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The Potential of Allelopathy as a Tool for Weed Management in Crop Fields

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The Potential of Allelopathy as a Tool for Weed Management in Crop Fields

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Summary. The increasing emphasis now placed on weed management as opposed to weed control raises the question of the role of allelopathy in agricultural systems. Evidence of allelopathic interactions between crops and weeds is briefly reviewed and two experiments designed to demonstrate the allelopathic effects of plant residues on seed germination are described. From these experiments it can be seen that *Tagetes patula, Amaranthus dubius,* bean (*Phaseolus vulgaris*) and cassava residues have widespread inhibitory effects on the germination of seeds of other species, while maize, *Cenchrus brownii, Eleusine indica* and *Portulaca oleracea* show considerable tolerance to the presence of such residues. Suggestions are made as to how the potential of allelopathy in weed management can be investigated and how the process can be exploited. A considerable quantity of research remains to be done in this area.

Introduction

Traditionally the basic principles of weed control have been directed at the survival mechanisms of weeds; preventing seed production, depleting seed reserves and destroying underground vegetative organs. The achievement of these goals has been obtained mainly through cultural or mechanical practices and, more recently, by chemical means.

Lately, weed researchers have considered the role of habitat manipulation in weed management. The maintenance of a crop in a dominant competitive position to the weed community depends on the differential response of the crop and the weeds to some biotic, climatic or edaphic factor which can be manipulated. By intelligent ecological modification of one or more of these factors, the crop-weed balance can be shifted to the crop's advantage (Bantilan *et al.,* 1974).

Recent findings have widened the scope of weed ecology. Baker (1974) has stressed the importance of the ecophysiological characteristics of weeds which condition their wide environmental tolerance and colonising ability. Young and Evans (1976) have correlated the acceleration of successional patterns in agriculture with the selection of competitive weed genotypes. Hoveland *et al.* (1976) have studied the response of various weeds to different levels of P and K and concluded that the local weed complex can be indirectly affected by the manipulation of soil fertility. New approaches to weed management include the suggestion of Sweet *et al.* (1974) that weed competition can be reduced by selecting crop varieties which will shade out sensitive weed species. Their work on potato varieties with different leaf area indices illustrates their point.

Research on traditional intercropping systems shows that crop mixtures with a canopy that covers the soil throughout the growing season minimise the need for weed control. Striking examples can be observed in Indonesia's corn–rice–cassava interplanting systems (Harwood, 1976) and in the bean (*Phaseolus vulgaris* L.)–cassava systems of tropical Colombia (Piedrahita *et al.,* 1975).

The effects of weeds on crops are not only competitive however but apparently are also due to allelopathy which is the inhibition of germination, growth or metabolism of one plant due to the release of organic chemicals by another (Del Moral and Cates, 1971). This process has long been recognised as capable of altering the structure

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TABLE 1. EXAMPLES OF WEEDS EXERTING ALLELOPATHIC EFFECTS ON CROP PLANTS

Weed	Crop	Type of effect	Source of inhibitors	Reference
Cirsium sp.	Oats	General growth inhibition	Not reported	Rice, 1974
Euphorbia sp. and *Scabiosa* sp.	Flax	General growth inhibition	Root exudates	Rice, 1974
Lolium sp.	Wheat	General growth inhibition	Root exudates	Rice, 1974
Camelina alyssum Thell.	Flax	Reduced yield	Leaves	Rice, 1974: Grummer and Beyer, 1960
Galium mollugo L.	Wheat, radish and onion	Germination and bulb development inhibition	Diluted plant materials	Rice, 1974
Lepidium virginicum L. *Oenothera biennis* L. and *Digitaria sanguinalis* (L.) Scop.	Crown vetch	Toxicity to germinating seedlings	Water extracts of plant material	Rice, 1974
Setaria faberi Herrm.	Maize	Inhibition of growth and accumulation of dry and fresh weight	Exudates of whole mature plant residue	Bell and Koeppe, 1972
Cyperus rotundus L.	Sorghum and soyabean	Inhibition of growth	Tubers	Lucena and Doll, 1976
Madia glomerata Hook.	Radish	Germination reduction and abnormal seedling growth	Plant leachates	Carnahan and Hull, 1962
Chrysanthemum morifolium Ramat	Lettuce	Germination inhibition	Foliage leachate	Kozel and Tukey, 1968
Polygonum persicaria L.	Potato and flax	Depression of dry weight	Root extract	Martin and Rademacher, 1960
Salvia occidentalis Swartz.	Young coffee	Growth suppression	Root extract	Eussen, 1972
Artemisia vulgaris L.	Cucumber	Inhibition of seedling growth	Leaf extract	Eussen, 1972
Imperata cylindrica (L.) Beauv.	Several crops	General growth inhibition	Not reported	Eussen, 1972

function, and diversity of plant communities by its influence on the rate and sequence of plant succession and on the species composition of natural communities (Whittaker, 1970).

In a few instances, research supports the concept of interspecific antagonism through the production of inhibitors, but in general these results do not demonstrate any ability of allelopathy to increase the competitiveness of crops against weeds under field conditions (Putnam and Duke, 1974). This paper reviews relevant examples of allelopathic interactions between crops and weeds, and suggests some possible practical uses of allelopathy in weed management.

Allelopathic interactions between crops and weeds

In a recent book on allelopathy, Rice (1974) emphasises the relative lack of research concerning allelopathic interactions between crops and weeds. Nevertheless, several interesting examples of allelopathy in agriculture can be found in the literature. Overland (1966) investigated the use of barley as a 'smother' crop for weed suppression, showing its effectiveness and specificity. In certain regions establishment of lucerne seedlings is not easily accomplished when the land is infested with *Agropyron repens* (L.) Beauv. The same effect has been observed for maize fields in Wisconsin (National Academy of Sciences, 1968).

Putnam and Duke (1974) found that some strains of cucumber (*Cucumis sativus* L.) inhibit weed growth by 87% whereas others have almost no inhibitory effect. They hypothesise that the predecessors of the crop may have possessed allelopathic properties which allowed them to maintain a dominant position in their native habitats but which were reduced or lost as plants were selected to grow in weed-free environments. Weeds, on the contrary, seem to have maintained or developed these properties, thus enhancing their invading ability.

Ecological observations in chaparral ecosystems (Biswell, 1974) suggest that allelopathy is well marked in habitats where one species is much more abundant than its competitors. This is usually the case in crop monocultures.

Tables 1 and 2 summarise much of the experimental evidence showing weed inhibition of crop development and *vice versa.* Most of the studies concerning allelopathic interactions between crops and weeds have been carried out under laboratory and glasshouse conditions in which root excretions and water extracts of several tissues have been tested. Several criticisms of these studies have been made of which the most important can be summarised as follows:

1. *In vitro* effects often disappear if experiments are subsequently carried out under field conditions (Etherington, 1975).
2. Although it is easy to extract metabolic inhibitory products and to demonstrate their suppressive effect on the growth of other plants, it is difficult to prove that the effect is due to allelopathy and not to competitive interaction (Etherington, 1975).
3. Laboratory experiments with plant extracts do not involve soil microflora which may play a major role either in ameliorating the effect of plant toxins or in converting harmless plant excretions and decay products into toxic substances (National Academy of Sciences, 1978). For example, McCalla and Haskins (1964) report that stubble mulch farming depresses the growth of maize under some conditions. They suggest that the inhibitive effects of the mulch might be due to a combination of toxins from the plant residues and from microorganisms caused to grow more profusely by substances in the mulch. *Penicillium urticae,* a fungus, produces a toxin (patulin) which is particularly potent against the growth of maize plants (Norstadt and McCalla, 1963).

Another technique for the study of the role of allelopathy in agriculture, involving measurement of the allelopathic effects of plant residues (Rice, 1974) was used in two experiments carried out in pots in the glasshouse at the Centro International de Agricultura Tropical (CIAT) in Cali, Colombia. A species of the genus *Tagetes* which is known to release toxic compounds (Hunter, 1971) was studied in the first experiment while a variety of crop and weed species were involved in the second.

Allelopathic effects of Tagetes patula *L. residues*

Plastic 1.85 *l* pots were filled with soil (clayey, pH 6.8, organic matter content 3.5%) and 13.1 g of chopped fresh *Tagetes patula* shoot was mixed carefully in the top 5 cm of soil. One hundred seeds of one of the weed species under study (Table 3) or 25 seeds of maize or beans were sown on the soil surface either just after incorporation of the residue or 10 days later.

TABLE 2. EXAMPLES OF CROP PLANTS EXERTING ALLELOPATHIC EFFECTS ON WEEDS

Crop	Weed	Type of effect	Source of inhibitor	Reference
Maize and lupin (*Lupinus albus* L.)	*Chenopodium album* L. and *Amaranthus retroflexus* L.	Inhibition of growth	Root excretions	Rice, 1974
Wheat, oats and peas	*Chenopodium album* L.	Suppression of growth, biomass accumulation and leaf area	Not reported	Rice, 1974
Oats	*Erysimum cheiranthoides* L.	Growth suppression	Not reported	Rice, 1974
Rye	*Matricaria maritima* L.	Depression of seedling development and general growth	Root extract	Martin and Rademacher, 1960
Oats	*Papaver rhoeas* L.	Depression of total dry weight or of roots and shoots	Root extract	Martin and Rademacher, 1960
Rye and oats	*Sinapsis arvensis* L.	Effects on total dry weight	Root extract	Martin and Rademacher, 1960
Cassava	*Amaranthus dubius* Mart *Ipomoea hederifolia* L. and *Digitaria sanguinalis* (L.) Scop.	Radicle elongation	Leaves	Doll (unpublished data)

TABLE 3. EFFECT OF TIME BETWEEN INCORPORATION OF *TAGETES PATULA* RESIDUE AND SOWING ON SEED GERMINATION†

Plant species	Planting	
	10 days after incorporation	Immediately after incorporation
Beans	9	83*
Maize	0	0
Euphorbia heterophylla L.	0	100*
Ipomoea tiliacea Choisy.	64*	100*
Amaranthus dubius Mart.	100*	100*
Desmodium tortuosum (Sw.) DC.	90*	100*
Momordica charantia l.	50*	100*
Rottboellia exaltata L.f.	80*	100*
Bidens pilosa L.	0	38

† Each value is given as % reduction of germination compared with the control
* Numbers followed by an asterisk indicate significant (p = 0.05) reduction of germination as compared to the controls.

The number of emerging seedlings in each treatment 10 days after planting was compared to the number in a plain soil control. Treatments and controls were replicated three times.

Table 3 shows the effect of the date of incorporation of residues on the germination of the weeds and crops studied. Residue incorporated 10 days before planting exerted a considerable effect on the germination of *Ipomoea tiliacea, Amaranthus dubius, Desmodium tortuosum, Momordica charantia* and *Rottboellia exaltata,* reducing seedling emergence by more than 50%. Maize, beans (*Phaseolus vulgaris), Bidens pilosa* and *Euphorbia heterophylla* were not affected. Incorporating the residue immediately before sowing enhanced its inhibitory effects, and all species except maize and *Bidens pilosa* showed an impressive reduction in germination.

These results show that *Tagetes patula* foliage contains toxic compounds (or substances which stimulate toxin production by soil microorganisms) which have a wide allelopathic spectrum, but which lose their effectiveness when the material decomposes in the soil. This may be due to microbial inactivation, colloidal adsorption, volatilisation, percolation or biochemical degradation (Daubenmire, 1974). It also seems that maize and *Bidens pilosa* are resistant or tolerant to these compounds.

Allelopathic interactions between several crops and weeds

To investigate possible allelopathic interactions between several tropical crops and weeds, the effects of the incorporation of fresh residues of *Leptochloa filiformis, Eleusine indica, Tagetes patula, Amaranthus dubius,* cassava, maize and beans (*Phaseolus vulgaris)* on the germination and seedling emergence of nine weed species and three crops was evaluated. The experiment consisted of 84 treatments, replicated twice. In each pot 20 g of chopped fresh foliage of one of the seven plant species were incorporated into the soil surface. At the time of foliage incorporation either 50 weed seeds or 10 crop seeds were planted in the pot and twenty days later the number of emerged seedlings was counted. Table 4 shows the percentage reduction of germination for each treatment.

As in the previous experiment corn exhibited considerable tolerance to incorporated material. Tolerance was also shown by *Cenchrus brownii, Eleusine indica* and *Portulaca oleracea.* Beans and sorghum were greatly affected by residues of cassava, beans and *Tagetes patula.* Beans were also very sensitive to *Amaranthus dubius.* The most sensitive weed species were *Ipomoea hederifolia, Amaranthus dubius* and *Bidens pilosa.* This sensitivity of *Ipomoea hederifolia* may have considerable practical potential since it is a very aggressive weed which is difficult to control with herbicides or cultural methods. Beans, cassava, *Amaranthus dubius* and *Tagetes patula* residues had the most widespread inhibitory action. *Eleusine indica* residues stimulated the germination of *Leptochloa filiformis* and those of cassava had the same affect on *Cenchrus brownii* and *Eleusine indica.*

Allelopathy in weed management

Knowledge of the main allelopathic interactions between the crops and weeds of a certain ecoclimatic region could have enormous potential for weed control. The practical use of allelopathy, however, is complex since

TABLE 4. EFFECT OF PLANT RESIDUES ON SEED GERMINATION

Seeds planted	% of germination reduction†						
	Leptochloa filiformis (Lam.) Beauv.	Beans	*Eleusine indica* Gaertn.	*Amaranthus dubius* Mart.	Cassava	Maize	*Tagetes patula*
Maize	5	0	10	5	15	10	15
Beans	0	53*	29	94*	53*	19	71*
Sorghum	0	75*	15	10	50	30	75*
Leptochloa filliformis (Lam.) Beauv.	100*	29	+157††	57*	71*	43	29
Ipomoea hederifolia L.	46*	75*	33	83*	75*	54*	96*
Digitaria sanguinalis (L.) Scop.	24	7	37	14	0	21	52*
Cenchrus brownii Roem. & Schult.	22	22	29	19	+12	19	46
Eleusine Indica Gaertn.	34	11	11	43	+20	26	11
Solanum nigrum L.	24	41	53*	12	100*	65*	12
Portulaca oleracea L.	13	39	0	26	39	0	43
Amaranthus dubius Mart.	88*	88*	82*	62*	76*	6	91*
Bidens pilosa L.	14	47*	22	53*	19	39*	50*

† As compared to the controls.
†† The symbol + indicates stimulation of germination.
* Numbers followed by an asterisk indicate significant ($p = 0.05$) reduction of germination.

these interactions rarely occur so markedly under normal field conditions as in the glasshouse. It is probable that most of the toxins are secondary chemical compounds stored in the foliage tissues and rarely released into the environment in effective quantities. Cultural practices may interfere with the dynamics of inhibitors, affecting their concentrations either in plants or in the soil and the presence of several weed species in close proximity, could result in interactions between inhibitory and stimulatory substances. Before attempts are made to control weeds by allelopathic means the following work should be carried out:

1. Intensification of programmes to identify allelopathic interactions between crops and crops, crops and weeds, and weeds and weeds, at the seed to seed, plant to seed, plant to plant, residue to seed and residue to plant level in different geographical areas.
2. Identification of the parts of the plants which contain inhibitors and of the ways in which inhibitors are released into the environment.
3. Investigation of the effects of residues from plants of different ages and from different plant parts.
4. Identification of possible synergisms and/or antagonisms between incorporated residues.
5. Evaluation of the effects of environmental factors and cultural practices on the behaviour of inhibitors.
6. Chemical identification of the inhibitors and their mechanisms of action.

Practical suggestions on the use of allelopathy in the field include:

1. Application of mulches of fresh residues, for example of *Tagetes patula,* in recently planted maize fields.
2. Spraying extracts from plant parts containing high concentrations of inhibitors. The optimum time of application (before or after planting) and the duration of the effect need to be determined.
3. Planting strips of species which actively release substances toxic to weeds but not to the crops under study.
4. Integration of allelopathic strategies with other methods of weed control.
5. Evaluation of the effect of hormonal stimulation on inhibitor production in crops or specific weeds.
6. Genetic incorporation of allelopathic properties into commercial cultivars of the main crops as suggested by Putnam and Duke (1974).

Conclusions

This paper has attempted to highlight the potential use of allelopathy in integrated weed management systems and the urgent need for further research in this area. The increasing cost of herbicides and the energy dependence of modern agriculture (Pimentel *et al.,* 1973) is stimulating investigation into the development of new cropping systems which will produce high yields using the minimum of non-renewable resources (Loucks, 1977). The utilisation of allelopathy for weed suppression seems to fit most ecological, economic and energy requirements for this new approach to agroecosystem management.

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