic analogs may provide the next generation of pesticides and growth regulants. Joint efforts of weed scientists, chemists, microbiologists, ecologists, and probably others, will be required to achieve these objectives. Research on the science of allelopathy offers unlimited opportunities to contribute both practical solutions to agricultural problems and fundamental knowledge regarding the chemistry and biology of interspecies relationships.

## INTRODUCTION

The term allelopathy was first used by Molisch (1937). The term generally refers to chemical effects of one plant species (the donor) on the germination, growth, or development of another species (the recipient). Allelopathy is different from other mechanisms of plant interference (allelospoly, allelomediation) in that the detrimental effect is exerted through release of chemical inhibitors (allelochemicals) by the donor species. Microbes associated with higher plants may also play a role in production or release of the inhibitors (McCalla and Haskins, 1964). Other mechanisms of interference involve subtractive processes (removal or less effective utilization of resources).

Allelopathy is included in a higher-level order of chemical ecology. Whittaker and Feeny (1971) have classified allelochemicals on the basis of whether the adaptive advantage goes to the donor or recipient. Allomones, which give adaptive advantage to the producer, include repellants, escape substances, suppressants, venoms, inductants, counteractants, and attractants. Allelopathic chemicals are usually classified as suppressants. Some inhibitors from plants also induce intraspecific effects (autotoxicity). Proof of allelopathy requires rigorous protocols similar to that of Koch's postulates (Fuerst and Putnam, 1983). There are many instances of alleged allelopathy that still require considerably more proof.

## IMPACTS ON AGRICULTURAL SYSTEMS

Impacts on agriculture were apparently recognized by Democritus and Theophrastus in the fifth and third century BC respectively, by deCandolle in 1832, and certainly more recently by many ecologists and agronomists (Rice, 1984, Putnam and Duke, 1978). Allelopathy has been related to problems with weed:crop interference (Bell and Koeppe, 1972), with phytotoxicity in stubble mulch farming (McCalla and Haskins, 1964), with certain types of crop rotations (Shreiner and Reed, 1907), and with orchard replanting (Borner, 1959) or forest regeneration (Horsley, 1977). In some alleged allelopathic interactions, it is not proven whether reduced crop growth is a direct result of plant toxins, or whether the toxins may precondition the crop plant to invasions by plant pathogens. Rice (1984), indicated that allelopathy may contribute to the weed seed longevity problem through at least two mechanisms: Chemical inhibitors in the seed may prevent seed decay induced by microbes or the inhibitors function to keep seed dormant, but viable for many years.

There is considerable evidence that allelopathy may contribute to patterning of vegetation in natural ecosystems (Bell and Muller, 1973). Distinct zones of inhibition are present under and adjacent to a variety of woody species, and often toxins from their litter are implicated (delMoral and Muller, 1970). One might speculate that aggressive perennial weed species that quickly gain dominance may do so by allelopathic mechanisms.

RELEASE OF ALLELOCHEMICALS

Chemicals with allelopathic potential are present in virtually all plant tissues, including leaves, stems, roots, rhizomes, flowers, fruits, and seeds. Whether these compounds are released from the plant to the environment in quantities sufficient to elicit a response, remains the critical question in field studies of allelopathy. Allelochemics may be released from plant tissues in a variety of ways, including volatilization, root exudation, leaching, and decomposition of the plant residues.

Reports on volatile toxins originate primarily from studies on plants found in more arid regions of the world. Among the genera shown to release volatiles are Artemisia, Eucalyptus, and Salvia (Rice, 1984). When identified, the compounds were found to be mainly mono- and sesquiterpenes. Work of Muller (1965) has indicated that these compounds may be absorbed as vapor by surrounding plants, be absorbed from condensate in dew, or they may reach the soil and be taken up by plant roots.

Numerous compounds are also released by plant roots (Rovira, 1969). The compounds are actively exuded or leaked, and may also arise from dead cells sloughing off the roots. Much of the evidence for root-mediated allelopathy has come from studies where nutrient solutions cycled by the root systems of one plant are added to media containing the indicator species. Recent research by Tang and Young (1982) successfully utilized an adsorptive column (XAD-4) to selectively trap organic, hydrophobic root exudates while allowing nutrient ions and other hydrophilic compounds to pass through. They identified 16 compounds exuded from the roots of Bigalta limporgrass (Hemarthia altissima) representing a variety of benzoic, cinnamic, and phenolic acids.

Allelochemicals may be leached from the aerial portions of plants by rainwater or by fog-drip (Tukey, 1966). Among compounds shown to be leached from plants are organic acids, sugars, amino acids, pectic substances, gibberellic acids, terpenoids, alkaloids, and phenolic compounds. Colton and Einhellig (1980) suggested that leaf leachates of velvetleaf (Abutilon theophrasti) are inhibitory to soybean (Glycine max). We have recently discovered specialized trichomes on the stems and petioles of velvetleaf plants which exude toxic chemicals.

After death of the plant, chemicals may be released directly by leaching of their residues. A variety of compounds may impose their toxicities either additively or synergistically. Microbes in the rhizosphere can also produce toxic compounds by enzymatic degradation of conjugates or polymers present in the plant tissue. Examples of this phenomenon are the action by microbes on the cyanogenic glycosides of johnsongrass (Sorghum halepense), and Prunus species to produce toxic HCN, and the corresponding benzaldehydes (Conn, 1980).

The toxicity arising from plant residues provides challenging problems and opportunities for agronomists and weed scientists. Where stubble-mulch farming has been practiced in the plains states of the United States for soil and water conservation, toxins from the stubble have proven toxic to certain rotational crops (McCalla and Haskins, 1964). Since there is a movement toward conservation tillage (including no-tillage) practices which preserve surface plant residues, these can influence crop emergence, growth, and productivity, and have similar influence on weed emergence and growth. Our recent work indicates that management of selected crop residues e.g. rye (Secale), wheat (Triticum) and Sorghum species can greatly reduce weed germination and growth (Putnam and DeFrank, 1983).

## FAMILIES OF ALLELOCHEMICALS

Inhibitors from plants and their associated microbes represent a myriad of chemical compounds from the extremely simple gases and aliphatic compounds to complex multi-ringed aromatic compounds.

The groups of compounds implicated in allelopathy have been divided into chemical classes by recent reviewers (Rice, 1984, Putnam, 1985). They can be arbitrarily classed as (A) toxic gases, (B) organic acids and aldehydes, (C) aromatic acids, (D) simple unsaturated lactones, (E) coumarins, (F) quinones, (G) flavonoids, (H) tannins, (I) alkaloids, (J) terpenoids and steroids and (K) miscellaneous and unknowns. Although many of these compounds are secondary products of plant metabolism, several are also degradation products which occur in the presence of microbial enzymes.

Swain (1977) recently reported that over 10,000 low-molecular weight secondary products have already been isolated from higher plants and fungi. In addition, he proposed that the total number might approximate 400,000 chemicals. Some of these chemicals or their analogs could provide important new sources of agricultural chemicals for the future. There is considerable interest within industry on at least two approaches involving allelochemics for weed control. One involves the production of crops (perhaps through genetic engineering) which can either themselves suppress associated weeds or provide a source of chemicals. Another approach is to produce natural herbicides through batch culture with microorganisms. Two phosphonated amino acid herbicides (bialophos and glufosinate) have already been discovered using this approach.

## ECOLOGICAL IMPACTS

Plant succession, particularly in old fields and cut-over forests has intrigued ecologists for many decades. The appearance and disappearance of species and changes in species dominance over time has been attributed to numerous factors including physical changes in the habitat, seed production and dispersal, competition for resources, or combinations of all these.

Rice and co-workers (1984) presents extensive evidence that allelopathy may play an important role in the disappearance of the pioneer weeds (those most rapidly invading old fields). Additional findings in this area could help us manage vegetation more effectively.

Certain reforestation problems have also been linked to allelopathy. For example, there are logged-over sites on the Allegheny Plateau in Northwestern Pennsylvania that have remained essentially treeless for up to eighty years (Horsley, 1977). Several herbaceous weed species have been shown to produce toxins that inhibit establishment of the black cherry (*Prunus serotina*) seedlings that normally reinfest these sites. Among the more active are goldenrods (Solidago) and *Aster* species. We wonder why this idea could not be exploited for vegetation management on right-of-way lands.

In many ecosystems, plants tend to pattern themselves as pure stands or as individuals spaced in rather specific densities or configurations. Many desert species show obvious zones of inhibition around which few, if any, aliens are allowed to invade. These patterns often cannot be adequately explained by competition along, and are probably caused by a combination of factors including allelopathy. The phenomenon happens with herbaceous plants as well as woody shrubs and trees.

Muller (1969) reported that black mustard (*Brassica nigra*) can form almost pure stands after invading annual grasslands of coastal southern California. This was attributed to inhibitors released from the dead stalks and leaves which do not allow germination and growth of other plants. These observations provide agronomists hope that similar results could be exploited with crops, specifically to achieve almost pure stands of crops (over weeds) by use of an allelopathic mechanism.

IMPACTS ON WEED SCIENCE

There is considerable evidence now accumulated to suggest that some of the more aggressive perennial weed species, including quackgrass (*Agropyron repens*) (Gabor and Veatch, 1981), Canada thistle (*Cirsium arvense*), Johnsongrass (Nicollier, et. al, 1983), and yellow nutsedge (*Cyperus esculentus*) (Drost and Doll, 1980) may impose allelopathic influences, particularly through toxins released from their residues. There are also several annual weed species in which allelopathy is implicated. Perhaps best documented is giant foxtail (*Setaria faberi*) whose residues have been shown to severely inhibit the growth of corn (*Zea mays*) (Bell and Koeppe, 1972).

Extracts of several important weed species were found to inhibit the nodulation of legumes by *Rhizobium* (Rice, 1984). Among those were Western ragweed (*Ambrosia psilostachya*), large crabgrass (*Digtaria sanguinalis*), prostrate spurge (*Euphorbia supina*) and annual sunflower (*Helianthus annuus*). Our recent studies indicate that quackgrass residues release compounds that are inhibitory to root growth, nodulation, and nitrogen fixation on a number of legumes. Adverse effects of weeds on N-fixation appears to be an agricultural problem that deserves much more research attention.

The classic seed burial studies of W. J. Beal and his successors have shown seeds of at least one weed species, Moth Mullein (*Verbascum blattaria*) can remain viable in soil for a period of 100 years, whereas three continued to germinate after 80 years of burial (Kivilaan and Bandursky, 1973). Weed seeds not only resist decay by soil microbes, but they vary in dormancy characteristics. There is considerable evidence that chemical inhibitors are responsible for both phenomena. Unsaturated lactones and phenolic compounds in particular, are potent antimicrobial compounds and are present in many seeds (Rice, 1984). Fruits and seeds are also known to contain diverse germination inhibitors including phenolic compounds, flavonoids and/or their glycosides and tannins. Unique methods to destroy inhibitors could provide an excellent weed management strategy.

Recently, some weed scientists have attempted to directly exploit allelopathy as a weed management strategy. One approach has been to screen for allelopathic types in germplasm collections of crops, the idea being to ultimately transfer this character into cultivars by either conventional breeding or other genetic transfer techniques. Superior weed suppressing types have been reported from searches of cucumber (Cucumis sativus) (Putnam and Duke, 1974), oat (Avena sativa) (Fay and Duke, 1977), sunflower (Leather, 1983), and soybean collections (Massantini, et. al., 1977). When thoroughly researched, this idea may be particularly suited to crop plants that are maintained in high density monocultures i.e. turfgrasses, forage grasses, or legumes.

Another approach has been to utilize allelopathic rotational crops or companion plants in annual or perennial cropping systems. Living rye (Secale cereale L.) and its residues have been shown to provide nearly complete suppression of a variety of agroecosystem weeds (Barnes and Putnam, 1983). Similarly, residues of sorghums, barley (Hordeum), wheat (Triticum) and oats can provide exceptional suppression of certain weed species (Putnam and DeFrank, 1983). These approaches could keep several weed scientists occupied for a number of years.

Allelopathic plants may also provide a strategy for vegetation management in aquatic systems. The diminutive spikerush (Eleocharis coloradoensis) has been reported to displace more vigorous and unwanted aquatic plants i.e. pondweeds (Potamogenton species) and Elodea in canals and drainage ditches. Frank and Dechoretz (1980) attributed this to allelopathic effects, and more recently the phototoxic compound dihydroactinidiolide (DAD) was isolated and characterized from the spikerush plant (Stevens and Merrill, 1980). This chemical has since been shown to be inhibitory to pondweeds.

Another payoff from allelopathy research may be the discovery of novel chemistries that could be useful as pesticides or precursers of pesticides. Both higher plants and microorganisms are rich sources of diverse chemistry. Some excellent leads are now being made in this area.

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# MICROBIAL PHYTOTOXINS

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## ABSTRACT

For microbial phytotoxins to contribute to the discovery of new herbicides, the challenges of identification and production by fermentation must be overcome. Possible solutions are discussed and illustrated with examples from the pharmaceutical and pesticide industries . Advances in biotechnology coupled with the structural diversity of microbial phytotoxins will ensure that they play an important role in the future search for novel herbicides.

## INTRODUCTION

In this paper we wish to examine the argument that microbial phytotoxins will, in the near future, make a significant impact in weed control. This is currently not the case as very few phytotoxins (Table 1) have been turned into commercial herbicides. If microbial phytotoxins are to make an impact in the search for novel herbicides they must serve as one of the following:

A) Starting structures (i.e. leads) for the chemical synthesis of analogues
B) Building blocks (i.e. leads) for further chemical/microbial modification
C) Commercially viable products in their own right

These last two options may require production of the toxin by fermentation.

The challenge which faces commercial organisations is how to discover the microbial phytotoxin and then, if necessary, be able to produce it economically by fermentation. It is this challenge and some solutions, in particular offered by biotechnology, which we will now discuss. There is little precedence in the herbicide area on which to draw, however, we can also use examples from the pharmaceutical and animal health industries where microbial metabolites have had a major impact as a source of novel antibiotics and therapeutics.

## 5—3

Table 1

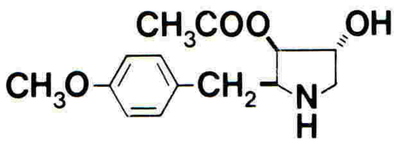
Examples of Patented Phytotoxins+ Grouped by Chemical Type

| | |
|---|---|
| AMINO ACID | NUCLEOSIDES |
| Rhizobitoxin | Herbicidins |
| Gabaculine | Tubercidin |
| | 9-B-D-Arabinoferenosyladenine |
| | Formycin A |
| GLUTARIMIDES | Formycin B |
| Cycloheximide | |
| E-73 | MACROCYCLES |
| Streptimidone | |
| | Ansamycins |
| SUGARS | |
| | Herbimycin |
| 2 - Deoxyglucose | 13 membered lactones |
| 6 - Deoxygalactose | Ascotoxin |
| 6 - Deoxylactose | 14 membered lactones |
| o - Nitrophenylglucophyranoside | Erythromycin |
| Nojirimycin | Oleandomycin |
| Deoxynojirimycin | Leucomycin A1 |
| KA - 3093 | Espinomycin A2 |
| Rhynchosporoside | 22 membered lactones |
| | Cytovaricin |
| PHOSPHINATES | |
| | MISCELLANEOUS |
| *Phosphinothricin (Basta) | |
| *Bialaphos (Herbiace) | Irpexil |
| | Moniliformin |
| | Unknown structures (4) |

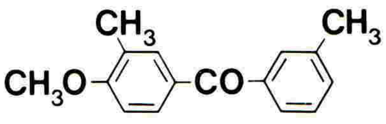
+Phytotoxins are defined as natural products with herbicidal activity
*Herbicides on sale or in development

PHYTOTOXINS FOR SYNTHESIS AND MODIFICATION

The general use of phytotoxins from microorganisms as leads either for chemical synthesis or modification to obtain more active analogues as potential products remains unproven, but was recently reviewed (Fischer & Bellus 1983). One successful example was the use of the phytotoxic natural product anisomycin (1), a lead structure for the synthesis of the rice selective herbicide kayametone (2). Microbial metabolites have provided leads for chemical synthesis and modification for many applications, for example, penicillins, cephalosporins and monobactams as antibacterial agents, (Hamanaka & Kellogg 1984), mevinolin as an anti- hypercholestremic agent (Fears 1983), avermectins as insecticides (Campbell et al 1983), and nucleosides as antiviral agents (Kelly & Beauchamp 1983, Suhadolnik 1979). By analogy phytotoxins from microorganisms should be suitable leads for chemical synthesis of analogues and structural modification. Phytotoxins from microorganisms are found as products of the major biosynthetic pathways of secondary metabolism (Stoessl 1981). Thus such compounds offer a diversity of structural types and, consequently, physical and biological properties.



(1)



(2)

DISCOVERY OF NOVEL PHYTOTOXINS

There are some 5000 known microbially produced antibiotics (Berdy 1980). These chemicals will have been investigated for therapeutic and antimicrobial activity, however few will have been examined for herbicidal activity. Hence, both known and novel metabolites are sources of potentially interesting phytotoxins. For example, phosphinothricin was first described as an antimicrobial agent (Bayer et al 1972, Rupp et al 1979) while gabaculine was first described as a GABA transaminase inhibitor (Kobayashi et al 1976, Flint & Estreicher 1983) and only later were they described as herbicides.

The traditional method of discovering novel bioactive metabolites is to screen newly isolated microorganisms for the desired activity. As it is impossible to screen all microbes, some form of rational selection is essential. The selection criteria must be chosen to optimise the chance of discovering the desired biological activity. One possible strategy is to select ecologically or physiologically related organisms, for example;

Plant pathogens

Plant pathogens have the obvious attraction that many produce phytotoxins. Regrettably the pathology of weeds (the target of most herbicides) is not as well documented as that of commercial crops. Selectivity is often proposed as an inherent advantage of a microbial phytotoxin. Although the host specificity may be a characteristic of the pathogen, it is not necessarily true for the toxin the pathogen produces. The former reflects a more complex microbial/plant interaction.

## 5—3

### Selected taxonomic groups

Of the various groups of microorganisms the actinomycetes, in particular the Streptomyctes, are the most prolific producers of biologically active secondary metabolites (Hopwood & Chater, 1980) and these organisms often form the bulk of a commerical screening programme.

### Novel microorganisms

These can be obtained, for example, from extreme environments or isolated, from the more frequently sampled ecosystems by using some selective factor in the isolation media or conditions.

Once the organism has been selected, the manner in which it is grown will determine the types of metabolites and hence the potential phytotoxins produced. This is because a microorganism's secondary metabolism is sensitive to minor changes in the media or growth conditions (Martin & Demain 1980), and dependant on the organisms growth phase (Bushell & Fryday 1983). An example is the fungus Alternaria eichorniae (a pathogen of the water hyacinth) which produces the phytotoxins alteichin and bosytrysin. They are both produced in Czapek-Dox but not potato-dextrose medium. However, bosytrysin is only produced in shaken rather than still culture (Robeson, et al 1984). While this variability is an advantage in the search for novel compounds it is a considerable problem in producing repeatable results. Analogues of the biosynthetic precursors of the phytotoxin may be added to the culture media to produce novel compounds with potentially different phytotoxic activity (Claridge 1983). The most noted example of the use of this technique has been in the development of the penicillins.

In addition to this physiological approach there is increasingly the possibility of using a genetic approach to the discovery of novel phytotoxins. One technique is the use of mutation, (Claridge 1983), for example, a mutant of Streptomyces aureofaciens produced the antibiotic tetracycline rather than chlortetracycline. More recently Hopwood et al (1985) produced a novel "hybrid" antibiotic from a Streptomycete using a cloning technique. This is an early example of the impact genetic engineering/manipulation will make on the discovery of novel metabolites. These powerful techniques will, allow us to explore the hypothesis that the unexpressed genetic information in, for example, Streptomycete spp. could be coding for novel metabolites (Hopwood & Chater 1980).

Once the strategy for identifying the source of the potential phytotoxin has been decided, the next crucial question is to evaluate the phytotoxic effect.

# CHARACTERISATION AND ISOLATION OF PHYTOTOXINS

It is comparatively easy to obtain a variety of preparations from microbial cultures grown under different conditions. It is often difficult, however, to assess the biological activity of these preparations accurately and then identify those with interesting phytotoxic effects (Yoder 1981).

There are two distinct roles for an assay:

A) To characterise the biological activity of the preparation.
B) To quantify, either absolutely or relatively, the amount of active ingredient present.

In the initial stages of an investigation it is essential to achieve a characterisation of the biological activity of a preparation efficiently, precisely and quickly to decide if isolation of the active principle is warranted. During isolation and associated work on strain improvement, a rapid high-throughput, quantative assay is required. This assay must be a bioassay for the initial isolation and identification of the active principle, but may subsequently be by physical methods alone e.g. HPLC.

In the literature, there are many assays to determine the phytotoxic activity of crude preparations and purified toxins from microorganisms. Most assay procedures described in the literature do not appear to use standards routinely as controls and consequently it is impossible to compare results from different researchers. The assays are also often abstract, using either selected plant tissue, for example, coleoptile sections, or the forced introduction of the assay sample by either a puncture or wounding technique. While such assay methods may be useful to quantify the amount of active ingredient present and follow an isolation procedure, they are not suitable for characterising the biological activity of either the crude preparation or the purified phytotoxin and establishing its potential as a herbicide or a lead for chemical synthesis.

Ideally the phytotoxicity of a preparation should be characterised by a whole plant assay on several plant species, grown in a suitable compost or soil rather than in sand. Symptomology, differences between plant species and the intensity of the phytotoxic effect must be noted. It should be remembered that the relative intensity of the phytotoxic activity of a preparation can be misleading as a criterion of interest, as gross activity at this stage depends on two unknowns, i.e. intrinsic activity and the quantity of phytotoxin present in the preparation. A preparation should be selected for purificaton on the basis of type and overall activity, with the emphasis on novelty and usefulness of effect, if good leads and potential products are to be discovered.

The rediscovery of known actives and rapid identification of novel effects (with a potentially new mode of action) are major problems. Comparison of the bioassay results with a database of the "biological activity fingerprints" of known phytotoxins will permit the rapid elimination of common actives. Conversely such comparisons will also facilitate the identification of novel herbicide effects. Such a database will be hard to generate from the literature, because of incomplete data, and will have to be generated both systematically and by "trial and error". Ideally the biological fingerprint should include data on other types, for example, fungicidal and insecticidal activity.

Cycloheximide is the classic example of a known phytotoxin encountered in any screening programme; it has been isolated from at least nine Streptomyces species, (Laskin & Lechevalier 1984). There are also many analogues of cycloheximide containing the glutarimide ring which are phytotoxic (see Table 2) and may be expected to have similar biological activity. The rapid identificaton of the "glutarimide" type of activity followed by confirmation of the presence of a known compound by chromatographic analysis should allow the elimination of these preparations from the isolation programme.

Table 2

Glutarimide Antibiotics

| COMPOUND | PHYTOTOXIC | COMPOUND | PHYTOTOXIC |
|---|---|---|---|
| CYCLOHEXIMIDE | YES | INACTONE | ND |
| STREPTOVITACIN A | ND | ISOCYCLOHEXIMIDE | ND |
| STREPTOVITACIN B | ND | ACTIPHENOL | ND |
| STREPTOVITACIN C2 | ND | C-73-X | ND |
| E-73 | YES | STREPTIMIDONE | YES |
| NARAMYCIN B | YES | 9-METHYLSTREPTIMIDONE | ND |

ND = NO DATA

In practice, a microbial preparation will contain many components. To ensure separation of these components and to confirm the presence of a known active several analytical methods would be required. Advances in HPLC, GLC and semi-quantitative scanners for TLC will facilitate the development of automatic methods for the analysis of preparations with interesting phytotoxic activity. Using these standard analytical systems, analytical fingerprints could be developed for the known actives. Such fingerprints could be compared with elution profiles of the preparations to determine the probability of a known compound being responsible for the phytotoxic activity. From the analytical methods, it should be possible to measure the amount of known active in the preparation. Ideally, the analytical amount of active should correspond with the quantity determined from the rate response curve of the standard bioassays. Theoretically, any discrepancy between these amounts should correspond to the effect of any unknown in the preparation. However, the variability of bioassays coupled with chemical complexity of the microbial preparations will, in practise, limit the value of this comparative approach.

The isolation of a pure sample of phytotoxin will be necessary before its intrinsic biological activity can be defined. Only if interest is confirmed will a determination of the toxin's structure be undertaken. Any isolation of an unknown phytotoxin will only be as fast and efficient as the bioassay used to monitor the purification methods. A rapid semi-quantitative, abstract bioassay is essential to aid the isolation. The isolation procedure should always be cross checked with the characterisation assay to ensure that the interesting phytotoxic activity is still being isolated.

The ease of isolation of a phytotoxin from the crude culture preparation will depend on the difference in physical properties between the toxin and other components and the relative amount of active toxin present. For some classes of molecules, the isolation is relatively simple. Those with acidic or basic functional groups, like bialaphos or phosphinothricin, can be concentrated and purified using ion exchange resins. For other classes of molecules, the isolation is difficult, for example, those with similar polarity, molecular weight and functionality to other components of the mixture. Provided there is sufficient pure isolated phytotoxin available modern analytical techniques should enable the rapid determination of the molecular structure.

## PRODUCTION BY FERMENTATION

If the biological spectrum of the phytotoxin indicates that it will be a commercially viable herbicide, then a choice between production by fermentation or chemical synthesis will have to be made. To evaluate and develop a microbial phytotoxin a structured plan must be available from the start to ensure that the microbiology is in step with the normal multi-disciplinary development of a pesticide.

Considerable effort is required to achieve economic production of the herbicide by fermentation. Many factors influence the economics of a fermentation process. For example, scale of production, fermentation time and conditions, and the downstream processing. However, the most important factor is the final product yield. Though each case must be considered on its own merits, it is unlikely that a phytotoxin which is not produced in grams per litre would ever be a commercial proposition. Generally the wild strains of microorganisms will usually yield only a few mg of the phytotoxin per litre of broth, yet within one year several kg of the phytotoxin will be needed for field trials and preliminary toxicology. As Ritchie (1985) has pointed out a fermentation capacity of 8000l would be required for 8 months to produce just 1 kg of product using a strain with a yield of 10 mg/l.

Yield improvement is crucial but can only be attempted when two criteria have been satisfied. The organism must be genetically stable and a high throughput analytical technique must be available to monitor progress. A two pronged, complementary approach can be used to improve the yield, firstly, modifications can be made to the media/fermentation conditions; for example altering the organisms growth rate, nutrient supply or by feeding precursors of the phytotoxin. The second, approach is to change the organisms genotype. Traditionally this is done by mutation followed by selection for overproducing strains. The strength and weakness of mutation is its unpredictability and non- specific nature. However, mutation has achieved some notable successes, for example, some streptomycete products are now produced in excess of 30 g/l.

The modern methods of genetic manipulation are making, or promise soon to make, significant contributions to the search for high yielding strains. For example, Hamlyn and Ball (1979) used protoplast fusion to obtain a strain of Acremonium chrysogenum (Cephalosporium acremonium) with a 40% better yield of cephalosporin C than the higher-yielding parent.

A phytotoxin can be the product of a multienzyme pathway (as are most secondary metabolites) or the product of one gene (as are some peptides). For the former, but perhaps not the latter, mutation and selection still remains the optimal route for yield improvement (Nisbet & Winstanley, 1983). As more detailed information on biosynthesis and its regulation becomes available, gene cloning should be valuable, while techniques such as cell fusion can be used to combine the desired characteristics from mutated strains.

The medium must be optimised for the higher producing strains whether produced by mutation or genetic engineering. The optimisation is a compromise between the nutrients required to give the highest yield, the cost of these nutrients and the product separation.

## CONCLUSION

There is no evidence, that we are aware of, to support the often made claims that microbial phytotoxins are intrinsically safer, cheaper, more selective or possess more advantageous persistence characteristics than synthetic herbicides. Such claims, however, are unnecessary to justify research on microbial phytotoxins, as either starting structures or building blocks for chemical synthesis or commercially viable herbicides. The promised diversity of chemical structure, coupled with the advances in biotechnology, will make microbial phytotoxins an attractive and viable area for herbicide research.

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# SPECIFIC WEED CONTROL WITH MYCOHERBICIDES

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## ABSTRACT

Mycoherbicides, formulations of fungus spores, kill specific weeds as effectively as chemical herbicides. Applied innundatively, using the same technologies as for chemicals, they kill weeds within 3 to 5 weeks. After weed death, the pathogen returns to background levels.

Mycoherbicides may be combined with certain herbicides and plant growth regulators or integrated with fungicide use. Data requirements for EPA registration are significantly less than for chemicals.

Mycoherbicides are consistent with current trends to develop more active, more selective, environmentally safe herbicides and are cheaper to develop than conventional organic chemicals.

## INTRODUCTION

The biological, technical and commercial feasibility of using specific fungal pathogens of weeds as mycoherbicides to kill native weeds has been demonstrated with two indigenous pathogens in the United States (Bowers, 1985; Woodhead and Kenney, 1985). Viable fungus spores, formulated either as a wettable powder or as a suspension, are diluted and applied each season with standard spray equipment just as chemical herbicides are used. They are termed mycoherbicides to denote their composition and use pattern; to distinguish them from the classical biological control strategy of introduction, self-perpetuation and passive dissemination (Templeton, TeBeest and Smith, 1979; Templeton and Greaves, 1984; Templeton, TeBeest and Smith, 1984; TeBeest and Templeton 1985).

Mycoherbicides are developed from pathogens that normally incite disease at endemic levels in specific weed populations. Endemic diseases are defined as those that are more or less constantly present from year to year in a moderate to severe form (Walker, 1969). They usually are constrained from epidemic development by innate deficiency of the pathogen to disseminate. It is also implied that environmental conditions are usually favourable for inoculum to develop, infection to take place and disease development to ensue. When the pathogen is applied as innundative inoculum, it infects and kills the weed within 3 to 5 weeks, and after death of the host plant, is reduced to background levels by natural constraints. Consequently there is little or no residual weed control from season to season after mycoherbicide application, particularly if it is an aerial pathogen. Some carry-over may occur with mycoherbicides produced from soil-borne pathogens (Ridings, 1985; Smith, 1985).

## EFFICACY AND UTILITY OF MYCOHERBICIDES

The mycoherbicide COLLEGO™ is used to control *Aeschynomene virginica* (L.) B.S.P. (Northern Jointvetch) in rice and soybeans in Arkansas and DEVINE™ is used to control *Morrenia odorata* Lindl. (Stranglervine) in

Florida citrus groves (Ridings, Mitchell, Schoulties and ElGholl 1976). They have been available commercially for 4 and 5 years respectively. These mycoherbicides are as effective as chemicals and have been well accepted by growers. The results of efficacy tests with a mycoherbicide in rice and soybeans are presented in Tables 1 and 2.

TABLE 1

Control of *A. virginica* (L) B.S.P. (Northern Jointvetch) in rice fields with mycoherbicide Collego™ 1972 to 1982[a] (After Smith, 1985)

| Year | Tests | Hectares treated | Average control % |
|---|---|---|---|
| 1972 | 1 | 1 | 95 |
| 1973 | 4 | 32 | 97 |
| 1974 | 8 | 191 | 76 |
| 1975 | 17 | 234 | 94 |
| 1976 | 20 | 76 | 93 |
| 1977 | 19 | 218 | 98 |
| 1978 | 13 | 112 | 94 |
| 1979 | 17 | 157 | 96 |
| 1980 | 22 | 214 | 86 |
| 1981 | 15 | 248 | 98 |
| 1982 | 2 | 18 | 90 |

[a] Mycoherbicide applied aerially to flooded rice fields non-replicated trials.

TABLE 2

Control of *A. virginica* (L.) B.S.P. (Northern Jointvetch) in soybean fields with the mycoherbicide Collego™ 1976 to 1981[a] (After Smith 1985)

| Year | Tests | Hectares treated | Average control % |
|---|---|---|---|
| 1976 | 4 | 15 | 100 |
| 1977 | 6 | 48 | 99 |
| 1978 | 2 | 20 | 100 |
| 1979 | 5 | 39 | 100 |
| 1980 | 7 | 67 | 91 |
| 1981 | 5 | 58 | 100 |

[a] Mycoherbicides applied aerially to soybean fields in non-replicated trials. Fields were wet from irrigation or rain just before applying the mycoherbicide.

The use of mycoherbicides appears to have greatest potential for weed control in non-agricultural areas, waterways, public use areas, rangelands and pastures (Templeton and Smith, 1977; Templeton and Trujillo, 1981). Application can be made to these areas during periods when environmental conditions and host physiological state are optimum for infection and disease development (Charudattan, 1984a, 1984b, 1985). However, they can also be integrated successfully into intensively cultivated agricultural systems that rely heavily upon chemical pesticides (Boyette, Templeton and Smith, 1979; Quimby and Walker, 1982; Smith, 1982; Klerk, Smith and TeBeest, 1985). This may be done by multiple sequential application, tank mixing with certain chemicals or using natural selections or mutants with tolerance to specific fungicides (TeBeest, 1984). Selectivity of certain chemicals can be extended with mycoherbicides. For example, trifluralin can be tank mixed with an indigenous collar-rot fungus to control Texas gourd, a weed that is not controlled by the chemical alone (Yu and Templeton, 1983; Boyette, Templeton, Oliver 1984).

## PRODUCTION AND FORMULATION

Mycoherbicides, in many cases, may be produced in existing fermentation facilities (Kenney, Conway and Riding, 1979; Couch and Kenney, 1981; Bowers, 1982; Churchill, 1982). Depending upon the fungus selected, large scale production may be simple or technically difficult. Some fungi can produce spores in submerged fermentation whereas some produce only mycelial threads which must be transferred to solid surfaces for sporulation. Others, obligate parasites, have not yet been cultured in artificial media. Immobilization of mycelium in agar-gel pellets is a mechanism for inducing spore production of fungi which require solid substrates. Spores may be harvested from the dried pellets or the spore-covered pellets may be applied to weeds and serve as a source of recurring inoculum in the field (Walker, 1982; Walker and Connick, 1983).

Most aerial pathogens can be dried and stored successfully at temperatures from 4 to 26°C. With some of the lower fungi, the watermolds, this is not possible. These are sold as suspensions for immediate use, being prepared on a custom basis.

## REGISTRATION OF "BIORATIONAL" PESTICIDES

The data requirements for EPA registration of mycoherbicides are significantly less than for chemical pesticides (Charudattan, 1982; Anonymous, 1982, 1983). Tests required are arranged in tiers of increasing complexity and duration. If the data from Tier I tests fall within acceptable levels then further tiers are not required. EPA Data Requirements for Tier I Biorational Pesticides are summarised in Table 3.

TABLE 3

Synopsis of EPA Data Requirements (Tier I) Biorational Pesticides

| Product analysis | Residue data |
|---|---|
| Product identity | Required only if Tier II or III toxicology are required |
| Manufacturing process | |
| Discussion of formulation of unintentional ingredients | |
| Analysis of samples | |

TABLE 3 cont'd

Product analysis
- Certification of limits
- Analytical methods
- Physical and chemical properties
- Submittal of sample

Tier I

| Toxicology | Nontarget organism; fate and expression |
|---|---|
| Acute oral | Avian oral |
| Acute dermal | Avian injection |
| Acute inhalation | Wild mammals |
| IV,IC,IP injection | Freshwater fish |
| Primary dermal | Freshwater invertebrates |
| Primary eye | Estuarine and marine animal |
| Hypersensitivity study | Nontarget insect |
| Hypersensitivity incidents | Honey bee |
| Cellular immune response | |
| Tissue culture (for viruses) | |

## COLLABORATION OF PUBLIC AND PRIVATE SECTORS

Commercialization of the two mycoherbicides developed in the United States has been a cooperative research and development effort of public and private sectors (Kenney, Conway and Riding, 1979; Templeton, Smith and Klomparens, 1980; Bowers, 1982, 1985). The organisms were found and evaluated by public sector scientists. Subsequently, the private sector provided fermentation and formulation technology plus registration and marketing expertise. A regional research project has been established in the southern region of the United States to enhance such collaboration. State and Federal weed scientists and plant pathologists from thirteen states are participating in this endeavor. The project provides a mechanism for area-wide searches for organisms on specific weeds and area-wide evaluation of promising candidate pathogens. It is also a means of encouraging industry to be involved and support extramural discovery and lead development, a facet of herbicide development usually achieved in-house in traditional agrochemical industries.

## PATHOGENS WITH POTENTIAL

The pathogens known from the literature to attack some of the more intransigent weeds are not so numerous in most cases as the pathogens known for major economic crops. Attention to weed diseases obviously has not received the same emphasis among agricultural scientists. Diseases of weeds are, however, quite abundant and increasing interest in their potential as biological herbicides has strengthened this interest (Daniel, Templeton, Smith and Fox, 1973; Hasan, 1974; Ridings, Mitchell, Schoulties and ElGholl, 1976; Boyette, Templeton and Smith, 1979; Scheepens, 1980; Walker, 1981, 1982; Scheepens and Van Zon, 1982). A list of potential biocontrol fungi for several serious weeds has been prepared by Sedlar et al. (1983), (Table 4).

TABLE 4

Numbers of fungi, other than rust fungi, associated with some specific weeds. (After Sedlar et al. 1983)

| Weeds | Numbers of fungi |
|---|---|
| Carduus nutans, C. pycnocephalus, Carduus species | 63 |
| Centaurea diffusa, C. maulosa C. solstitialis, Centaurea species | 106 |
| Chondrilla juncea, Chondrilla species | 22 |
| Cirsium arvense, C. vulgare, Cirsium species | 17 |
| Senecio alpinus, S. jacobaea, S. vulgaris, Senecio species | 99 |
| Convolvulus arvensis, C. sepium, Convolvulus species | 52 |
| Euphorbia cyparissias, E. esula, E. virgata, Euphorbia species | 71 |
| Rumex crispus, R. obtusifolia, Rumex species | 55 |

The USDA Index of Plant Diseases in the United States, even though quite out-of-date, lists many candidate pathogens. The Commonwealth Mycological Institute, with its publication Index of Fungi, is ideally suited as a source of known weed pathogens throughout the world and should be encouraged to compile lists of pathogens described on specific weeds.

A great deal of research and evaluation must be done to determine the extent to which mycoherbicides can serve as alternatives to chemical herbicides. The comparatively low development/registration costs, their high activity and specificity, and lack of adverse environmental effects suggest that they may become widely used a) for specific weeds that represent small market sizes or b) for specific weeds in multiple crops. Mycoherbicides are, thus, consistent with the current trend in herbicide development to control weeds with more active, more selective, environmentally safe herbicides and to do this at costs that are lower than required for conventional organic chemicals (Braunholtz, 1981; Hill, 1982). In view of the increasing constraints on public funds, it is essential that industry should become involved in supporting the discovery and early research into mycoherbicides.

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# SESSION 6

## CROP RESIDUES IN SOILS

CHAIRMAN MR E. J. LESTER

SESSION ORGANISER MR C. E. FLINT

INVITED PAPERS 6-1 to 6-6

# STRAW INCORPORATION - TECHNIQUES AND PROBLEMS

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## ABSTRACT

In 1983 there was an estimated 6 million tonnes of straw surplus to requirement. The only feasible alternative to burning, in the absence of a major change in alternative uses of straw, is incorporation and in 1984, 7% of straw was disposed of in this way. Reductions in crop yields and extra expenditure as a result of incorporation are problems that are likely to be encountered. However, recent Agricultural Development and Advisory Service (ADAS) experiments would suggest that reductions need not exceed 3% provided guidelines are carefully followed.

There are 2 distinct methods of incorporation: inversion with the plough and mixing into soil with tines and discs. Incorporation by ploughing is less prone to yield loss than mixing but involves substantially more time and energy. For most soils, ploughing is the best option but for slow draining clays the choice is less obvious and a more reliable non-plough system would be attractive. Problems associated with incorporation by mixing are more weeds, more nitrogen deficiency and more slug damage.

Changes in weed control efficiency associated with incorporation could be economically critical. Where straw is well inverted by ploughing, volunteer and grass weed problems are likely to be minimal, but incorporation by mixing will inevitably increase grass weed competition and will call for very effective control systems.

## INTRODUCTION

With increasing cereal yields and more specialised crop production, the quantity of surplus straw in the United Kingdom is estimated at 6 million tonnes (Larkin 1984). Disposal of this surplus has been and still is, mainly by burning, but resistance to this practice has increased and since 1984 burning has been restricted by regulations. In England and Wales 40% of straw was burned in 1983 and only 2% incorporated; a similar proportion was burned in 1984 but 7% was incorporated largely in place of straw baling (MAFF 1984).

Experiments in Britain lasting 19 years showed that where straw was burned or incorporated at rates of 1.9-3.8 tonnes/ha/year, crop yields were maintained irrespective of straw management, provided that additional nitrogen fertiliser was applied to compensate for immobilisation (Short 1973). So why the current concern over straw incorporation? This concern stems from the following:-

1. The large quantities of straw produced by today's crops.
2. The incompatability of shallow cultivation systems with incorporation.
3. The likely extra cost of incorporation compared with burning.

# 6—1

Acceptance of current knowledge about straw incorporation is not helped by several common preconceptions, in particular that:

1. A fine straw chop is essential.
2. Unless straw is premixed before ploughing yields will suffer.
3. A rapid rate of straw decomposition is necessary to avoid loss of yield.
4. Incorporation will cause severe grass weed problems.
5. Autumn nitrogen will be needed to avoid loss of yield.
6. Large yield reductions will result from incorporation.

Some of these statements are not borne out by experience or experiment: others are true but only in part. This paper examines evidence relevant to these statements.

There is not, as yet, common usage of terms for straw incorporation. In this paper the following definitions are used:

| | |
|---|---|
| Incorporation | - disposal of straw by placing it into soil by any method. |
| Mixing | - incorporation using implements other than the mouldboard plough. |
| Inversion | - incorporation with the mouldboard plough. |
| Anaerobic conditions | - decomposition of organic residues in the absence of oxygen. |

Methods of incorporation compared

There are 2 distinct methods of incorporation: inversion with the plough and mixing into soil using tined implements or discs. Shallow mixing (5-10 cm) of straw from high yielding crops can severely depress yields (Lynch 1980, Rydberg 1982 and Oliphant 1982). More recently deeper mixing of straw (10-15 cm) has given less severe yield reduction averaging 3% compared with burned treatments (Rule 1985). Incorporation by ploughing in the same trials gave negligible yield loss compared with burning.

It will be helpful to consider the problems and risks of the 2 types of incorporation by means of the summary table 1.

TABLE 1

Potential problems of straw incorporation relative to burning followed by shallow cultivation (less than 10 cm)

| Risks | Straw incorporated by Ploughing | Mixing |
|---|---|---|
| Need for extra cultivation. | Time and energy spent on cultivation will be greater. | Similar cultivation need. |
| Unconsolidated seedbeds. | Greater risk. | Greater risk. |
| Poorer establishment due to cloddy seedbeds. | Greater risk. | Not a problem unless cultivation is deep. |
| Land prone to rain causing loss of traction and delays. | Less risk. | Substantial risks. |
| Volunteer grass weed problems. | Less risk. | Greater risks. |
| Slug damage. | Greater risk. | Greater risk. |
| Trash borne and root diseases | No greater risk noted. | Potentially greater risk. |
| Anaerobic conditions. | Slightly greater risk but not important unless drainage is poor. | Greater risk. |
| Nitrogen deficiency. | No evidence of need for nitrogen. | Greater risk of nitrogen deficiency during first 6 months. |
| Financial cost. | Likely to be greater. | The main extra cost will be yield depression. |

From this analysis it can be deduced that ploughing as a means of incorporation introduces fewer risks and should in general be the advised method. This is undoubtedly true for most sandy and medium textured soils where ploughing is already the "normal" system. However, for clays where shallow cultivation is at present the favoured system of cultivation, the disadvantages of ploughing on a whole farm scale may outweigh the risks associated with incorporation by mixing. There is no universal best option for clayland farmers; it will depend on farm size, existing cultivation machinery, type of clay and the long-term effects of ploughing in straw on soil friability.

Straw chopping

There is a wide consensus that chopping on the combine achieves a better cut for less energy than trailed choppers. However combines of 5 m width or more do not achieve a satisfactory spread of the chopped straw and leave high concentrations of chaff. Length of stubble, length of chop and evenness of spread are less critical for plough incorporation than for mixing. For satisfactory mixing the stubble needs to be short and preferably trimmed after harvest. Straw more than 5 cm long tends to stay at the soil surface and thick patches of chopped straw and chaff hinder drill performance and retard crop growth.

Premixing before ploughing

German experience favours premixing of straw before ploughing but so far experimental results in Britain do not support this practice. An apparent advantage of premixing is improved seedbed quality on some clays but this is mainly a consequence of the loosening effect of premixing, rather than any influence of the straw itself. Premixing obviously involves extra time and energy but in addition it can prove harmful by putting land at risk from rain, increasing the emergence of volunteers and grass weeds and increased risk of early take-all (Yarham 1985) due to loose seedbeds.

Soil type and straw incorporation

Incorporation into some United Kingdom soils presents much greater difficulties than others and such evidence as exists suggest 3 approximate soil type groups (Thomasson 1984).

| Ease of incorporation | Soil description | Examples of soil series |
|---|---|---|
| Easy | Sands, well drained loamy brown earths | Bridgnorth, Newport, Wick, Bromsgrove, Coombe, Batcombe, Adventurers. |
| Some difficulties | Shallow soils over rock, loamy soils with impermeable clay sub-soil and very stony soils | Sherborne, Elmton, Wickham, Salop, Beccles, Hornbeam |
| Difficult | Clay soils | Hanslope, Evesham, Worcester, Denchworth, Windsor, Ragdale, Foggathorpe, Dale, Fladbury, Wallasea |

Soils in the "Easy" group are unlikely to present problems irrespective of climate. Those in the intermediate group are likely to present problems in wet autumns which by definition occur most frequently in the wetter fringe arable areas. Clays will cause problems for incorporation every year but abnormally dry and wet summer/autumn seasons will provide the greater tests. There is a range of physical behaviour in clay soils and in general the non-calcareous higher clay content and slower draining types (pelo-stagnogleys) present more problems for incorporation.

Effect of straw incorporation on soil behaviour

Previous and past experiments do not suggest that sequential incorporation of straw will have significant beneficial effects on soil behaviour, or on crop yield in the short-term. In the longer term (more than 10 years), the extra humified organic material accumulating may have small beneficial effects. Sandy soil (Norfolk Agricultural Station 1971-72) and intractable clays are most likely to benefit; the former through enhanced soil nitrogen status (Mattingly 1973) and available water capacity and the latter through improved friability.

Incorporation and weed control

As with any modification to tillage system changes in weed population and weed control efficiency may become dominant features. Volunteers and annual grass weeds appear to be the critical weed groups and effects of burning versus non-burning and of inversion versus shallow cultivation, the critical management changes.

Well inverted ploughing is likely to minimise volunteers and annual grass weed populations and where, for example, a clayland farmer moves from burning with shallow cultivation to straw chopping and ploughing, he may be able to save on herbicide costs particularly if the wild-oat seed number is low. The quality of ploughing will play a part to the extent that incomplete inversion will allow for more emergence from seeds that have fallen in the previous crop. Premixing as an operation before ploughing can significantly increase weed pressure by hindering burial. On the other hand if premixing encourages weeds and volunteers to emerge before ploughing an advantage may accrue. There is one doubt about the efficacy of ploughing for grass weed control; namely, that seeds of Bromus sterilis (sterile brome) can sometimes survive after poor ploughing particularly if they are not buried more than 12.5 cm deep.

I anticipate incorporation by mixing, unlike ploughing, will inevitably increase volunteer and grass weed pressure compared with burning and shallow cultivation to a similar depth. Probably the major effect will be through greater seed survival in the absence of burning, and there is already field evidence to indicate how serious this pressure can become, even after only one year of mixing if weed control efficiency is lower than normal.

Possible indirect effects of straw on the surface in hindering absorption of residual herbicides on soil, and of enhanced absorption of residual herbicides on humified residues are imponderables at present, but are unlikely to be as important as the effects of surface ash in reducing efficiency of residual herbicides. Another unknown is the possibility that enhanced biological activity due to the greater level of organic substrate, may cause accelerated degradation of residual herbicides.

Optimum weed control strategies for fields in which straw is incorporated by mixing have yet to be worked out. They will need to be flexible and to take advantage of the flush of emergence resulting from early incorporation where soil moisture is adequate. It may prove necessary to place more emphasis on post-emergence foliar uptake and rotational ploughing is likely to be even more important in predominantly cereal rotations (Orson 1985).

Nutrients

Except for nitrogen it is unlikely that crop nutrition and fertilisation will be significantly affected by straw incorporation. Nitrogen is the most important input for most crops and as straw influences the behaviour and quantity of nitrogen in the soil, it will be important to appreciate these effects and their likely relevance for optimum fertilisation.

Straw contains nitrogen (0.2-0.6% in dry matter), which during a complete burn is lost into the atmosphere as a mixture of oxides of nitrogen. The nitrogen content of straw in relation to its carbon content is low (C/N approximately 150), so that during microbial decomposition nitrates if present are withdrawn from a surrounding medium. In most agricultural situations straw decomposition and crop uptake are not significantly limited by shortage of nitrogen, because of substantial quantities of mineral nitrogen in soils after harvest. The table below gives results of soil nitrate levels from a current ADAS experiment in Essex in which available nitrogen was high.

TABLE 2

ADAS straw incorporation experiment Rochford Essex (winter wheat after winter wheat 8 tonnes/ha) - levels of soil mineral nitrogen in 0-20 cm of soil

| Treatment | Autumn N kg/ha | Soil mineral nitrogen kg/ha |
|---|---|---|
| Burn, tine and roll | 0 | 73 |
| | 40 | 114 |
| Straw incorporation with tine, roll | 0 | 48 |
| | 40 | 64 |
| Straw incorporation with plough, roll | 0 | 55 |
| | 40 | 91 |

These results show that when straw was mixed into the top soil 25 kg/ha/mineral nitrogen was immobilised compared with burning. When 40 kg/ha was applied to the seedbed a further 24 kg/ha was immobilised. Where straw was ploughed in, immobilisation was less at 18 kg/ha (73-55) and increased by only a further 6 kg/ha in the presence of seedbed nitrogen. Ploughing releases some extra nitrogen through enhanced mineralisation but it minimises the opportunity for immobilisation of applied autumn nitrogen, by physical separation of straw from fertiliser.

In this experiment the soil mineral nitrogen sustained autumn and winter growth adequately in both straw incorporation treatments but where soil levels are low (perhaps less than 10 kg/ha in 0-20 cm), incorporation of large quantities of straw into the surface layers may so restrict crop nitrogen uptake that a small application of fertiliser nitrogen applied post-emergence may give a yield potential that cannot be achieved by spring applied nitrogen. However, it must be stressed that current evidence suggests that yield response of winter cereals to autumn nitrogen is rare, provided optimum levels of spring nitrogen are used.

Both the nitrogen which is a constituent of straw and the nitrogen immobilised by straw is slowly returned to the soil over a period of years (Poulson 1984). This means that in the first year of incorporation, risk of nitrogen shortage is higher than in subsequent years and that with each succeeding year of incorporation soil nitrogen supply will gradually increase. Eventually, after many years of incorporation an equilibrium will be reached whereby immobilisation is balanced by mineralisation. Where 10 tonne/ha crops are grown each year this equilibrium will provide for an enhanced soil nitrogen supply of about 40-60 kg/ha compared with burning. This difference should be reflected in lower optimum nitrogen levels for crops but detailed long-term trials are needed to examine this claim.

Cereal pests and diseases

If switching from burning to incorporation results in greater use of pesticides the gain in reduced environmental pollution becomes less tangible and additionally farm profits would be reduced. There is no doubt that slug numbers and activity are enhanced by the use of organic residues and also by the absence of straw burning, but the extent to which this may result in greater use of molluscides is so far unclear. It is probably only on soils high in clay or silt in wet seasons, that this increased risk will be realised but there is not yet sufficient sequential straw incorporation practiced on these soil types to judge the extent of any increased problem. However, slugs remain a serious potential threat where straw incorporation is practiced.

Similarly, trash borne diseases such as net blotch (Pyrenophora teres) and leaf spot (Septoria spp.) may be encouraged by extra straw. However, there is as yet little indication that incorporation will result in the need for use of fungicides above those routinely used on cereals. We can anticipate that problems may be worse in arable areas of wetter climate and particularly where incorporation is by mixing rather than by ploughing. Recent ADAS trials have shown that incorporation by mixing has been associated with greater incidence of early season take-all (Gaeumannomyces graminis), possibly due to looser seedbeds produced by these techniques.

CONCLUSION

For the majority of soil/site situations incorporation with the mouldboard plough is the obvious system for farmers to adopt. Incorporation by mixing as practiced at present involves substantially higher risks of yield loss without sufficient potential advantages except perhaps on clayland. For these soils which constitute about 30% of the total cereal growing area of England and Wales, mouldboard ploughing is wasteful of energy and time and results in poor seedbeds whereas incorporation by mixing would avoid these problems.

Mixing needs further development particularly in the area of straw chopping and spreading with the aim of achieving more uniform incorporation within the soil.

There is as yet no evidence that premixing before ploughing is necessary. For farming systems with high autumn workloads this is a very important finding. The advantage in seedbed quality of shallow loosening of clays before ploughing is not to be confused with premixing of straw.

6—1

Rate of decomposition of straw is probably of no significance except possibly where straw is incorporated very shallowly (less than 10 cm): a practice which is unlikely to find a commercial use in British Agriculture. There is concern amongst some agriculturalists that slow decomposition of straw will allow partially decomposed residues to accumulate in land eventually causing problems. For the great majority of arable soil, I am unaware of any evidence which supports this fear. Except in poorly drained or very compact conditions, or where unchopped straw is incorporated in large wadges, soils appear able to absorb and decompose the quantities of straw grown without difficulty. Even where residues remain at the end of the season they are strongly degraded and quickly disappear when ploughed up.

Incorporation with the plough is likely to reduce weed control problems compared with shallow cultivation after burning. However, if residues are incorporated by mixing, annual grass weed problems will be greater and may pose a serious threat to yield.

Experiments so far do not support the need for autumn nitrogen. Most soils contain adequate mineral nitrogen at harvest to accommodate straw incorporation without provoking a unique crop response to autumn nitrogen.

Straw incorporation will result in extra expenditure compared with burning but if ADAS guidelines are carefully followed there is no cause to fear large yield reductions. The economic consequences of changing from burning to incorporation cannot be generalised but will vary depending on farm size, soil type, level of machinery investment and labour. The greatest adverse consequences are likely on large minimum cultivated cereal farms where advantages of lower machinery and labour costs have already been realised.

Close monitoring of increasing amounts of commercial incorporation coupled with existing experiments should enable most of the industry to accommodate a complete change from burning to incorporation - if this proves necessary - without severe technical or financial problems at current grain prices.

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# STRAW DISPOSAL ON HEAVY CLAY SOILS

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## INTRODUCTION

Clay soils have traditionally been difficult to cultivate. In dry autumns the use of a mouldboard plough can result in large clods which are difficult to work down to produce an adequate seed bed, while in the spring, surface wetness and associated poor trafficability can prevent timely sowing. Similar situations can also arise in wet autumns. The adoption of simplified cultivation systems using tined impliments operating at only shallow depths, or even direct drilling into uncultivated soil, enable the continuous cultivation of winter cereals on these soils, without yield penalties when compared with ploughing. However when autumn sown crops are grown continuously there is only a short interval between harvest and

Additionally if straw is left, difficulties may arise from a number of factors; 1) cultivations and drill performance; 2) pests and diseases; 3) availability of nitrogen; 4) phytotoxins from straw decomposition. The relative importance of each factor may vary with cultivation method and weather conditions. Many farmers have responded to these problems by burning surplus straw. A 1983 Ministry of Agriculture survey showed that 40 % of the total surplus straw was burnt whilst only 2 % was incorporated into the soil (Table 1.).

Table 1. Estimated production (million tonnes) and fate of straw, England and Wales 1983

| | Wheat | | Barley | | Oats | | Total | |
|---|---|---|---|---|---|---|---|---|
| Straw treatment | Mt | % | Mt | % | Mt | % | Mt | % |
| Baled | 3.12 | 40 | 4.26 | 81 | 0.20 | 85 | 7.58 | 56 |
| Burnt in field (a) | 4.60 | 58 | 0.98 | 18 | 0.04 | 15 | 5.62 | 42 |
| Incorporated | 0.17 | 2 | 0.07 | 1 | 0 | 0 | 0.24 | 2 |
| Total | 7.89 | 100 | 5.31 | 100 | 0.24 | 100 | 13.44 | 100 |

(a) Excluding burnt stubble
Source: Ministry of Agriculture, Fisheries and Food, Straw Survey 1983.

In 1984 it was estimated that the amount of straw incorporated had risen to about 10 %. The scale at which burning has increased in recent years has caused much public disquiet about the practice, and has encouraged work on alternatives to burning, particularly its incorporation into soil. In this paper we discuss some of the consequences of the presence of straw on crop growth and yield.

## EFFECTS OF STRAW ON CROP ESTABLISHMENT

Most difficulty with establishment of a crop has been associated with direct drilling (Oliphant 1982, Graham et al. 1985). With this system poor crop establishment commonly results and is often associated with poor seed placement. Drill coulters may fail to penetrate the soil or become blocked by straw resulting in seed being left on the surface or deposited in clumps. Straw may also be folded into the drill slot leaving seed in close proximity to the straw, and separated from the soil.

When straw and stubble are incorporated into the soil effects on establishment are reduced, although the extent of successful establishment is often influenced by depth of incorporation (Table 2.).

Table 2. Effects of depth of straw incorporation compared to burning on seedling establishment (Plants/m2) on a clay soil, (Denchworth series).

| Straw Burnt# | Direct Drilled | Depth of Straw Incorporation 5 cm | 10 cm | 15 cm | 20 cm | 30 cm |
|---|---|---|---|---|---|---|
| 251 | 191 | 201 | 204 | 218 | 290 | 237 |

#: mean of all depths of incorporation
Source: Christian unpublished data.

Increasing the depth of incorporation of chopped straw reduces differences in plant establishment compared with that achieved after burning followed by cultivation to the same depth. The data suggests that a depth of 15-20 cm is necessary to overcome early establishment effects. Method of incorporation may also affect establishment. Ploughing inverts soil and buries straw in one pass, leaving a straw-free surface for sowing (Figure 1.). A tine cultivator on the other hand does not bury straw completely and tends to sort material so that shorter straw moves downwards whilst longer straw is sifted towards the soil surface. Therefore, relative to ploughing more straw will be located in the seed zone.

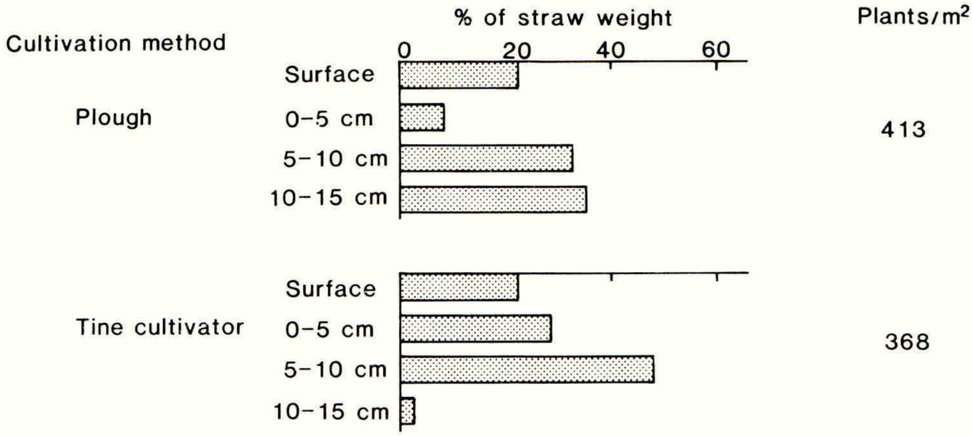


Figure 1. Effect of tillage implement on the distribution of straw in the profile and on plant establishment.

Apart from the mechanical problems of straw influencing establishment, slugs may be more abundant where straw is present and will damage seed and seedlings, particularly under direct drilling (Glen et al. 1984), (Table 3.).

Table 3. The effects of straw disposal and cultivation on the percentage of winter wheat seeds and seedlings killed by slugs

| Cultivation | % seeds and seedlings killed by slugs | | |
|---|---|---|---|
| | Straw burnt | Straw baled stubble left | Straw chopped and spread |
| Direct drilled | 5.1 | 21.3 | 38.3 |
| Tine cultivated 5 cm | 4.1 | 12.5 | 9.7 |
| Tine cultivated 10 cm | 4.6 | 4.3 | 13.5 |
| L.S.D. | 12.2 | | |

#: all treatments had methiocarb pellets drilled with the seed
Source: Glen et al (1984)

Secondly there is evidence from laboratory studies which show microbial decomposition of straw may produce toxic leachates which can retard or prevent seedling germination, particularly where the seed and straw are in close contact as with direct drilling. These effects are worst where the soils are wet and the oxygen status is low (Lynch 1977,1978).

Additional stress from weeds may also influence establishment. In the absence of burning, the population of weeds such as Alopecurus myosuroides (black grass) are likely to increase because of a build up of seed particularly with shallow cultivations and direct drilling. Cussans et al. (1982), have shown that the percentage kill required to maintain a static population of A. myosuroides needs to be greater in the absence of burning.

It is during establishment that problems of volunteers from the previous crop are clearly noticeable. Often they germinate just before the sown crop so providing additional competition and forming a "green bridge" which can provide the first source of infection for diseases such as net blotch (Jorden and Allen, 1984). Volunteers are also an additional problem where it is necessary to maintain the purity of a variety such as for seed or in the production of quality wheats.

VEGETATIVE GROWTH

The effects of straw are not soley related to establishment. Growth of the crop during the vegetative phase of growth is also restricted by the presence of straw. Results from a long-term field experiment have shown that compared with burning plant weights in November were reduced in the presence of straw and the effects were even greater when measured again in April (Table 4.).

Table 4. Effects of straw on plant weight (mg) in November and April for a crop sown on 29 th Sept.

| Straw Treatment | Nov | April |
|---|---|---|
| Burnt | 34 | 84 |
| Chopped | 22 | 57 |

This was in spite of the fact that plant populations were also lower following incorporation of straw. Relative growth rates from autumn to early spring were also slowed in the presence of straw as was the production of tillers. These trends were the same whether the crop was direct drilled or sown following shallow cultivation. The poor growth during the winter and early spring in the presence of straw, could be because microbes breaking down the straw might compete with the plant for available nitrogen. However, a growth inhibitory factor is a more likely explanation. because there was an almost immediate improvement in tillering as soon as the straw was removed in the direct drilled treatment (Figuire 2.) and with direct drilling the surface straw is unlikely to affect nitrogen avaliablity beyond the top few centimetres of soil (Cochran et al.1980).

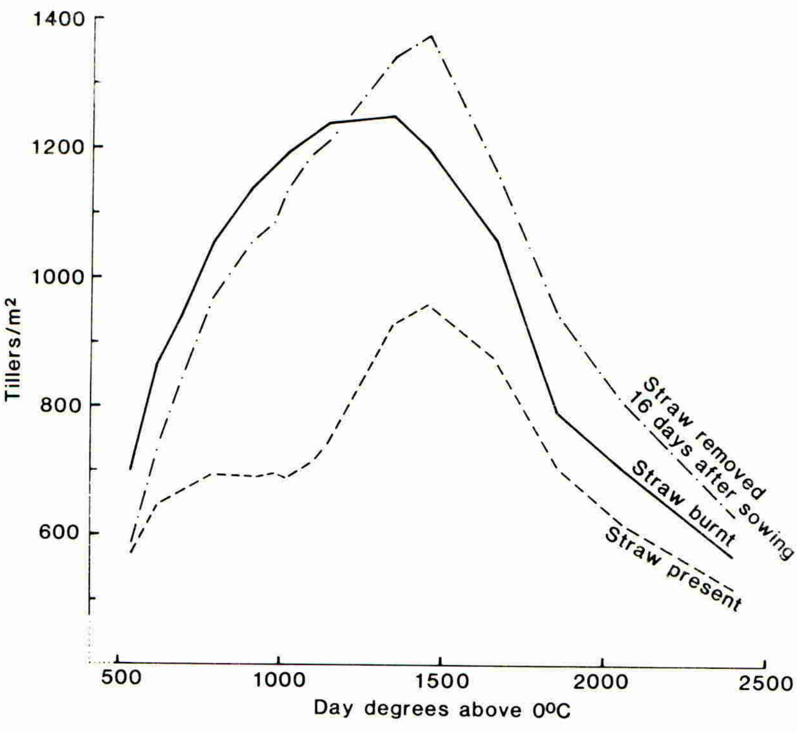


Figure 2. Effects of straw on tillering in winter wheat.

Furthermore there is no evidence to suggest that additional autumn nitrogen is necessary. Early work recognised that straw immoblized nitrogen during decomposition and yield reductions could be avoided by the addition of small quantities of nitrogen (Patterson 1960, Short 1973). More recent studies have shown little need for additional autumn nitrogen.

This is thought to be because current large N inputs for cereal production leave sufficient residues in soil for biological decompostion to take place ( Powlson et al. 1985). Indeed straw may immobilise nitrogen which might otherwise be lost.

At this stage it has not been possible to establish the exact nature of the growth inhibitory factor/s in the field. Under simulated conditions investigations by Lynch (1977) showed wheat decomposing anaerobically had considerable potential for producing toxins such as acetic acid that would inhibit root and shoot growth. However the potential to produce acetic acid only lasts about 6 weeks after straw incorporation.

Table 5. Effect of incorporated fresh straw decomposing under aerobic conditions and position of seed on growth of winter wheat seedlings.

| | Shoot weight (mg) | Root weight (mg) | Shoot/Root ratio |
|---|---|---|---|
| Experiment 1. | | | |
| Control# | 36.6 | 15.5 | 2.36 |
| Seed on the straw | 34.9 | 20.2 | 1.73 |
| Experiment 2. | | | |
| Control# | 31.1 | 14.7 | 2.11 |
| Seed on the straw | 25.1 | 17.0 | 1.50 |
| Seed 2.5 cm above | 29.7 | 17.3 | 1.72 |

#: Control straw free soil

More recently experiments in controlled environments, have shown that straw uniformly incorporated and maintained under aerobic conditions also produces compounds which inhibit seedling growth (Table 5.). In this case the dry matter of the shoot and shoot/root ratios were less than in the absence of straw. In the second experiment, seedling growth was improved if the seed was sown in a layer of straw-free soil 2.5cm above the incorporated straw. Lynch et al. (1980) found that when straw was decomposing anaerobically it was benifical to separate the seed from the straw. The mechanism responsible needs further investigation. Close contact between seed and straw is most likely to occur where a crop is direct drilled and this may account for some of the poor performance of direct drilling in the presence of straw on heavy land.

GRAIN YIELD

Our results suggest that once tillering has finished there are no additional effects of straw on plant growth other than those caused by disease. The most frequently reported effects of straw on the components of grain yield are fewer fertile ears and lower grain weight (Oliphant 1982, Rule 1984, Graham et al. 1985). This appears to result from an inability of the crop to compensate fully for the smaller plant populations, presumably because of its slow growth rate throughout the season.

Table 6. Effect of straw incorporation using minimal cultivation on grain yield on 4 clay soil sites, one-year experiments

| Site | % of yields after burning |
|---|---|
| Boxworth | |
| 1976-77(1) | 98 |
| 1983(2) | 94 |
| Drayton | |
| 1975-77(1) | 86 |
| 1983(2) | 99 |
| Buscot | |
| 1983(4) | 94 |
| Northfield | |
| 1979(3) | 89 |

source: (1) Oliphant (1982), (2) Rule (1984), (3) Graham et al (1985), (4) Christian unpublished data.

In many one-year straw incorporation experiments compensatory growth has virtually eliminated early plant population and growth differences. Where the crop has been unable to fully compensate in these one-year experiments yield reductions are generally small (Table 6.). However in an experiment where the cumulative effects of shallow incorporation and burning have been compared for 5 years the yield difference between treatments gradually increased with time. At this site Cephalosporium gramineum (wheat leaf stripe) has been found in large amounts on straw plots compared with burning. This may be related to slug populations (Christian and Miller 1984). There is therefore a need to assess the longer term effects of straw incorporation at a number of sites to determine whether this trend will apply universally or if it is more related to specific site factors. Recently established experiments at Rothamsted and at a number of MAFF Experimental Husbandry Farms will examine the effects of repeated annual straw incorporation.

In this paper we have confined our comments to experimental results where all the straw residue has been returned. Where cut straw is removed and stubble remains, yield reductions are generally less than where all the crop is incorporated. In one experiment testing the response of winter wheat to increasing loadings of straw, yields declined with increasing amounts of added straw above 10 t/ha, and at 20 t/ha yields were 21 % less than where no straw was present.

## OPTIONS FOR STRAW DISPOSAL

The evidence thus far suggests that following incorporation of straw to 15-20cm there is likely to be less effect on growth and yield than with shallower incorporation. However this may possibly be at the expense of reducing the area of clay soils that can be sown with autumn cereals, particularly if ploughing is the only successful way of deeper incorporation. Straw will be easier to incorporate if chopped short particularly where non-ploughing technques are used. Evidence from both pot and field experiments shows that the adverse effects of straw are often less if the seed germinates in straw-free soil. This suggests that inversion to leave a layer of straw-free soil at the surface could be more benefical than mixing techiques where a higher proportion of straw remains on the surface.
Wet seasons will reduce the area of land that can be prepared for autumn sowing and risks from phytotoxins produced by microbial decay will be greater. To minimise these risks incorporation should start as soon as possible after harvest.

## ACKNOWLEDGEMENTS

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# ALTERNATIVE USES FOR STRAW

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## ABSTRACT

About 7 million tonnes of straw are annually burned in the field in the United Kingdom. The practice is under threat and may be banned. Soil incorporation is the only alternative method of disposal for most of this surplus in the immediate future. Other promising outlets which could develop within a few years are considered in this paper. They include mushroom and other horticultural composts; mulching and frost protection; fuel; pulping for paper; straw board; chemical production. Other aspects considered are whole crop harvesting and the traditional uses for livestock bedding and feeding. Wherever relevant, the effect of the use of crop protection chemicals on straw is taken into account.

## INTRODUCTION

The only immediate alternative method of disposal of the greater part of the 7 million tonnes which are now field-burned is incorporation.

There are, however, a number of other alternatives which could absorb a large proportion of the surplus within the next five to ten years. Some of these would use only small quantities, others would take up several hundred thousand tonnes. All, of course, involve removal from the field of that part of the straw (perhaps no more than half) which goes through the combine harvester and is picked up by the baler (or other straw harvester).

This paper reviews these alternatives to burning or incorporation and summarises possible developments within the next ten years. Special mention will be made, where appropriate, to links between methods of straw utilisation and the use of chemicals on the growing crops.

## WHOLE CROP HARVESTING

Before considering the alternative uses for straw, mention should be made of developments which might have a fundamental effect on straw disposal and use - whole crop harvesting. This is no more than a heavily mechanised return to the whole crop harvesting system carried out for centuries. The system employs a type of forage harvester to gather in the total grain and straw crop, which then has to be separated at a central site.

Transport and storage - of both the whole crop before it can be separated and the straw fraction after separation - present great difficulty.

The success of any scheme must depend on the economic use of the straw by-product.

Whole crop harvesting is being developed in Scandinavia (Vind, 1984) and in the U.K. (Wilton et al., 1980). If widely undertaken it would have a considerable effect upon weed and volunteer cereal populations and probably upon the incidence of some diseases.

ALTERNATIVE USES

Mushroom compost

Currently uses about 200,000 t/annum in U.K. - the biggest single non-farm use. No big change expected.

The effect of pesticide application on the degradation of straw in composts has been investigated to a limited extent (Grossband & Harris, 1979). There are indications that glyphosate and paraquat can inhibit the breakdown of straw (Pollard, 1979).

Growers are always concerned about possible effects on mushroom growth of any pesticides which may persist in straw. There was concern that late applied glyphosate could persist and affect mushroom growth. No serious effects have been reported.

However, spent mushroom compost made from straw contaminated with herbicides (2,3-6-TBA and clopyralid) has been known to affect crops to which it has been applied.

Other horticultural composts

Ground or chopped straw has been shown to be a good substitute for peat and bark in various types of horticultural compost. Straw-based horticultural compost is sold commercially in the United States (Ticknor, 1984) and trials are being carried out in the U.K.

The potential U.K. market for horticultural composts made with straw is 100,000 t/annum at least. There is a danger that phytotoxic residues from herbicides or pesticides could endanger plants grown on composts which include straw and there is need for research on this aspect.

Cucumbers, strawberries, carrots and other horticultural mulches

Most U.K. cucumbers have been grown on straw bales - around 7,000 t/annum used for this purpose.

There were some disastrous results where the straw was from crops treated with 2,3-6 TBA and clopyralid. Flamprop-M-isopropyl is another herbicide which should be avoided.

Up to 10,000 t/annum of straw are used on strawberries.

The use of a covering of straw and polythene sheet to protect carrots stored in the ground from frost is being extended. Several thousand tonnes are now used in the U.K. for this purpose. Since the object is simply to conserve the crop in a fresh condition and since further growth of tops is undesirable, herbicide residues on straw are probably unimportant.

Around 30 tonnes per hectare are used for this purpose. The remains are usually burned but, if chopped and ploughed in, the effect of herbicide residues could be serious on sensitive following crops. Two or three hundred thousand tonnes of straw per annum may be required for carrot storage in the U.K. in the foreseeable future as the demand for crisp, pre-packed carrots increases.

There are numerous other uses for straw as a mulch for horticultural crops. In the Netherlands, large quantities are used on tulip fields. Here also there is a need to guard against contamination of straw with certain persistent chemicals.

Fuel

Straw has about half the calorific value of a high-grade coal and rather more than one third that of fuel oil. If coal costs £100/tonne and oil £150/t., straw is theoretically worth around £50/t. as fuel. It is possible to provide dry, baled straw at the furnace site for, say, £20 per tonne. If efficient stoking and combustion arrangements can be made there are possibilities for appreciable fuel economies (Martindale, 1984; Requillart, 1984).

The past ten years have seen some very interesting developments in the use of straw as fuel in the U.K. (and in continental Europe). Around 200,000 t/annum of straw are now used for this purpose and much more may be so used, for instance in glasshouse heating and small local industry.

Pulping

At the end of World War II about 350,000 t/annum of straw were used for paper making in the U.K. None is so used now. Straw got a bad reputation because of supply problems and also because of variable quality (Staniforth, 1979).

There are now very large quantities of high quality straw available. Straw is no longer infested with docks, thistles and other weeds, as in earlier years. Large quantities of straw are used for pulping abroad. Timber is saved. Over a period of years the economics of straw pulping look attractive.

Low-pollution pulping methods are now available. There are strong arguments for again using large quantities of straw for pulping in the U.K. and feasibility studies are in hand.

Little is known about the possible effects of the use of chemicals on the straw-producing crop.

There has been some interest in the effects that growth regulators may have upon fibre length. This could be important in the production of so-called dissolving pulps, very pure cellulose fibre for rayon production.

Board

Compacted straw, known commercially as 'Stramit', has been used to make board in the U.K. for more than 30 years. This board is used mainly for partitions and walls in houses. The tonnage of straw so used in the U.K. is comparatively small - about 15,000 t/annum (Mosesson, 1983).

The process has been exported to many countries - factories have recently been installed in China. The process is interesting as a means of conserving timber resources. Compaction is achieved by heat and pressure without artificial binders and relies upon the lignin, hemicellulose and wax fractions.

It is not known what effect pesticides may have on the suitability of straw for Stramit board manufacture. Clean, bright, straw is required and it may well be that fungicides have an appreciable effect upon the suitability of straw.

Another, denser, type of straw particle board is also now being made in the U.K. This relies upon the use of a binder to ensure compaction. Again, clean, bright weed-free straw is required. The effect of the use of chemicals - particularly late-applied chemicals - on the suitability of straw for this process remains to be researched. Straw particle board is an attractive looking product and if it can be produced at competitive prices it could be used in large quantities and take up, perhaps, 100,000 t/annum of straw.

Chemicals

Straw can be used as raw material for the production of many chemicals, and there are many references to these processes in the literature (Stacey, 1976). Ethylene, alcohol, xylitol and furfural are only a few of the possibilities. Lignin and wax can be extracted from straw by well-known processes. None of these processes is being commercially exploited at present, but they are being researched in several countries. If they become economic, very large quantities of straw could be required for them.

Semi-industrial and craft uses

There are several interesting and small-scale uses (Staniforth, 1979).

Thatching uses around 12,000 t/annum in the U.K. Clean, bright wheat straw is preferred and the use of herbicides and fungicides undoubtedly improves straw quality. Brittle straw, perhaps caused by fungal infection, is bad for this purpose.

Straw with a high nitrogen content appears to degrade more rapidly than other straw. It may be that the presence of some chemicals, particularly fungicides, may help to preserve thatched roofs.

Archery targets and rope (for packaging) are also made from straw in the U.K. The quantities of straw needed are only a few hundred tonnes per annum.

Other craft products such as bee skeps and chair backs and corn dollies use even less.

Polystraw insulating blankets, now imported, could be a small local industry.

Livestock bedding and feeding

These traditional uses for straw are still by far the largest consumers, but are not dealt with at length in this paper because they are already well understood. The following points only will be made:

1. The use of straw for bedding has declined for some years because of the labour involved in handling straw and manure and the comparatively low value that has come to be put on the manure which is produced. This trend could be reversed as environmentalist pressures increase against the nuisance arising from slurry disposal. It is also possible that a move towards 'organic' farming may cause a certain increase in the use of straw as bedding.

2. The quantity of straw used as feed for ruminants has probably not been greatly influenced by the recent expansion in chemical straw

treatments. Between 100 and 150 thousand tonnes have been treated with alkali and pelleted for use mainly in compound feedstuff for cattle, but no large expansion in this process is foreseen. Other treatments of straw in bales can upgrade the feeding value and may also increase the total use of straw for feeding to some extent. The economic advantages of these chemical treatments depends greatly upon the price of coarse grains and any great expansion of the chemical treatment systems in the near future seems unlikely. If straw became widely used as a means of soaking up effluent from silage, a very large amount would be used - running into hundreds of thousands of tonnes. Two factors could influence development in this direction - increased environmentalist pressure against silage effluent and a move towards direct cutting of silage and against wilting (Jackson & O'Regan, 1982).

## CONCLUSION

The histogram of the estimated current use and disposal of straw is compared below with another to indicate possible changes by 1992. (Histograms based on Staniforth, 1982)

There may have to be major changes to this projection, and the following qualifying factors should be noted:

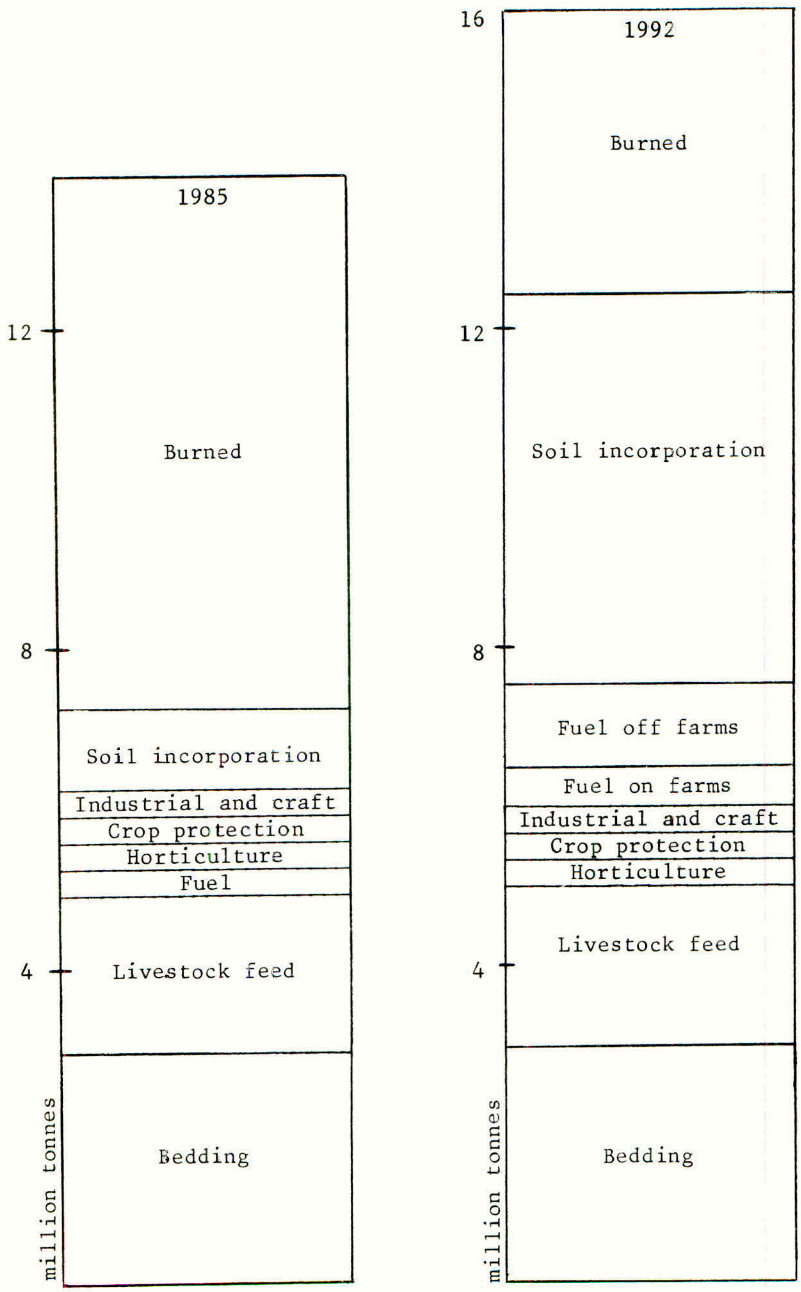
1. The projection assumes that, with careful management, burning will be allowed to continue in some less sensitive areas. However, we have to take into account the possibility of a total ban on field burning.

2. Paper is unlikely to need more than 500,000 t/annum. However, if an economically successful process for producing a chemical which is in heavy demand - such as motor fuel - should be developed, it could take up some millions of tonnes of straw as raw material.

3. Horticultural uses - for crop protection, mulching and compost production - might expand very considerably and take up to a million t/annum.

4. The amount used for fuel could be even greater than shown in the histogram if, for instance, many schemes for district heating, using straw as fuel, were introduced.

**6—3**




N.B. The above histograms represent no more than informed estimates: the smaller quantities are not shown strictly to scale.

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# EFFECTS ON STRAW AND ORGANIC MATTER ADDITIONS TO SOIL ON CHLORSULFURON USED PRE-EMERGENCE

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ABSTRACT

Adding more than 4% of sphagnum or fen peat to a sandy loam top soil with 4% o.m content or more than 2% straw ash resulted in decreased activity and increased adsorption of chlorsulfuron. Less than 0.1% activated charcoal inactivated chlorsulfuron at concentrations normally found in field applications. Field soils were amended by thoroughly incorporating chopped straw or straw ash in amounts typical of cereal fields or had 30 tonnes $ha^{-1}$ (adding 2% to a 10 cm soil layer) of mushroom compost incorporated. None of these treatments altered availability, distribution in the soil or persistence of chlorsulfuron applied at normal field rates. It is concluded that chlorsulfuron performance is not likely to be affected by changes in soil organic matter or ash contents typical of arable cropping with cultivations but large local concentrations particularly of straw ash on the surface might give variable performance in minimal cultivation systems.

## INTRODUCTION

There are few published reports on how soil factors affect chlorsulfuron persistence, activity and performance. Shea (1982) observed that chlorsulfuron adsorption was generally very low on most of the natural soils he examined. Persistence has been reported to decrease (Peterson & Arnold 1983) or to increase (Sampson et al, 1982) with increased soil organic matter contents. The performance of other soil applied ureas such as chlortoluron and isoproturon is adversely affected by burnt straw residues especially when they are on the soil surface in direct drilling systems (Wilson & Cussans, 1975; Cussans et al, 1982) but Hance (1973) did not observe any effects of straw or mineral salts on linuron activity.

These studies were therefore carried to examine how chlorsulfuron performance in soil might be altered by changes in soil composition that could possibly occur in arable cereal systems.

## MATERIALS AND METHODS

### Maize bioassay in soil

Air dried top soil from Plant Science Laboratories experimental grounds was passed through a 3 mm sieve. Mechanical analysis was 74% sand and gravel, 6% silt, 16% clay and 4% o.m. Samples of this soil were mixed with 0, 2, 4 or 8% w $w^{-1}$ of dried sieved sphagnum peat or black fen soil (40% humic o.m) or 0, 0.05, 0.1 and 0.2% activated charcoal and thoroughly mixed by shaking in sealed jars for 24 h. The soils were brought back to 10% water content with chlorsulfuron solutions containing 0, 3, 4.5 or 6 ng ai

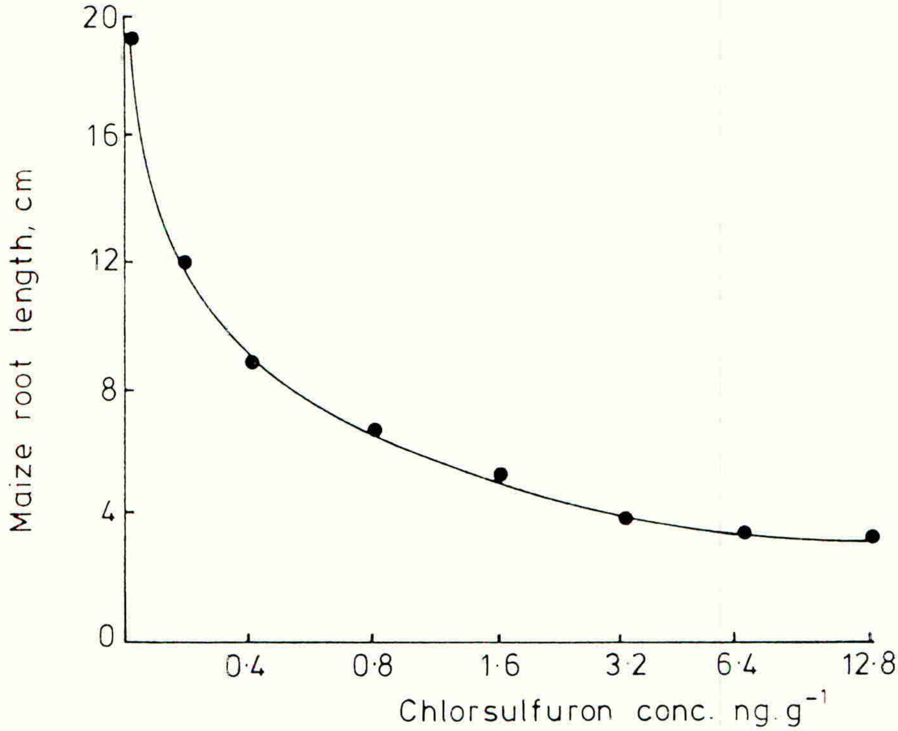


Fig. 1. Typical maize root growth response to chlorsulfuron applied to Plant Science Laboratories soil in petri-dish bioassay procedure.

chlorsulfuron per g air dry soil, and again thoroughly mixed. 2 replicate treatments were set up. The maize root growth bioassay was carried out using sweetcorn cv. Northern Belle, $F_1$ hybrid seed. Uniformly germinated seeds were chosen after germinating in plastic boxes on cellulose wadding for 25 h at 30° ± 2°C in the dark. Treated soil equivalent to 20 g air dry soil was added to a petri dish and one pre-germinated seed placed in each, before returning to 30° ± 2°C for 5 days. Distilled water was added as necessary. Main root length (omitting laterals) was measured to the nearest 2 mm. Results of a typical bioassay are shown in Fig. 1; 4 bioassays were carried out for each treatment replicate.

Adsorption equilibrum studies were carried out on the same soil amended as above with sphagnum and fen peat and also with 0, 1, 2, 4 or 8% of wheat straw ash. Duplicate 100 g air dry soil samples treated to give 8 ng g$^{-1}$ chlorsulfuron were shaken at 20°C for 24 h in sealed jars with a 1:1 soil water ratio. Buchner filtrate samples were collected and used in a similar bioassay to that above with the pre-germinated maize seed added to 20 g air dry herbicide free soil and watered with 5.5 ml of filtrate. Standards of known chlorsulfuron concentration were also prepared. 3 bioassays were carried out for each replicate soil treatment.

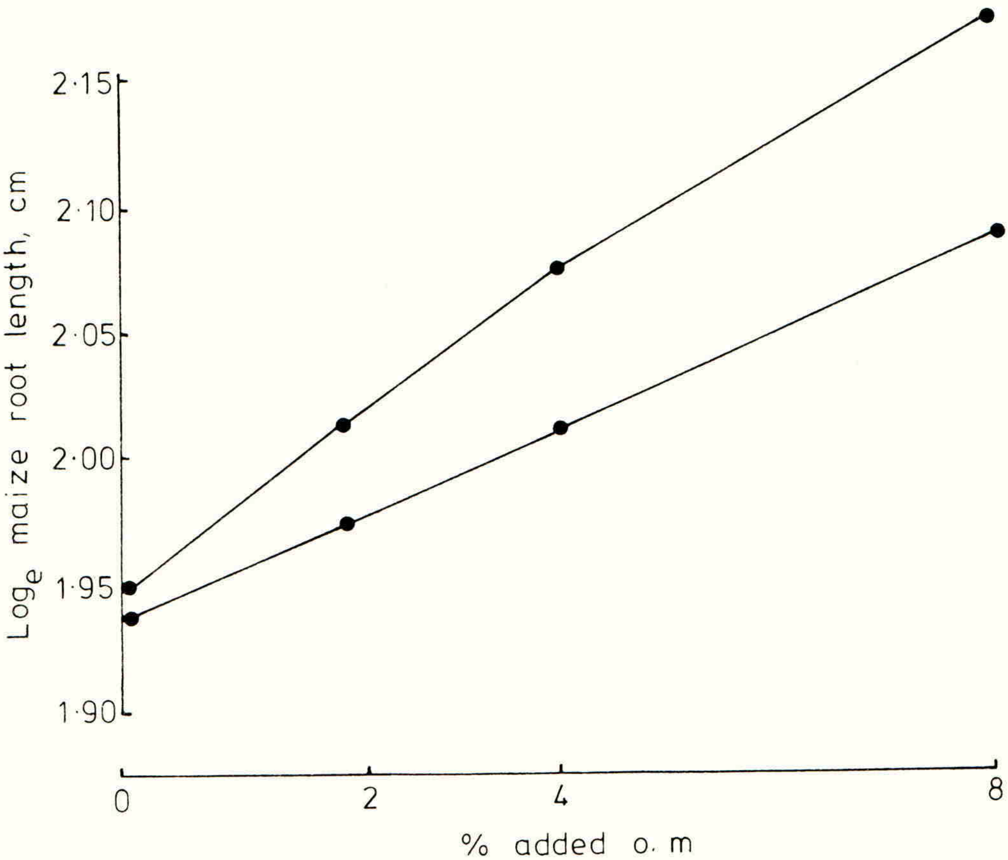


Fig. 2. Log Maize root length of Plant Science Laboratories soil amended with sphagnum (S) or fen peat (F), (mean of chlorsulfuron rates).

Effect of soil amendment on chlorsulfuron activity

Field plots (2x2 m) were set out at Plant Science Laboratories experimental grounds in spring 1984. The area was ploughed and thoroughly disced to give a loose seed bed. Plots were either unamended or treated, with 3 kg $m^{-2}$ wet mushroom compost, 400 g $m^{-2}$ chopped wheat straw, 20 g $m^{-2}$ wheat straw ash (= 400 g $mg^{-2}$ straw) or combinations of mushroom compost with straw or ash. Amendments were cultivated in by hand to 10 cm. There were 3 replicates of each amended treatment in two parallel experiments, one sown to spring wheat and the other left fallow. Chlorsulfuron at 10 g ai $ha^{-1}$ was applied after sowing the wheat (10 April). DPX 4189 (75% dry flowable formulation) was applied in 200 l $ha^{-1}$ with an Oxford Precision Sprayer (Teejet 8002 nozzles at 3 bars pressure). Effects of cropping are not discussed here and did not alter the effects of amendment. Soil samples to a depth of 20 cm (4x7 cm diam. cores/$plot^{-1}$) were taken from each replicate and four replicate maize root growth bioassays were carried out per treatment as described earlier. Soil samples were taken at 0, 30, 60, 120 and 180 days after application.

## RESULTS AND DISCUSSION

### Laboratory studies on soil amendments

When sphagnum peat were added to Plant Science Laboratories soil there was no interaction between chlorsulfuron rate and amendment treatment. So only the mean effect of soil amendment is considered. Sphagnum peat appeared to decrease chlorsulfuron activity more than fen peat but the effect was just significant at 8% addition (Fig. 2). This is probably a reflection of the lower pH (5.2 v. 7.2) associated with sphagnum peat. Shea (1982) and Eleftherohorinos (1985) have shown increased adsorption in soils as pH decreases.

For both peats there was a linear effect of increased amount of o.m on chlorsulfuron activity, but herbicide activity was still considerable even with 8% o.m added. The estimated chlorsulfuron amounts present were 1.9, 2.7 and 3.7 ng $g^{-1}$ for applied concentrations of 3, 4.5 and 6 ng $g^{-1}$ respectively with this amendment.

By contrast adding only 0.05% activated charcoal completely inactivated all rates of chlorsulfuron applied, in keeping with its reputation as one of most effective adsorptive materials known, (Klingman & Ashton, 1982). Field studies following up these observations, confirmed that activated charcoal at 25 g $m^{-2}$ could inactivate soil applied chlorsulfuron at 1, 5 and 10 g ai $ha^{-1}$ (Eleftherohorinos, unpublished data).

In the adsorption equilibrium studies, analyses of the differences between sphagnum peat and fen peat additions were not usually significant but the Kd* averaged over all chlorsulfuron rates was 1.70 for sphagnum compared with 1.46 for fen peat which parallels the slight difference between them noted above.

TABLE 1

Equilibrium solution concentrations and Kd of chlorsulfuron at 8 ng $g^{-1}$ applied in a 1:1 soil:water ratio

| | % added amendment | | | | | |
|---|---|---|---|---|---|---|
| Peats | 0 | 1 | 2 | 4 | 8 | LSD |
| Equil. conc'n ng $ml^{-1}$ | 5.66 | - | 4.47 | 2.83 | 2.08 | 1.08 |
| Kd | 0.50 | - | 0.92 | 1.97 | 2.94 | 0.64 |
| Straw Ash | | | | | | |
| Equil. conc'n ng $ml^{-1}$ | 5.60 | 3.87 | 2.43 | 0.77 | 0.45 | 1.89 |
| Kd | 0.52 | 1.15 | 2.66 | 9.68 | 17.10 | 3.18 |

* Kd = ng herbicide absorbed $g^{-1}$ soil/ng herbicide $ml^{-1}$ solution at equilibrium.

Adding more than 2% peat to this soil with 4% o.m content, considerably increased chlorsulfuron adsorption with about 3 times more adsorption with 8% peat addition. Straw ash was a much greater adsorbent with 2% ash roughly equivalent to 8% peat and very large adsorption with 4 or 8% ash present.

The effects of the soil amendments on chlorsulfuron activity, its residual persistence and its distribution within 5 cm layers of the upper 20 cm of the soil profile in the field experiment were found on statistical analysis to be non-significantly different from the unamended soil at all sampling times. Calculating on the basis of a soil density of 1.5 g $cm^{-3}$, a 10 cm layer of soil would weigh 1500 t $ha^{-1}$. Thus the effect of adding 30 tonnes $ha^{-1}$ of mushroom compost (assumed to be 100% o.m) would raise soil o.m content by an additional 2%. The 400 $g/m^2$ straw and the ash derived from this correspond to average wheat straw yields in England (Hughes 1979) but these would only add 0.26% o.m or 0.013% ash to a 10 cm soil layer. Clearly, where such materials are thoroughly incorporated, as they were here, they are not likely to result in any significant alteration in chlorsulfuron adsorption or activity. Anderson and Barret (1984) found small effects on chlorsulfuron persistence in controlled conditions of large additions of wheat straw, 2.5 to 5.0% in a sandy loam soil and a loamy soil. There was a slightly longer persistence in the sandy loam soil, possibly because the straw changed the soil from pH 6.1 to 7.2. The pH of the loam was unaffected and there was no change in herbicide persistence. Again there is no hint of decreased herbicide activity in this study. If however these materials were restricted to only a 1 cm surface layer, and were not uniformly distributed but present in high local concentrations, as might occur with windrowed straw burning, then ash concentrations could easily approach the 1% necessary to alter adsorption by a detectable amount and might give spatial variability in its performance. However the adsorption studies confirm that only with more than about 8% o.m in a soil would there be much reason to expect altered performance from this herbicide shortly after its application. Herbicide activity could then depend on how available for desorption the herbicide would be that had been absorbed on the soil organic matter.

ACKNOWLEDGEMENTS

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# THE SIGNIFICANCE OF THE RATE OF STRAW DECAY IN SOIL

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ABSTRACT

Increased constraints on burning have meant that much of the surplus of cereal straw must be disposed of by incorporation into the soil. The rate of decay in soil is important since it determines the length of the early stages of decomposition when growth of cereal seedlings can be slowed if roots come into contact with straw. In a clay loam soil the method or depth of incorporation had little effect on decay except that straw at or near the soil surface decomposed more slowly. Treatments which accelerate the rate of decay, such as a reduction in the size of straw, might shorten the toxic phase but this approach remains to be fully evaluated in the field. The mechanical strength of straw and thus the risk of interference with agricultural machinery is also lost during decay. Most of the strength is retained during autumn but has largely been lost by the following summer except when straw remains on the soil surface.

## INTRODUCTION

Recent restrictions on burning have meant that alternative methods must be found to dispose of surplus straw. Little of the straw can be used and, unless burnt, the bulk must be incorporated into the soil. This increases costs and can result in smaller crop yields. Techniques are being sought appropriate for incorporation into the wide range of soil types on which cereals are grown in the United Kingdom. In many cases ploughing provides the best alternative to minimise effect on crop yields but it is also the most expensive. Faster, cheaper methods are available but these normally leave some straw in the seedbed thereby increasing the risk of slower seedling growth rates and subsequent reduced yields.

In the presence of straw from a preceding crop the rate of cereal seedling growth can be slowed. Phytotoxins such as acetic acid can be produced during decay and available nitrogen is immobilised from the soil into microbial biomass. Although the full nature of these effects of straw on seedlings remains uncertain they appear limited to the early stages of decay. The rate at which straw decomposes in soil is important since ideally this initial toxic phase should be completed before the next crop is sown. Evidence is accumulating to show how crop yields vary following straw incorporation into different soils but it is not clear whether the rate of straw decay also varies. Currently it is thought best to leave buried straw to decay for 4-6 weeks but this may not be appropriate for all soils and for all methods of incorporation. Techniques which accelerate the rate of decay might be expected to shorten the toxic phase. One approach that has frequently been suggested is to chop straw to shorter lengths but there is very little data to relate straw size to decay rate.

Decay is also important in that mechanical strength is lost as straw decomposes and it is then less likely to impede agricultural machinery. Problems are particularly severe in autumn when straw can impede penetration of the soil by seed drills. There is also concern that straw left on the soil surface or buried at depth by the plough may decay slowly and present a problem in the following autumn.

## MATERIALS AND METHODS

### Straw incorporation

Complete crops (approximately 7 tonnes) of wheat straw were incorporated into a clay loam (Lawford series) soil on September 20th 1983 by ploughing (to 20 or 30 cm) or by a combination of tines and discs (to 5, 10 or 15 cm).

### Straw sampling and analysis

Samples were collected as 1-2 kg of soil-straw mixture, excluding any residue on the soil surface. Straw was separated from dried (60°C) soil after crushing to break soil aggregates. Nylon mesh (1mm) was secured across the end of a length of 5cm diameter plastic tubing connected to a domestic vacuum cleaner. Straw was collected on the mesh when passed at approximately 1cm above the sample. Finally the few remaining pieces of straw were removed by hand using forceps. Weight loss was determined from the increase in lignin content (Harper & Lynch, 1981a).

### Straw strength

The breaking strength of internodes was measured by a modification of the method of McCalla (1945). Lengths of undamaged internode (5cm) were selected from decomposed samples and suspended across a gap (3cm) between two metal plates. A plastic bottle (200g) was hung on the straw and water pumped into it at 100mls/min until the straw broke. Strength was recorded as the combined weight of bottle and water and expressed as a percentage of the strength of undecomposed samples of the same diameter.

Effect of straw size

In the laboratory the effect of straw size on decay rate was determined using samples of wheat straw cut to length by hand (to ensure uniformity) or milled (<1 mm). Samples (1g) were weighed into 250ml conical flasks containing 100mls of a mineral salts solution (Harper & Lynch, 1981a). Flasks were inoculated with soil (Lawford series, 0.01g) and incubated at 20°C on an orbital shaker (180rpm). Straw was recovered on filter paper and weight loss determined after correction for ash content.

## RESULTS

In a dry autumn rainfall was retained by the surface layers of the soil for several weeks after incorporation. Thus straw buried to 20cm or 30cm by ploughing was initially drier than when the residue remained nearer the soil surface. However the rate of straw decay did not decrease significantly with increasing depth of incorporation.

The mechanical strength of straw is also lost as decay procedes but not in parallel with loss of weight (Table 1). Most of the strength is retained until weight loss has reached approximately 60% but then it is lost rapidly. There is little if any loss of strength during autumn.

TABLE 1

Loss of mechanical strength from wheat straw internodes decomposed in the field. Straw was incorporated on September 20th 1983.

| Sampling date | % Wt. loss | Strength (as % of strength of undecomposed straw) |
|---|---|---|
| Surface straw | | |
| October 21st | 8 | 102 |
| December 7th | 14 | 109 |
| March 15th | 32 | 95 |
| June 7th | 30 | 115 |
| August 14th | 38 | 85 |
| Buried straw | | |
| June 7th | 52 | 108 |
| August 14th | 60 | 41 |

In the laboratory chopping or milling the straw increased decay rate and greatly shortened the time taken for half the straw to be decomposed (Table 2).

TABLE 2

Decomposition at 20°C of wheat straw reduced to different lengths.

| Length (cm) | Days to lose 50% weight |
|---|---|
| <0.1 | 14 |
| 0.5 | 29 |
| 1.0 | 30 |
| 2.0 | 47 |
| 5.0 | 54 |

DISCUSSION

The losses in weight from straw result primarily from the decomposition of cellulose and hemicelluloses (Harper & Lynch, 1981b). Following straw incorporation microbial activity, and thus the decay rate of these plant polysaccharides, is limited primarily by temperature and by the availability of water and nitrogen. Available nitrogen is thought to be adequate for decay in normal agricultural soils receiving fertilisers but the mobility of nitrogen might be limited in dry soils. Nitrogen is most likely to be limiting when straw is incorporated as a narrow band or into a shallow depth of soil. Water might be limiting when straw is ploughed down with dry soil and rainfall retained initially in the surface soil. However studies in a clay loam soil during a dry autumn failed to show any effect of depth of incorporation on decay rate. These studies excluded straw remaining at or near the soil surface which will decay more slowly (Harper & Lynch, 1981b). A major problem with shallow incorporation is to ensure that little of the straw remains on the surface.

Mechanical strength is lost slowly and is unlikely to change significantly during autumn but after 12 months of burial, although straw appears physically unaltered, strength is greatly reduced. There is little cause for concern that straw brought to the surface after 12 months in the soil will interfere with machinery. Problems might be experienced when straw remains on the soil surface but in practice it is found that much of this straw enters the soil as the result of faunal activity.

Straw decomposes faster as chop size is reduced (and also becomes easier to incorporate). However it remains to be demonstrated whether an increased decay rate is beneficial in the field and whether these benefits can justify the costs of chopping.

The rate of decay in the field has seldom been assessed in trials of straw disposal in the United Kingdom. It is uncertain whether differences are likely either between soils or years or following different methods of incorporation. Current investigations aim to examine the extent to which decay differs between soils and within the extremes of autumn conditions experienced across the cereal-growing areas of the UK., and what influence this has on selection of the most appropriate technique for straw incorporation.

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6—6

# EFFECT OF SOME WINTER CROP MULCHES ON THE SOIL WEED INFESTATION

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ABSTRACT

The allelopathic effects of straw,from certain winter crops, on the seed germination of some wild and cultivated species, were shown by germination tests using the water extract method. Wheat, triticale, rye, oat, lupin, forage turnip and rape mulches were studied in field conditions. It was observed that the allelopathic effect intensity was correlated with the amount of straw produced by them and its rate of decomposition. The winter oat mulch gave the best control of weeds for the longest time, followed by rye, forage turnip and rape. However, the latter two crops affected the yield of maize which was cultivated in their mulches. The mulches showed specific allelopathic effects on the weeds, modifying the weed complex.

## INTRODUCTION

Allelopathic effects have been reported for many crop residues on other crops (Bhowmik & Doll,1982; Chou & Lin,1976; Chou & Patrick,1976; Cochran et al, 1977; Elliot et al,1979; Guenzi & McCalla,1962; 1964; Kimber,1973; Overland,1966) and on weeds (Altieri & Doll,1978; Guenzi & McCalla,1962; Guenzi et al,1967; Kimber,1967; Kummedahl & Linck,1958;Putman & Duke,1974; Rose et al,1984) through the release, by decomposition, of toxic substances (Kimber,1973; McCalla & Norstadt,1974; Norstadt & McCalla,1968; Park, 1962; Patrick & Toussoun,1965) or leaching by water, of allelopathic chemicals.

The utilization of these effects in field conditions to reduce the weed infestation in crops has been recognised by some authors (Altieri & Doll,1978; Overland,1966; Putman & Duke,1974); Rose et al,1984), while others do not believe that it is practicable (Etherington,1975; Newman, 1982).

This difference of opinion could be due to the different tillage systems. With conventional tillage the crop residues are buried, and the toxins liberated are diluted in the soil. In the non-tillage system they remain in the surface and the allelopathic substances concentration in the top layer,which contains the majority of the annual weed seeds that have the potential to germinate. If the crop residues have allelopathic substances, it is in the non-tillage system that they will show more effects.

Another aspect to be considered is the time interval between the harvest of one crop and sowing the following crop. If the interval is long the toxins liberated by the residues can be decomposed by the microrganisms or leached by water, and no effects will be shown on the weed infestation on the following crop (Putman & Duke, 1978; Rice, 1974).

In the sub-tropical region of Brazil, were double cropping systems are common, it was observed that with no-tillage, some winter crop residues reduced the weed infestation of the following summer crop. From this arose the hypothesis that these reductions were due to allelopathic substances, liberated by the winter crop mulches, and with some of them it was possible to reduce the soil weed infestation of the summer crops. To confirm this hypothesis, seed germination tests using winter crop residue extracts as humidificants were tested and field experiments carried out.

MATERIALS AND METHODS

Seed germination tests

At harvest time, the straw of different winter crops was collected, dried in a stove at 60°C, until dry, and ground in a mill with a 20 mesh screen. One hundred grams of the ground material was added to 1 litre of water and agitated for 5 minutes in a mechanical shaker. The solutions were filtered and centrifuged to remove any soil. Extract solutions were maintained at 7°C when not used.

Germination tests using the extracts were conducted with seeds of wild species,(Euphorbia heterophylla, Cenchrus echinatus and Brachiaria plantaginea) and cotton, rice, beans, maize and soyabeans.

In a gearbox of 11.0 x 11.0 x 4.5 cm, provided with polyethylene foam, covered with filter paper, were placed 40 seeds of the wild species and 25 of the crops, with 4 replications for each treatment. Fifty millilitres of extract was added to each gearbox. Germination occurred in temperature controlled conditions of 30°C during the day and 20°C in the night, 100% humidity and permanent light. Distilled water was used as the check solution. Germination counts, radicle and aerial lengths were measured on the eight day.

Field trials

In the winter, wheat, triticale, rye, oats, lupin, forage turnip and rape were sown in plots 30 x 4 m. The sowing dates were chosen so all the crops would reach maturity at the same time and be harvested on the same day. A harvest machine with a straw cutter, which distributed the straw uniformly over the plot area, was used. Each plot was divided in two sub-plots. One, 20 x 4, was reserved for studying the influence of the different crop mulches on the weed infestation and the other 10 x 4 m, was used to study the influence on the summer crop. The former did not receive any crop or herbicide. At 15 day intervals, 2 x 1 m randomized samples of the mulches were collected and d.wt./ha calculated. Maize was sown in the other sub-plots and received contact and pre-emergence herbicides. The contact herbicide used was paraquat at 0.3 kg a.i./ha and the residuals were metolachlor, at 2.4 kg a.i./ha + atrazine at 1.6 kg a.i./ha. The former was applied one day before sowing the maize and the latter one day after. A split plot design, with four replications was used where the main plots were the winter crops and the sub-plots, the presence or absence of the summer crop.

Assessments of the weed infestation intensity on the sub-plots without the summer crop, were made on the 9th (% canopy), 21st (number plants/$m^2$) and 118th day (biomass fresh wt.g/$m^2$)after sowing. The decomposition rate of the different winter crop mulches were made by assessment of the dry biomass at 15 day intervals. The influence of the winter crop residues on the summer crop was assessed by height of the maize on the 72nd day and by the grain yield on the 154th day.

The data were subjected to an analysis of variance and the Tukey test was used to determine significant differences among mean values at the 0.05 probability level.

RESULTS

Seed germination tests

The water extracts from the winter crop straws had an effect on the germination of the wild seeds or on seedling development. This influence was specific, and has been observed by a number of other authors (Bendall, 1975; Cochran et al, 1977; Guenzi & McCalla, 1962; Hussain et al, 1981). The lupin water extract inhibited the seed germination of B. plantaginea and reduced drastically the germination of C. echinatus but had no effect on E. heterophylla (Table 1). The forage turnip straw extract reduced only the B. plantaginea germination and the rape affected all three species. The hypocotyl length of *E. heterophylla* was reduced by all extracts with the exception of wheat whereas the coleoptile of *C. echinatus* and *B. plantaginea* was affected only by lupin and rape. The radicle development was more sensitive to the allelopathic effect of water extracts, with the length of *E. heterophylla* affected by all crops and the *C. echinatus* and *B. plantaginea* only unaffected by wheat.

TABLE 1

The effect of water extracts of certain winter crop residues on the seed germination and seedling development of certain weeds

| Winter crop | *E. heterophylla* | *C. echinatus* | *B. plantaginea* |
|---|---|---|---|
| | | number of germinated seed | |
| water | 31 ab | 16 a | 7 a |
| oats | 34 a | 12 a | 4 a |
| wheat | 33 a | 13 a | 5 a |
| rye | 33 a | 10 ab | 6 a |
| triticale | 33 a | 12 a | 8 a |
| lupin | 34 a | 1 c | 0 |
| turnip | 29 ab | 0 ab | 1 b |
| rape | 23 b | 3 bc | 0 |
| | | radicle length (cm) | |
| water | 7.4 a | 9.1 a | 4.9 a |
| oats | 0.9 cd | 0.7 c | 1.7 c |
| wheat | 4.2 b | 7.7 a | 4.2 a |
| rye | 1.2 c | 3.2 b | 1.5 c |
| triticale | 1.3 c | 3.5 b | 3.8 b |
| lupin | 0 | 0 | 0 |
| turnip | 0.5 d | 0.0 c | 0.6 c |
| rape | 0.1 d | 0.1 c | 0 |
| | | aerial length (cm) | |
| water | 5.1 a | 5.9 a | 5.3 a |
| oats | 2.7 c | 5.5 a | 3.3 a |
| wheat | 4.8 a | 6.7 a | 4.8 a |
| rye | 3.4 b | 6.2 a | 5.0 a |
| triticale | 3.5 b | 6.5 a | 5.1 a |
| lupin | 0 | 0 | 0 |
| turnip | 3.0 b | 4.9 a | 2.3 a |
| rape | 0.1 d | 1.6 b | 0 |

The crop residues can also affect the following crops that are sown in the same place, thus seeds of cotton, rice, beans, maize and soyabean crops were included in the test. With the exception of rye-grass, birds-foot and hairy vetch, all the other winter crop residues to some extent affected seedling development or the seed germination (Table 2) of the summer crops.

These germination tests, using extracts of plants, are useful to prove the existence of allelopathic substances in them, but in field conditions their effects often disappear (Altieri & Doll,1978; Etherington,1975). These substances are organic compounds, and attacked and decomposed by microrganisms and, being soluble, are easily leached in the soil. For this reason the laboratory results must be confirmed by field tests (Drost & Doll,1980; Etherington, 1975; Putman & Duke 1978).

TABLE 2

Allelopathic effects of water extracts of some winter crop residues on seed germination and seedling development of some summer crops

| Winter crops | cotton | rice | beans | maize | soyabean |
|---|---|---|---|---|---|
| | | number of germinated seeds | | | |
| water | 23 a | 25 a | 25 | 25 a | 25 a |
| oats | 5 c | 25 a | 25 | 23 ab | 25 a |
| wheat | 18 b | 25 a | 25 | 25 a | 25 a |
| rye | 3 b | 25 a | 25 | 23 ab | 25 a |
| turnip | 1 c | 2 c | 24 | 21 b | 23 b |
| lupin | 1 c | 17 b | 24 | 25 a | 25 a |
| rye-grass | 22 ab | 25 a | 25 | 25 a | 25 a |
| birds-foot | 21 ab | 24 a | 25 | 25 a | 25 a |
| hairy-vetch | 23 a | 25 a | 25 | 25 a | 25 a |
| | | radicle length (cm) | | | |
| water | 6.7 a | 8.47 ab | 11.8 a | 10.4 a | 11.6 a |
| oats | 0 | 0.92 c | 5.9 c | 5.5 abc | 5.9 bc |
| wheat | 3.75 b | 1.95 c | 9.0 b | 8.5 ab | 8.6 ab |
| rye | 0.19 | 9.21 c | 3.8 c | 5.6 bc | 3.2 c |
| turnip | 0.03 c | 0 | 0.5 d | 0 | 0 |
| lupin | 0 | 0 | 0.5 d | 0.2 c | 0 |
| rye-grass | 5.5 ab | 19.28 a | 11.2 ab | 10.4 a | 11.4 a |
| birds-foot | 6.17 a | 9.07 ab | 11.8 a | 6.6 ab | 11.5 a |
| hairy-vetch | 5.87 ab | 7.3 b | 12.3 a | 8.3 ab | 11.1 a |
| | | aerial length (cm) | | | |
| water | 3.37 a | 3.97 a | 6.2 bc | 5.2 a | 5.0 ab |
| oats | 0.13 c | 3.00 a | 1.2 d | 1.5 cd | 0.7 c |
| wheat | 1.15 bc | 3.53 a | 2.9 d | 2.8 bc | 1.7 c |
| rye | 0.1 c | 2.95 a | 1.3 d | 1.5 cd | 0.9 c |
| turnip | 0.03 c | 0.07 b | 0.8 d | 0.4 d | 1.2 c |
| lupin | 0.03 c | 1.45 b | 0.8 d | 1.0 d | 1.3 c |
| rye-grass | 2.12 ab | 2.92 a | 5.3 c | 4.6 a | 4.2 ab |
| birds-foot | 2.64 ab | 4.07 a | 8.8 a | 4.1 ab | 5.4 a |
| hairy-vetch | 2.62 ab | 3.55 a | 8.2 ab | 3.6 ab | 3.5 b |

Field experiments

The weed infestation that developed in the plots is presented in Table 3. All the crop residues reduced the weed infestation when compared with the control. The crops that left the soil cleanest of weeds were oats and forage turnip, followed by rape and rye.

TABLE 3

Effect of crop mulches on the soil weed infestation

| | days after harvest | | |
|---|---|---|---|
| | 9 (% canopy) | 21 (no.plants) | 118 (biomass fresh wt. g/$m^2$) |
| fallow | 67a | 83 a | 1541 a |
| wheat | 14 b | 13 bc | 1347 a |
| triticale | 10 b | 31 b | 1269 b |
| rye | 3 c | 6 c | 695 d |
| oats | 0 | 5 c | 361 e |
| lupin | 21 b | 9 bc | 1613 a |
| turnip | o | 2 c | 861 dc |
| rape | 1 c | 6 c | 987 c |

In relation to lupin, there was a contradiction between the results obtained in the germination tests with water extracts and the results obtained in the field experiments. While in the former the lupin showed a strong allelopathic effect, in the latter it was the crop that permitted the greatest infestation. This can be explained by the plant's morphology. The aerial part of lupin is constituted mainly of leaves that after harvest are easily decomposed, leaving the soil sparcely covered by the stems. These, although having toxins, are liberated only on the place were they cover the soil, letting the weeds grow freely in the bare spaces. This fact increases the importance that the quantity of residues and their uniform distribution have in relation to the concentration of toxin necessary to affect weed germination and development (Rice,1974;Swaint, 1977; Whittake,1970).

From the winter crops tested those that produced the greatest amounts of mulch were oats and forage turnip, followed by rye and rape (Fig.1), the same crops that kept the soil with the lowest weed infestation.

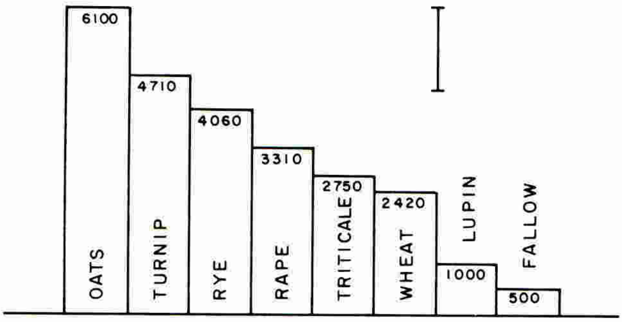


Fig. 1 Mulch biomass yield (dry wt. kg/ha) of the winter crops

Relating the mulch biomass yield (dry wt.) of the winter crops with the weed biomass (fresh wt.) that, 118 days later, infested the soil, it was possible to obtain the regression function $Y = 3095.31 x^{-0.32}$, represented in Fig. 2. The shape of the curve indicates that crops producing more than 4,500 kg of mulch (dry weight) are likely to be the most effective for reducing the weed infestation.

To obtain under field conditions, the desired effects from the allelopathic compounds, they need to be liberated into the soil for as long a period as possible. Thus in its early stages of development (where the crop is usually most susceptible to weed competition), the following crop could grow unhindered by weeds.

Figure 3 presents the decomposition rates of the winter crop residues, defined by their weights determined at 15 day intervals during a period of 199 days. The forage turnip residues decomposed at the fastest rate followed by oats. However, due to the high straw yield of the latter, on the 116th day, the straw weight was still 4.64 t/ha. Thus it can be deduced that the oat mulch can satisfactorily control weeds for a period of, at least, 116 days.

Since the allelopathic compounds produced by plants differs from one species to another, and since they are specific, the weed complex that develops in each mulch must be different. This was highlighted by this work. At 118 days after harvesting the winter crops, the weed complex that had developed in the lupin, wheat, rape, forage turnip and oats was composed, essentially, of the grasses (B. plantaginea and Digitaria horizontalis) which dominated almost entirely the broad-leaved species. On the other hand in the rye and triticale mulches and on the fallow, the opposite was true. The broad-leaved weeds, which constituted mainly of Bidens pilosa and Richardia brasiliensis, dominated the grasses (Fig. 4)

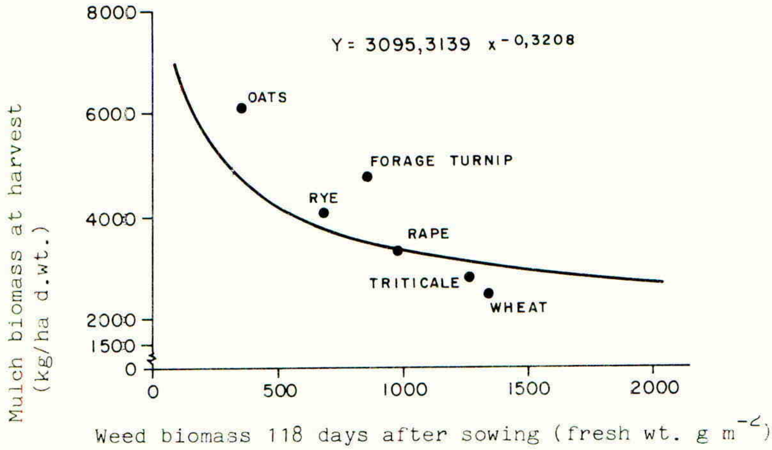


Fig.2. Correlation between the winter crop mulches biomass (dry wt.kg/ha) at harvest and the weed biomass (fresh wt. g $m^{-2}$) 118 days later

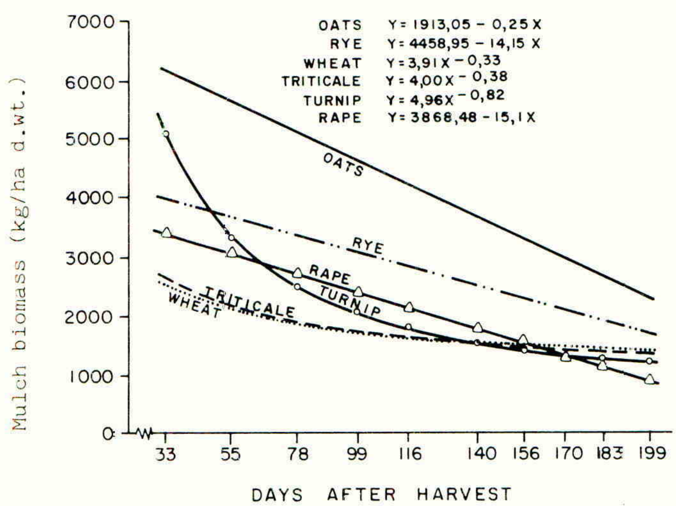


Fig. 3. Decomposition rate of different winter crop residues

It was also observed that some winter crop residues affected the maize. On the 72nd day the maize height on the triticale and forage turnip mulch was significantly lower (Table 4). Also the maize yield was reduced by the lupin, forage turnip and rape mulches (Table 4).

These differences can only be explained by the presence of the winter crop mulches, since weed competition was elminated by the use of herbicides.

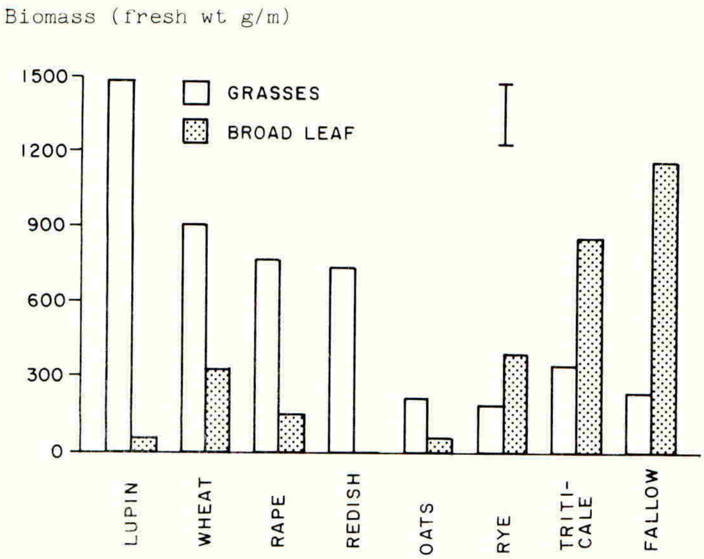


Fig. 4. Influence of the winter crop mulches on the composition of the soil weed infestation at 118 days after sowing

TABLE 4

Influence of the winter crop mulches on the height and yield of maize

| | height (cm) 72nd day | yield´(kg/ha d.m.)152nd day |
|---|---|---|
| fallow | 240 a | 5910 ab |
| wheat | 241 a | 5990 a |
| triticale | 225 cd | 5850 ab |
| rye | 239 ab | 6150 a |
| oats | 240 a | 6210 a |
| lupin | 244 a | 5330 bc |
| turnip | 222 d | 4900 d |
| rape | 234 abc | 5530 bc |

DISCUSSION

Several winter crop residues have been tested for their allelopathic effects on the germination of wild and crop seeds. In these experiments the effects were specific, also confirmed by a number of other authors (Bhowmik & Duke, 1974; Cochran et al, 1977; Etherington, 1975; Overland, 1966; Putman & Duke 1974). The winter crop extracts that had the broadest spectrum of susceptible species (wild and cultivated) were oats, rye, forage turnip and lupin.

Although it is easy to extract metabolic inhibitory products from plants and to demonstrate their suppressive effect on the growth of other plants, the effects often disappear if experiments are subsequently carried out under field conditions (Altieri & Doll, 1978; Etherington, 1975). For this reason the wheat, triticale, rye, oats, lupin, forage turnip and rape crop where grown in the field, harvested at the same time and the effect of their mulches on the soil weed infestation compared with a control (winter fallow). The oat mulch produced the lowest weed infestation after a period of 118 days, followed by rye, forage turnip and rape.

It was possible to correlate the weight of the residues produced by the winter crops with the weed infestation through the regression function $Y = 3095 x^{-0.32}$. From the slope it was inferred that crops with a yield of more than 4.5 t/ha of mulch at harvest, were the most effective for reducing the weed infestation, i.e. oats and forage turnip.

Ideally toxin liberation from the decomposing straw should continue for as long as possible, enabling the following crop to develop with very few weeds present and experience little or no competition. It was found that the oat mulch had a decomposition rate slightly higher than wheat, triticale, rape and rye. However, due to the greater quantity of residue produced, after 116 days, 4.64 t/ha still remained on the soil, the highest of the mulches tested. From this, it was deduced that the oat mulch could control weeds in the following crop for at least 116 days.

The allelopathic effects of the mulches were specific, modifying the soil floristic complex. It was observed that the lupin, wheat, rape, forage turnip and oat mulches promoted the development of grasses, while on the rye, triticale and fallow the natural vegetation consisted mainly of broad-leaved species. For the same reason, commercial crops can be affected by plant residues. Maize that was cultivated in the triticale, forage turnip, lupin and rape mulches had a lower height, and grain yield was affected by the forage turnip, lupin and rape mulches.

From these results it can be concluded that with some winter crop mulches the weed infestation in the following summer crop can be reduced but the mulch must be selected carefully, since some of them can affect development and yield of the summer crop.

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# BIOCHEMICAL REGULATION OF WILD OAT GERMINATION AND GROWTH BY WHEAT AND WHEAT CROP RESIDUES

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## ABSTRACT

Field and glasshouse data are presented which show that the germination and growth of wild oat, Avena sterilis ssp ludoviciana, can be stimulated by the post-harvest residues of a wheat crop, and inhibited by rhizosphere leachates from living wheat plants. It is hypothesised that the same biochemical regulator is responsible for the range of responses observed, the critical factor being the effective concentration of the regulator in soil. At a high concentration the regulator inhibits germination, at a low concentration it acts as a stimulant. The possible benefits to wild oat of variations in regulator level during a cereal cropping cycle are discussed.

## INTRODUCTION

Despite the volume of research undertaken with respect to the biology and dynamics of wild oat populations, and the annual cost of herbicides for wild oat control, the weed has successful survival strategies which enable it to flourish. There is little doubt that the severity of the wild oat problem in cereal crops has increased with the decline in the practice of rotational cropping and the trend towards continuous cereal monoculture (Elliott 1972, Cussans 1976).

Many examples of selectivity of response of test species to natural chemicals produced by plants or plant residues are reported in the literature (for example, Overland 1966, Singh and Pandey 1982, Steinsiek *et al.* 1982, Williams and Hoagland 1982, Leather 1983). Purvis *et al.* (1985) in a series of field experiments, demonstrated that selective weed response to the post-harvest residues of wheat, field pea, sunflower, sorghum and rapeseed crops resulted in a range of weed spectra which related directly to the type of crop residue incorporated into the soil. Of particular interest was the stimulation of germination, growth and seed production of wild oat (Avena sterilis spp. ludoviciana [hereafter referred to as A. ludoviciana] and Avena fatua) in the presence of wheat crop residues. Subsequent glasshouse experiments verified that chopped and incorporated wheat straw stimulated germination and post-emergent growth of wild oats and exerted a selective stimulatory/inhibitory effect on other weed species. The magnitude of the effect was governed by the length of time that the straw had been decomposing in the soil, and the amount incorporated (data to be published elsewhere).

This paper presents a brief summary of field and glasshouse experiments which demonstrate that wild oat germination and growth can be controlled by a growth regulator present in wheat plants and wheat crop residues. Possible implications of these findings for continuous wheat systems are discussed.

## MATERIALS AND METHODS

### Field study

This experiment was conducted at the University of New England Field

Station, Armidale, New South Wales, on a chocolate soil (Lithic Vertic Ustrochrept) with 4.6% organic matter and pH 6.0 (1:5, soil:water). In a randomised block design with four replicates, residues from mature harvested crops of wheat, field pea, sunflower, sorghum and oilseed rape, which had been grown in the absence of any added chemicals, were incorporated at the rate of 5 t $ha^{-1}$ to a depth of 10 cm, in field plots 0.5 x 8 m. The area had been cultivated to remove existing weed growth and no herbicides, pesticides or fertilizers were applied. Wild oat seed, (a mixture comprising 82% A. ludoviciana, 15% A. fatua and 3% hybrid between wild and cultivated oat), was sown 2 cm deep at the rate of 125 kg $ha^{-1}$ (720 seeds $m^{-2}$) on the same day that crop residues were incorporated. Wild oat seedling numbers in each of six fixed metal quadrats, set at one metre intervals in each plot, were recorded 14, 18, 34 and 47 days after sowing. At the final count, above ground parts were harvested for dry matter determination. Wild oat panicles were harvested from the entire area on day 64 to prevent seed shedding. Many were still immature. The oven-dry weight of seed (caryopsis enveloped by lemma and palea) was determined after drying for 48h at 80°C.

Glasshouse study one

Soil collected adjacent to the field site described above was used in this glasshouse study. A. ludoviciana, the predominant species in the wild oat mixture, was separated into biotypes on the basis of lemma colour (cream, buff, grey, chestnut and dark brown). Twenty even primary seeds of each colour were sown per 15 cm pot and received either wheat leachate or water, with 4 replicates. Wheat straw, from the same source as that used in the field study, was soaked without agitation for 24h in cold water, and the resulting tea-coloured leachate filtered through calico cloth. The leachate was produced as a bulk solution from 25 g wheat straw $litre^{-1}$ water which, when applied as 300 ml per pot, represented the water-soluble components of an equivalent of 5 t $ha^{-1}$ of wheat straw (7 g per pot). Control pots received 300 ml of water. Treatments were applied once a week. Emerged A. ludoviciana seedlings were thinned to 7 plants per pot, 16 days after sowing, and leaf and tiller number per plant recorded every 4 days from that day through to harvest at day 32. Top and root weights were determined after drying for 48h at 80°C.

Glasshouse study two

Wheat leachate concentrations of 0,3,6,12,25,50,100 and 150 g straw $litre^{-1}$ were obtained by soaking coarsely ground wheat straw (Christy Norris Laboratory Mill:3mm mesh) in cold water for 2h. Twenty even primary seeds of A. ludoviciana with dark brown lemmas were sown per 15 cm pot of washed sand, in a randomised block design with 4 replicates. Treatments were applied as 300 ml at the commencement of the experiment and at weekly intervals thereafter. Emergence of wild oat seedlings was recorded daily for 30 days.

Glasshouse study three

Ten wheat plants per 15 cm pot were grown for 30 and 15 days prior to the commencement of this experiment, which was in two parts. In part one, wheat plants grown in pots of soil obtained from the field study site were cut at ground level and twenty dark brown primary seeds of A. ludoviciana sown per pot. Subsequent wheat-shoot growth was removed to prevent above-ground interference between the wheat and emerging wild oats. In part two, 500 ml water was applied at the top of pots containing intact wheat plants growing in sand culture, and 300 ml of rhizosphere leachate collected at the base. This was then applied to wild oats sown in separate pots. Water percolated through blank sand culture pots was applied to controls. A 6 g straw litre$^{-1}$ wheat leachate treatment was included for comparison, and all treatments randomised within blocks and replicated four times. Leachate treatments were applied once a week, and wild oat emergence recorded daily for 30 days.

## RESULTS

### Field study

Number emerged, seedling dry weight, and seed production of wild oats were greater in plots where crop residue of any type had been incorporated, the greatest stimulation occurring in the presence of wheat straw. In this treatment, twice as many wild oats emerged, having ten times the dry weight and producing 42 times the oven-dry weight of immature seed of their non-residue counterparts (Table 1).

TABLE 1

Field study one: plant density, dry weight at 47 days, and seed production at 64 days of wild oats in wheat residue and no residue treatments

| Treatment | Plant density (number m$^{-2}$) | Dry weight (g m$^{-2}$) | Seed weight (g m$^{-2}$) |
|---|---|---|---|
| No residue | 258 | 14 | 1 |
| Wheat residue | 500 | 138 | 42 |

### Glasshouse study one

The germination response of *A. ludoviciana* seeds was related to lemma colour, and there were distinct morphological differences between the seedlings of each biotype. However, no significant differences in the rate of post-emergent growth of seedlings arising from seeds of different lemma colour were apparent during the 16 day test period. The application of wheat leachate (water soluble components of wheat straw) stimulated post-emergent growth of all *A. ludoviciana* seedlings irrespective of biotype, as indicated by mean leaf number (Fig. 1) and tiller number (Fig. 2) per plant. Top and root dry weights 32 days from sowing were .09 and .17 g per plant respectively for wheat leachate treatments and .02 and .03 g per plant for controls, averaged over the five biotypes tested.

### Glasshouse study two

The stimulation observed in glasshouse study one is similar to that expected if abundant quantities of plant nutrients were applied. However, it is considered unlikely that mature wheat straw would contain nutrients in the amounts necessary to produce such a response. Stimulation produced by a plant growth regulator, on the other hand, usually occurs at only low concentrations and, as concentration is increased beyond the optimal point, plant growth becomes significantly inhibited. The growth regulator hypothesis was tested by producing a range of concentrations of leachates containing the water-soluble components of from 0 to 150 g straw per litre of water. At the highest concentration, 150 g litre$^{-1}$, no germination of wild oats occurred, while at low concentrations, germination was stimulated. The germination response over the concentration gradient, Fig. 3, is that typical of a plant growth regulator effect.

The rate of emergence of wild oats, as well as the final number emerged, was affected by wheat leachate concentration. In the 6 g litre$^{-1}$ treatment,

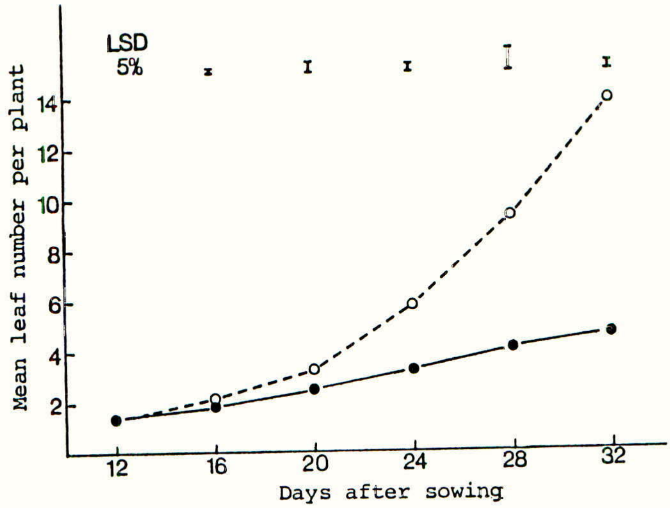


Fig. 1. Effect of wheat straw leachate (O--O) and water (●—●) on mean leaf number of A. ludoviciana seedlings of 5 biotypes.

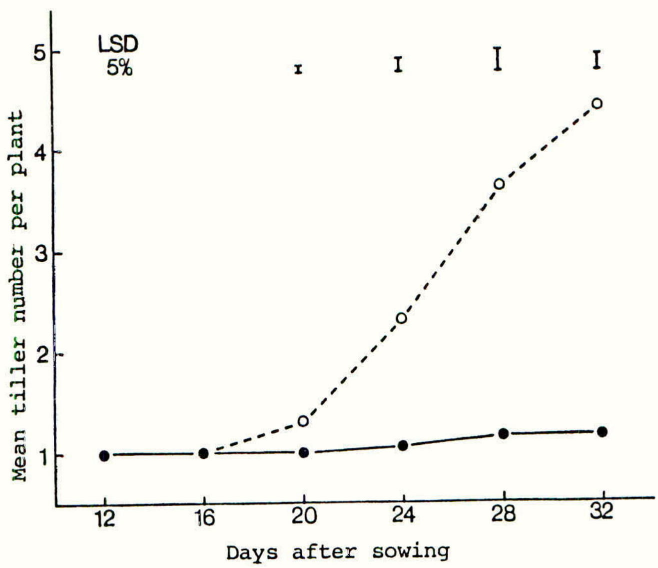


Fig. 2. Mean tiller number including main stem, of A. ludoviciana seedlings after application of wheat straw leachate (O--O) or water (●—●).

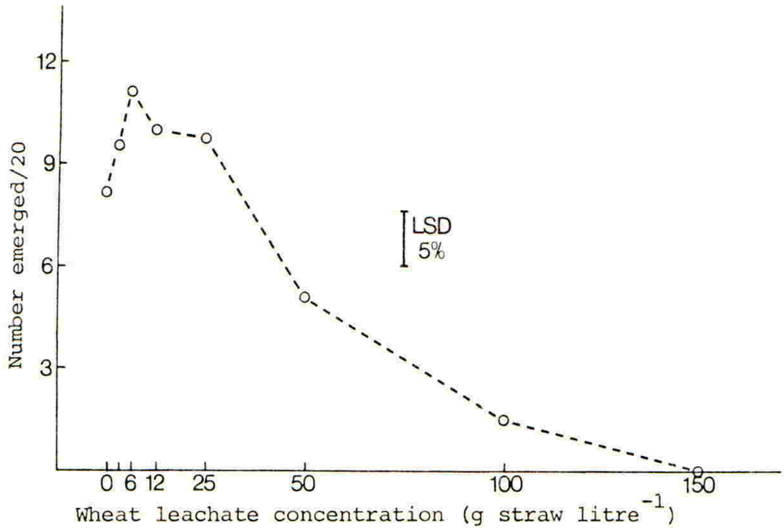


Fig. 3. Total number of A. ludoviciana emerged after 30 days. Wheat straw leachates applied at concentrations of 0,3,6,12,25,50,100 and 150 g straw litre$^{-1}$.

seedlings emerged very rapidly and had achieved maximum emergence 11 days after sowing. Seeds receiving water took 14 days to reach maximum emergence, while those receiving 50 and 100 g litre$^{-1}$ wheat leachate emerged very slowly (not shown graphically).

Glasshouse study three

The roots of living wheat plants were found to be inhibitory to wild oat germination and growth. The level of inhibition was related to wheat seedling age at the commencement of the experiment. Germination was inhibited to the same degree whether wild oat seeds were sown directly into pots containing living wheat roots or sown in separate pots to which wheat rhizosphere leachate was applied. Pooled data for the two techniques are presented (Fig. 4), plus the water and 6 g litre$^{-1}$ leachate treatment. From these emergence patterns it can be seen that both the number emerged and the germination rate were increased in the presence of wheat straw leachate. In the presence of the rhizosphere leachate from living wheat plants, wild oats emerged at a slow rate and took longer to reach maximum emergence. The number emerged was far lower in the presence of rhizosphere leachate from wheat seedlings 15 days old (2 leaf stage) than from those 30 days old (4 leaf stage) at the commencement of the experiment. This suggests that the level of growth regulator in wheat plants increases very rapidly during the early stages of seedling growth.

## DISCUSSION

The experiments described here provide evidence for the existence of a biochemical growth regulator in wheat plants and wheat crop residues which can influence the germination percentage, emergence rate, seedling vigour and seed production of wild oats. It is hypothesised that the level of growth regulator in wheat plants increases rapidly during the early stages of

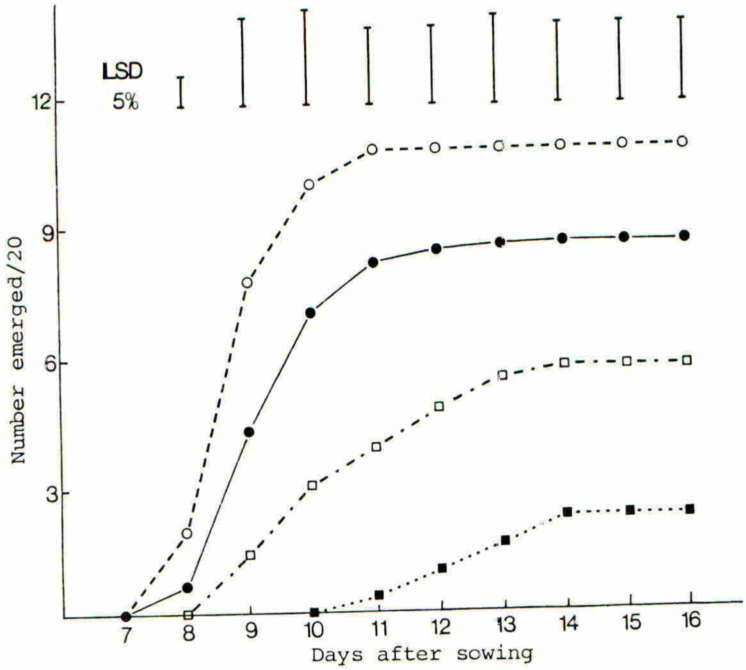


Fig. 4. Emergence of A. ludoviciana in presence of wheat leachate from 6 g straw litre$^{-1}$ (○- -○), water (●——●), rhizosphere leachate from 30 day old wheat seedlings (□-·-□), rhizosphere leachate from 15 day old wheat seedlings (■···■).

seedling growth and then declines during senescence, so that only low levels are present in the straw. In these experiments, fifteen-day old wheat plants were found to be more inhibitory to wild oat germination than thirty-day old plants. It is of interest that Overland (1966), in a comprehensive study of the effects of barley on four test species, found that two-week old barley plants were far more inhibitory to Stellaria media than were four-week old plants. Overland (1966) suggested that the production of an inhibitor by barley was rhythmic and occurred at specific growth stages of the crop, and further, that this periodic production partly explained the lack of total inhibition of receiver species.

How would changes in regulator level in the soil during the annual cereal cropping cycle be advantageous to wild oats?

Firstly, the suppression of germination of wild oats once the crop has established would reduce the number of wild oats emerging into an unfavourable environment. Many investigations have shown that wild oat plants emerging after cereal crop establishment produce less seed and often suffer a higher mortality rate than those emerging at about the same time as the crop (e.g. Pfeiffer *et al.* 1960, Chancellor and Peters 1972, Peters and Wilson 1983, Peters 1984). The selection pressure placed on genotypes which are not inhibited by the high levels of regulator produced by an actively growing crop would ensure that they represent only a small percentage of the wild oat population, as their emergence in an established crop results in them producing little, if any, seed for subsequent generations. Suppression of responsive genotypes prevents depletion of the soil seed reservoir in circumstances unfavourable to the species.

Secondly, decomposition of crop stubble and root residues during the intercrop period in a continuous cereal system would result in the addition of low levels of regulator to the soil. Wild oats germinating before or at the same time as the next crop would be stimulated by these low levels. This may cause a flush of germination at an opportune time and/or result in greater seedling vigour, thus improving the competitive ability of the weed.

While it is not denied that the cultural practices associated with cereal growing contribute to the proliferation of wild oats, and that these can be manipulated to reduce the annual rate of increase to some extent, the biochemical regulation of wild oat germination and growth by substances produced by growing plants and present in post-harvest crop residues must surely ensure their survival in a continuous cereal system.

Ongoing work (Purvis unpublished) indicates that the roots of some crops are more inhibitory than those of wheat. Perhaps the presence of an inhibitory crop at the time of year wild oats normally germinate would serve as an effective biological control measure, especially if the alternative crop was grown for several years in succession. Wild oat seed which had not germinated due to inhibitors in the soil would presumably lose viability and eventually perish.

Reported effects of tillage and other cultural practices on wild oat seed and seedling numbers vary with the experiment and results sometimes appear contradictory (Cussans 1976). This could possibly be due to interactions between the effects of the cultural technique under investigation on placement and viability of wild oat seeds, and the equally important but often overlooked influence of the crop stubble and its type, quantity, placement, and rate of decomposition, on subsequent wild oat germination percentage and seedling vigour.

## ACKNOWLEDGEMENTS

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