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Use of Allelopathy in Agriculture

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Abstract: Biorational alternatives are gaining increased attention to weed control because of concerns related to pesticide usage, degradation and buildup in the soils. Allelopathy offers potential for weed control through the production and release of allelochemicals from leaves, flowers, seeds, stems and roots of living or decomposing plant materials. Allelopathy is a challenge at present and allelochemicals a resource.

Key words: Weed control, allelochemicals

Introduction

The definition of "Allelopathy" accepted by the International Allelopathy Society is 'any process involving secondary metabolites produced by plants, algae, bacteria and fungi that influence the growth and development of agricultural and biological systems' (Anonymous, 1996). Allelochemicals are defined as 'biocommunicators', suggesting the possibility of active mixtures, because of the increasing number of findings in which single compounds are not active or are not as active as a mixture (Macias, 1998). Accordingly he emphasizes that traditional agriculture practices based on ancient knowledge are useful as starting points for new allelopathic studies. The approach is based on the belief that these practices result from the close contact between nature and humans throughout history. Allelopathy will play an important role in future weed control and crop productivity. The allelopathic compounds can be used as natural herbicides and other pesticides; they are less disruptive of the global ecosystem than are synthetic agrochemicals. Many important crops, such as rice, sugarcane and mung beans (*Vigna radiata*) are affected by their own toxic exudates or by phytotoxins produced when their residues decompose in the soil (Einhellig, 1995). Eliminating or preventing the formation of the phytotoxins through field treatments can minimize autointoxication. These treatments may be a combination of crop rotation, water draining, water flooding and the polymerization of phytotoxic phenolics into a humic complex.

Integrated pest management: Contemporary plant production systems rely heavily on inputs of chemicals to provide protection against insects, diseases and weeds. This extensive use of chemicals in plant protection has given rise to concerns about pesticide residues in the environment and to the development of pesticide resistance by many organisms. Alternative approaches to plant protection include the continued use of pesticides as components of integrated pest management programmes and more radical developments, such as enhancing and harnessing the array of defensive chemicals produced naturally by plants. An increasing body of evidence points to their ability to contribute to plant protection (Lovett, 1990). Allelopathic chemicals have already been used to defend crop plants against insects, nematodes and diseases however parallel approaches in control of weeds may be possible by finding compounds that inhibit seed germination, inhibit plant growth or prevent progagule production. There is a greater emphasis on the control of weeds in sustainable agricultural systems by reduced or non-chemical means that are compatible with reduced tillage and both traditional and recent weed management practices (Regnier and Janke, 1989). Allelopathic elements are involved in practically every aspects of plant growth; they can act from stimulants to suppressants. The intelligent exploitation of these processes can be a major break through in the agriculture sector. Crop rotation, competitive varieties, allelopathic varieties, cover crops, tillage, relay cropping, dead and living mulches, flame weeding and ridge tillage together with classical biological control agents is being employed. Allelopathic interactions between plants and other organisms may become an alternative to herbicides, insecticides and nematicide for weed, disease and insect control. The recognition of the role allelopathy may have in producing optimum crop yields is of fundamental importance (Waller, 1989).

Natural phytotoxic compounds: Green plants produce hundreds of thousands of compounds that are not involved in the primary metabolism of the plants (secondary products); the compounds involved in interspecific chemical interactions (allelopathy) with higher plants are often phytotoxic or herbicidal to other species or even to the species producing them (Duke, 1986). Allelopathy is the direct influence of a chemical released from one living plant on the development and growth of another plant. Secondary compounds in plants may act as attractants or repellants, phagostimulants or antifeedants, nutrients or toxins to phytophagous insects. In initial efforts to develop botanical herbicides from allelochemicals, active principles of allelopathic chemicals have been isolated and identified in Asia and the U.S.A. (Kim, 1992). Four percent out of 10,000 rice germplasm lines possess various degrees of allelopathic activity against certain rice weeds (Smith, 1992). These lines differ in origin, grain type, plant height and maturity, which are desirable in developing commercially acceptable cultivars with allelopathic traits (Dilday, 1994). Mattice *et al.* (2000) have developed an assay using the HPLC chromatograms to predict whether an accession of rice will inhibit growth of barnyard grass (*Echinochloa crus-galli*). These inhibitory rice accessions contain four to six compounds that inhibit the growth of this weed.

Allelochemicals production: To establish the cause and effect relationship of allelopathy one needs to demonstrate the production of allelochemicals(Table 1) by the host plant, their transport from the host plant to the affected plants in the surroundings, and exposure of affected plants to these chemicals in sufficient quantity for a sufficient time to cause the observed allelopathy (Einhellig, 1995). A key to the deciphering of the mechanisms of allelopathy could be through an understanding of such soil processes as retention and transformation, which affect the fate and transport of allelochemicals. While dealing with allelochemicals in plants it is important to consider stresses like temperature, mineral deficiency, water stress, diseases and herbicides applied. These stresses have been shown to affect the amount of the allelochemicals produced. Toxic compounds of crop plant origin accumulate in agricultural soils. A great variety of organic compounds are released by numerous plant species, each having an active life in the soil that is determined by factors such as volatility, leaching, adsorption and microbial action.

While making use of these chemicals it is also necessary to minimize the influence of toxins on crop plants. It is important that the utility of allelopathy be based on treatments of short duration rather than those that persist for long periods in soil. Most plant residues contain or produce substances which are inhibitory to plant growth to some extent, and that the toxic effect is normally of an ephemeral nature disappearing within 14 to 21 days. The degree of toxicity depends on the type of residue, maturity and extent of weathering. Reviewing literature both recent and old, it is evident from the contradictory results often obtained, substances highly toxic, nontoxic, stimulatory to plants can be obtained during the decomposition of similar plant residues. Breland (1996) results suggests that retarded germination observed in the field is mainly caused by phytotoxic substances indigenous to fresh crop residues and that these substances were degraded during 3-4 weeks of aerobic decomposition at 15°C. Plant residues form various sources constitute an important component of the soil. During decomposition many complex interactions, transformations and synthesis occur. Thus at any one time, the soils and the environment of plant roots could contain a vast variety of chemical compounds, many of which, no doubt, have important effects on all phases of plant development. When phytotoxic compounds are produced there are problems of accumulation, stability, persistence and concentrations of these compounds in soils that have to be considered. There are also questions regarding the chemical nature of the phytotoxic compounds, their specific effect on plants in the absence of other causal factors and their overall ecological significance. In research on the accumulation of allelochemicals as influenced by microflora, it was found that in particular zygogenic, macrotrophic bacteria and fungi were responsible for the formation of allelopathic inhibitors of rye and wheat

Table 1:Allelochemicals produced by plants

Plant	Chemicals	Reference
Datura stramonium L.	Tropane alkaloids Scopolamine, Hyoscyamine	Lovett *et al.* (1981)
Secale cereale L. (Rye)	2,4-dihydroxy-1, 4(2H) benzoxazin-3-one (DIBOA) 2(3H)-benzoxazolinone (BOA)	Barnes & Putnam (1987)
Avena sativa L.	Ferulic acid	Rice (1984)
Sorghum bicolor L. (Sorghum), *Triticum aestivum* L. (wheat)	P-cumaric acids	
Triticum aestivum L.	2,4-Dihydroxy-7-methoxy -1,4-benzoxazin-3-one (DIMBOA)	Perez (1990)
Melilotus alba Desr. (Sweet clover)	Coumarin	Winter (1961)
Avena sativa L. (Oats)	Scopoletin	Fay and Duke (1977)
Sorghum halepense L. Pers. (Johnson grass)	Dhurrin (a cyanogenic glycoside) and its epimer taxiphyllin	Rizvi and Rizvi (1992)
Sorghum bicolor	P-benzoquinone dimethoxy-substituted P-benzoquinone 2,6-dimethoxy-P-benzoquinone (most active primary haustorical inducer)	Chang and Lynn (1987) Chang *et al.* (1986)
Sorghum bicolor	Sargoleone	Nimbal *et al.* (1996)
Trianthema portulacastrum L. *(Horse purslane)*	Caffeic, cholorogenic P-hydroxy benzoic, P-coumaric and ferulic acids	Varadi (1987)
Pistia stratiotes L.	Linoleic acid, gamma-linolenic acid, alpha-asarone	Alliota (1991)
Barley	Hordenine	Liu and Lovett (1993)
Wheat	Hydroxamic acid	Corcuera *et al.* (1992)
Mungbean	glucosyl flavonoids (Vitexin and isovitexin)	Tang and Zhang (1986)
Catharanthus rosea L. (periwinkle)	Vinblastine, Vincristine	Vaughan and Vaughan (1988)
Medicago sativa L.	Saponins	Krol *et al.* (1995)
Chenopodium ambrosioides L.	Ascaridole, alpha-terpinene gamma-terpinene, Limonene	Jimenez-Osornio (1996)

Table 2: Allelopathic effects of weeds on crops

Weed	Crop	Type of inhibition
Comellina alyssum (flax weed)	Flax	Dry matter production
Setaria faberii (gaint foxtail)	Corn	Growth and yield reduction
Rumex crispus (curly docks)	Corn Sorghum	Growth Seedling growth
Agropyron repens	Corn	Mineral deficiency, particularly nitrogen and potassium reduced biomass, phosphorus deficiency
Cirsium arvense (Canada thistle)	Several crops	Seed germination
Asclepias syriaca (common milkweed)	Grain Sorghum	Seedling growth, yield
Conyza canadensis	Corn	Growth, germination
Pteridium esculentum	Lucerne *Trifolium repens*	Radical elongation
Datura stramonium	Sunflower	Seedling growth

(Weyman-Kaczmarkowa and Wojcik-Wojtowiak, 1992). Under aerobic conditions these compounds disappear rapidly and an ample supply of decomposable organic matter is available, volatile fatty acids and other organic acids accumulate while synthesis of microbial material is suppressed. Decomposition of the plant residue is important in toxin production. Unless the residue is decomposed no phytotoxins can be produced; but recent evidence has also suggested potential of plants and their essential oils as safe

Table 3: Allelopathic effect of crops on weeds

Crop	Weeds inhibited	Type of inhibition
Barley contains the alkaloid gramine and hordenine	Stellaria media *Capsella bursa- pastoris* *Sinapis alba*	Germination Germination Germination
Sweet potato (*Ipomoea batatas*)	*Cyperus esculentus*	Root growth Harrison & Paterson (1991)
Secale cereal (Rye) (*Triticum aestivum*) Wheat	Several weeds Several weeds	Growth reduction Germination and Growth (Cheema *et al.*,1990)
Sunflower	Carthamus *Oxyacantha Bieb.* *Asphodelus tenuifolius Cav.* *Phalaris minor Retz.* *Silybum marianum (L.) Gaertn.* *Centaurea* sp. *Achyranthes aspera* L.	reduction in seed germination (Khalid and Shad ,1987)
Wheat	*Avena fatua*	Seed germination (Perez, 1990)
Sunflower (*Helianthus annuus*)	*Helianthus annuus* *Erigeron canadensis* *Amaranthus retroflexus*	reduction of seed germination
Wheat	*Convolvulus arvensis* *Dactyloctenium aegyptium*	germination and growth
Rice (allelopathic Varieties)	*Echinochloa crus-galli*	Seed bank reduction (Hassan *et al.*, 1998)

natural herbicides, growth promoters and other agents in agriculture as well as their importance in the natural control of insects (Brud and Gora, 1990).

Sources of phenolic acids: Free phenolic acids and their salts in root, stubble and other parts of the plant left in the soil should be considered as one of the sources of phenolic acids in the soil during the decomposition of plants (Patrick, 1971). A number of guiacyl and p-hydroxy-phenyl derivatives, together with a number of unknown phenolic compounds are formed during the decomposition of plant materials, this being another source of the phenolic acids in soil. During oxidation of these products, the essential reactions are decomposition of the side chain, demethylation, and oxidation to quinones, dimerization and polymerization. In the presence of amino compounds like amino acids or peptide, it is possible that nitrogen containing polymerization products are formed. These polymerization products can be further oxidized and their phenolic constituents once again liberated into the soil. When soil humic substances are degraded by means of chemicals, they yield a large number of phenolics; such degradation by microbial activity could be expected to take place in soil (Brown *et al.*, 1991).

Identification of the period of toxin production: Several research reports suggest the period of time required for toxic substances to be formed is markedly affected by the stage of maturity of the plant residues added to the soil. When residues from young plants are added, toxic substances are produced relatively early in decomposition but are also broken down relatively fast. When mature plant material is added, longer period of decomposition is required before toxic materials are formed but the toxicity remains high for a longer period. However Kimber (1973) working with fully mature plants was of the opinion that inhibition was always maximum early in the rotting period. Lucerne extract prepared without rotting was toxic to wheat; un-rotted green pea extract was extremely toxic to wheat. The green pea vine straw obviously contained much toxic material, which was removed during the rotting process; the dried pea straw contained much less toxic material, which disappeared on rotting. Lucerne showed a marked initial toxicity that decreased with rotting, but not as rapidly as green pea straw. It has been reported that varietal difference occurs in toxic element production. In one oat variety (*Early burt*) the toxin was converted to a stimulant within 4 days. The oat extract was particularly interesting as the early stimulation disappeared after 14 days and reappeared after 35 days; for agricultural use particular crops have to be reviewed. The period of toxin production depends on the storage condition of straw. With wheat straw it has been suggested that toxic factors which produce inhibition of root growth are present in the un-rotted straw, that they are more prevalent in less mature straws and that they are in fact usually dissipated by microbial action during the rotting process. Rice husk showed high potential allelopathic activity, which could enable control of paddy weeds in Korea (Kim 1995). Identification of the time of toxin production is required for planting rabi(winter) and kharif (summer) crops.

Conditions of toxin production

Soil type and toxins: In *Sorghum vulgare* the growth of the second crop (one after the other) decreases markedly in sandy soils but not at all in soils high in montmorillonite. Toxins in soils are usually inactivated eventually. Whether an inhibitory effect occurs depends, therefore, on the relative rates at which the toxins are released and inactivated.

Saturated conditions: It is apparent that allelopathy must be considered in relation to rainfall and the soil water balance (May and Ash, 1990). Saturation conditions, however, do not have to be maintained throughout the whole decomposition period to give rise to phytotoxic products. Flooding the soil for three to five days, especially after the residues had begun to decompose, are equally effective. Highest levels of phytotoxicity are obtained during relatively early stages of the decomposition process. Anaerobic conditions in soil during decomposition of a number of plant species are very important for development of toxicity. Many studies on soil aeration and the micro-ecological relationships within the soil suggest that fluctuations between aerobic and anaerobic conditions occur rapidly. There is a possibility of the presence of localized pockets of anaerobiosis in the soil.

Allelopathy in saline soils: In addition to the toxic organic substances formed during the decomposition of plant residues phytotoxicity may be enhanced by the increased salinity.

Rate of travel of the toxin in soil: Apparently the toxins do not move far from the place where they are produced, the extent of root injury would depend on how frequently the growing root systems of the plants encounter fragments of crop residues in which toxic chemicals are present. Klein and Blum (1990) working with ferulic acid are of the suggestion that information on root and allelochemical distribution is soils in important when assessing the potential of allelopathic interactions between plants.

persistence of toxins: Phytotoxicity of the alkaloids of *Datura stramonium* persisted in the soil from 5 to 8 months depending on the type of soil tested (Lovett *et al.*, 1981). By any standard, this is considered long persistence for natural products in soil (Putnam, 1988).

Toxin detection: The phytochemical study of allelopathy is a challenge since it requires determinations on whole leaf extracts, natural leaf leachates and soil extracts. Decomposition of plant residues or any organic substrate is a continuing process and requires rapid and sensitive assay methods so that they can be detected during the interval of production or disappearance. The rapid turnover of active substances in the soil is an analytical hazard requiring attention. Gas and liquid chromatography, suitable experimental procedures must be employed, in order to work only with the loci where production of such substances is most likely. The concentration of the toxic substances in soil and their effects on plants should be considered from a micro ecological aspect. As far as the roots of plants are concerned, during their growth through the soil they come in contact with the decomposing plant residue fragments and would be affected by the types of substances then being produced in that micro habitat. Kimber's (1973) results indicate that a high RCF (relative conductivity factor) would normally mean a high RTF (Relative toxicity factor). Hence the determination of conductivities could make it unnecessary to carry out time-consuming bioassays of potentially toxic straw extracts. However Qasem and Hill (1986) emphasize the need for more than one test using different experimental techniques to substantiate any results of allelopathic studies. Dornbos and Spencer (1990) have used small tissue culture wells for rapid bioassay. Other workers have developed an assay using HPLC chromatograms (Mattice *et al.*, 2000).

pH changes: As rotting progresses the pH increases in the range pH 5.5 to 8.5. Changes in pH with period of rotting are normally greatest when the extracts were initially toxic; non-toxic extracts give no such changes.

Dormant weed seeds: Any attempt to explain the longevity (Lewis, 1973) of weed seeds in the soil without considering the involvement of allelochemicals will be incomplete. This ecological role of Allelopathy may be the most significant in weed management (Table 2 and 3). Two of the major functions of allelopathic compounds in seeds are to prevent seed decay and to control germination.

Therefore important points for consideration would be:

a Weed seed decay
b Stimulation of seed germination
c Inhibition of seed germination

Research efforts directed towards methods to increase weed seed decay under field conditions have been largely unsuccessful. The methodology used may have to include inactivation of the inhibitors that may be protecting the seed against decay or using micro- organisms for seed destruction. Various compounds can stimulate weed seeds; strigol compounds and ethylene enhance germination of *Striga*. Methyl isothiocyanate (MIT) kills dormant seeds, while most herbicides kill only the small fraction of weed seeds that germinate each year (Teasdale and Taylorson, 1985). The compound produced by papaya and plants in the mustard family (Brown *et al.*, 1991). The ether extract from roots of *Rorippa sylvestris* Besser was identified by TLC as 8 methylsulfinyloctyl isothiocyanate the compound completely inhibited the germination of lettuce seed at 200 pm and reduced root and hypocotyl elongation at 93 ppm (Kawabata *et al.*, 1989). Enzymatic hydrolysis of glucosinolates a class of compounds found in *Brassica* species, results in a number of products with potential to inhibit seed germination (Brown and Morra, 1996). Therefore it is concluded that glucosinolate containing plant tissues may contribute to reductions in synthetic pesticide use if weed seeds are targeted.

Plant responses to allelochemicals: Roots become brown, stunted, and void of root hair, the leaf tip becomes yellow, plants stunted; one ppm of para. hydroxy benzoic acid depressed root of wheat, soya bean, and corn significantly (Guenzi and Mc Calla, 1996). Some phenolic acids are associated with indoleacetic acid activity in plant respiration. One of the effects noted is a rapid inhibiting effect on respiration of root tips and of seedlings. Another striking feature is the extreme sensitivity of the roots to the phytotoxic extracts; roots appearing more sensitive to allelopathic effects than shoots (Qasem, 1993). Lawrence *et al.* (1991) working with *Ailanthus altissima* found that individuals of neighboring plant species has either incorporated active portions of inhibitory compounds or responded to *Ailanthus* by producing growth inhibiting substances. The cellular effects of plant-derived compounds are arrested pro-metaphases (Colchicine, dinitroanilines), multipolar divisions (*Vinca* alkaloids, carbamates) and production of binucleate cells (Caffeine, dichlobenil), (Vaughan and Vaughan, 1988).

Crop rotations: In crop rotations, allelopathins produced by a preceding crop may favor or adversely affect the following crop (Hedge and Miller 1990). Thus avoiding inhibitory effects or exploiting favorable interactions could improve crop production. In agro forestry, the allelopathic effects of tree species on the crop/fodder plant must be investigated to avoid deleterious effects (Rizvi and Rizvi, 1992).

Rice-legume crops: Soybean yields are increased by several hundred pounds per acre when the rice straw is not allowed to remain in the field and decompose, but instead is burned before the planting of soybean. There is evidence that decomposing rice straw inhibits the growth of nitrogen-fixing bacteria, nodulation and hemoglobin formation because of the phenolic toxins.

Stimulatory effect of compounds: The ability of root exudates to stimulate germination is of wide occurrence in the plant kingdom. It has been demonstrated that a number of synthetic and natural compounds have the ability to stimulate parasitic weeds. *Striga* species are stimulated by lactone-forming acids found in the genus *Euphorbia* (Ibrahim *et al.*, 1985). All the *Euphorbia* species induced seed germination and haustorial initiation of *Striga*. However phenolic and flavonoid substances are important for haustorial initiation (Steffens *et al.*, 1982). Ethylene gas is liberated by many plant tissues and is produced by ripening fruits in relatively high quantities. One of the most promising agricultural uses for ethylene is the stimulation of weed seed germination. There are several reports of ethylene stimulating *Striga* to germinate in the absence of a host. Chang and Lynn (1987) demonstrated the role of para-benzoquinones as natural seed germination stimulants for *Striga*. Root exudates of *Pisum arvense* (pea) and *Vicia villosa* (hairy vetch) produce substances that apparently stimulate both photosynthesis and the absorption of phosphorus by barley and oat plants. *Agrostemma githago* (corn cockle) increases the grain yields of wheat. Three compounds stimulatory to the growth of wheat seedlings, agrostmemin, allontoin and gibberellins were isolated from corn-cockle seeds. Cotton and corn roots yield strigoles. *Orobanche* spp. is stimulated by the exudates of potato, tomato, tobacco, cucurbit, sunflower, broad bean, melon, carrot, brassica, Medicago, and melilotus. *Striga* is a host on maize, sorghum, millets and broad bean.

Inhibition: Several plants inhibit the germination, growth and development of other plants by exudates, leachates, and decaying or fresh materials. Traditional systems of agriculture in tropical America often make empirical use of the phytochemical potential of plants. Various species of *Commelinaceae* are used as ground cover for weed control in coffee plantations (Anaya-Lang, 1989).

Application of allelopathic compounds

Natural herbicides: There are several examples of allelochemicals as herbicides, these phytotoxic compounds from plants are used in the production of new herbicides. Phytotoxic compounds from plants and microorganisms represent a wide range of chemistries and mechanisms of action that have potential in the design and development of new herbicides (Anaya-Lang, 1989; Duke and Lydon, 1987). Photosensitizes (light-activated compounds) are potentially useful in agriculture as herbicides (Towers and Arnason, 1988). Some of these compounds are naphtho and anthraquinones of fungi and higher plants, polyines of the *Astraceae* porphyrins, extended quinones and isoquinoline alkaloids. Macias (1995) has concluded that the most potential natural allelochemicals in terms of bioactivity are terpenoids, monoterpenes, sesquiterpenes, sesquiterpene lactones and triterpenes, and fatty acids with activity range of 0.25-10 5 ppb, rather than the traditionally considered phenolics, quinines or alkaloids. Terpenoids and fatty acids will receive a great attention in years to come in development of natural products as herbicides.

Already identified compounds: Cyanobacterin produced by the cyanobacterium *Scytonema hofmanni* inhibit electron transport and extensive damage to the thylakoid membranes of the chloroplasts, effect similar to that of diuron (Gleason, 1990). Several *Eucalyptus* oils (Dellacassa *et al.*, 1990). Tentoxin produced by *Alternaria alternata* is effective against *S. halepense* in maize and soybean. Artemisinin produced by *Artemisia annua L.* is phytotoxic to weeds and an antimalarial drug (Duke *et al.*,1987). Rhizobitoxine, a compound produced by the bacterium *Rhizobium japonicum* is an effective herbicide in amounts as low as 3 ounces/acre. Agrostemmin produced by corn cockle decreases weeds, increases yield of wheat at 1.2 gms/hectare. Scopoletin is produced by cultivated *Avena* species. Cinmethylin, a new herbicide is a product based on 1,8-Cineole produced by *Salvia* species (Sage). Herbicidal principal has been identified from *Caesulia axillaris L.* (Srivastava *et al.*, 1983). Flavonoids alter the permeability of mitochondrial and chloroplast membranes (Moreland and Novitzky, 1987). The flavones are the most active inhibitors of electron transport compared to benzoic acids, benzaldehydes, cinnamic acids and coumarins. Maytansinoids from *Maytenus* species are highly effective disrupter of plant mitosis at relatively low concentrations Phosphinothricin glufosinate, when synthetic a product of *Streptomyces viridochromogenes*, is a successful herbicide that is environmentally and toxicologically benign. Bialaphos, bilanafos, a tripeptide from *Streptomyces hygroscopicus*, which degrades to phosphinothricin in target plants, is the only commercial herbicide produced by biosynthesis (Einhellig, 1995).

Integrated chemical ecology: Chemical ecology with particular emphasis on different aspects of Allelopathy should form an integral part of present day conservation. Chemical ecology can be responsible for the potential application of secondary metabolites as herbicides, pesticides, growth regulators antibiotics and cytotoxic agents. Intensive research on active secondary metabolites will lead to the reduction in the use of pesticides and thus pollution and build up of toxins in the environment. Interest in chemical ecology is expanding rapidly, and these compounds are either volatile terpenes or simple phenolic acids, depending on whether the plant is growing in a semi-tropical or a temperate climate respectively.

a Terpenes, and B-pinane are volatile alleopathic agents in many plants, they also serve as repellents to the bark beetles of several coniferous trees.
b 1,8- cineole (a terpene) a volatile allelopathic agent, an important pollinator attractant in many species of orchids.
c Tannic acid- allelopathic agent against higher plants. Inhibitory to nitrogen-fixing and nitrifying bacteria.
d Chlorogenic acid - important in the resistance of plants to various diseases.
e Para- hydroxybenzoic acid - a benzoic acid insect repellent.
f The diterpeniod compound taxol, isolated from the western yew (*axus brevifolia L.*) and other species of *Taxus* has great potential as a herbicide safner (Vaughan and Vaughan, 1988).

Plant- plant interactions: Plant - plant interactions involve so called allelopathic substances which one plant exudes from its roots or leaves in order to present or enhance the growth of other plant species in its vicinity.

a Use of mulches to suppress the growth of certain weeds.
b New allelopathic chemicals from plants with allelopathic potential for IPM. Development of crop cultivars that would release natural herbicides to provide satisfactory weed control is required. Wheat cultivars are capable of inhibiting root growth of ryegrass and it is possible to breed for cultivar with enhanced allelopathic activity for weed suppression (Wu *et al.*, 2000). Rice hull extracts may be a source of natural herbicides (Ahn *et al.*, 2000).
c. Identify and utilize crop rotations that allow maximum utility of allelopathy with a minimum of toxin accumulation in the soil. The rotational crop in a cropping sequence may or may not be harvested but should be capable of providing toxicity to weeds by exudation or upon decay of its residues.
d. Agro-phytocoenosis:There is a great emphasis on selection and breeding of compatible plants for mixed cropping throughout the world, reducing both the need for herbicides and the labor costs of weed control (Chou *et al.*, 1987; Tozer, 1992). Beneficial plant associations have shown the yield increase of several crops by the addition of 1-2 kg ha^{-1} of white mustard. *Heliotropium europaeum* (wild heliotrope) at the rate of 1-2 kg ha^{-1} increases the yield of several legumes.
e. *Sorghum halepense* infestation in maize does not allow the germination of *Amaranthus retroflexus* even though the soils contain the seed
f. Water extracts of *Conyza canadensis* leaves, *Digitaria sanguinalis* roots and *Cirsium arvense* roots are sufficiently strong to inhibit germination of Amaranthus retroflexus. Allelochemicals action of *C. canadensis* and *D. sanguinalis* can synergies with the activity of herbicides. If *C. canadensis* and *D. sanguinalis* are destroyed by a contact herbicide its residues will act as an allelochemical and show inhibitory effect on its own seedlings or other weeds. (Varadi *et al.*, 1987).

Plant - animal/insect interactions: Compounds known to be involved in plant-animal interactions are primarily alkaloids and cardiac glycosides, mustard oil glycosides, steroids or volatile terpenes. The secondary plant compounds may variously act as feeding attractants or repellents, have hormonal effects on the insects or provide the insects with a useful defense mechanism against predation. The ability of plants to synthesize compounds that are physiologically active in other organisms provides them with one of their most important defenses against predators. Sequestration by insects of unpalatable compounds has been widely recorded. The conversion of phytochemical to pheromones or metabolic intermediates provides additional grounds for regarding them as key elements in the biology of a variety of species (Blum, 1992). *Lycoris radiata (cluster amaryllis)* is repellant to mice in rice paddies; the alkaloids in the bulbs keep mice away. Cluster amaryllis has beautiful flowers. A great many border plants will be found that will be used in this manner around fields and gardens to keep undesired animals away. We can select for many types of chemical compounds in plants in order to prevent grazing.

Microorganisms

Useful microorganisms: Microbial produced toxins have more potential as herbicides, because they are selective and compared to using the actual pathogens easier to formulate, less likely to spread disease to non-target species, and their activity is less dependent on environmental conditions. Microbial toxins may be produced by fermentation and used in the natural state, subjected to synthetic modification, or their chemistry used as a basis for producing synthetic herbicides (Edwards and Regnier, 1989). *Trichoderma viride* and species of *Aspergillus* are responsible for eliminating in a short time the inhibitory effects of aqueous extracts of sorghum roots on sorghum seedling growth. 2,2- Oxo-1, 1-azobenzene (AZOB), a compound with strong herbicidal activity, was isolated and characterized from a soil supplemented with 2,3- benzoxazolinone (BOA). A parallel experiment with 6-methoxy, 2,3 benzozxazolinone (MBOA) yielded AZOB as well at its mono- (MAZOB) and dimethoxy (DIMAZOB) derivatives. These compounds were produced only in the presence of soil microorganisms, via possible intermediates II, and I, which may dimerize or react with the parent molecule to from the final products. AZOB was more toxic to curly cress (*Lepidium sativum* L.) and barnyard grass (*Echinochloa crusgalli*) than either DIBOA or BOA (Nair *et al.*, 1990).

Effect of phenolic acids on micro organisms: Effect of three phenolic acids, ferulic acid, caffeic acid and p-coumeric acid, was studied on nitrite production by micro organisms (Nitrosospira, Nitrosomonas or Nitrosolobus) grown on a defined medium containing NH^4 + the phenolic acids did not retard ammoniac oxidation by autotrophic microorganisms even when their concentration in cultures of these micro organisms greatly exceeded their concentrations in soils (McCarty *et al.*, 1991).

Secondary compounds and the defense mechanism of plants and animals: Insects may be prevented from feeding by the presence of a wide variety of secondary compounds including terpenoids, flavonoids and alkaloids. Minor structural differences between secondary compounds many be accompanied by significant differences in their biological activity in insects or other organisms. At the biochemical level, the elucidation of the ways in which plant toxins affect insects is of considerable economic importance. Knowing that a secondary compound disrupts a metabolic pathway present in insects but not in mammals or interferes with an enzyme system present in one insect but not in another could well be of significance in developing new pest control agents (Bell, 1987). The compounds involved in the resistance of host plants to pathogens are divided into two categories:

a) Phytotoxins secondary compounds that are generally present in the host but may .,increase subsequent to infection.
b) Phytoalexins, which are new compounds formed only after infection.

Specialist herbivores that can tolerate high concentrations of allelochemicals may gain protection from pathogens by feeding on plants or plant parts with higher levels of toxins (Krischik *et al.*, 1988). Secondary compounds from plants include insect antifeedants as well as toxins and it must be emphasized that toxicity and antifeedant properties are not necessarily related.

Nematocides: Tagetes nana contains terthienyl, a powerful nematocide (thiophene derivatives). *T. erecta, T. patula and T. minuta* reduced root-knot eelworm (*Meloidogyna javancia*) populations. Spectacular nematode control was obtained by interpolating alternate crops of tomato with marigolds; tobacco and marigold. Interplanting Africa marigold with eggplant and chilies lowered the nematode population. Simultaneous culture of marigolds with a main crop appears to be effective around and between trees and woody ornamentals. Some genera of the tribe Helenieae (Sneeze weeds) are effective against nematodes. *Crotalaria spectabilis* (rattle box), *C. pumila, C. mucronata*, and *C. brevifolia* are known to reduce nematode populations. Field tests have demonstrated that *C. spectabilis* is very effective in reducing soil populations of a wide range of parasitic nematodes. *Chrysanthemum* is resistant to the *Chrysanthemum eelworm. Chrysanthemum* and tomato, when grown together, reduce nematode infection in tomato. Mixed cropping of *Azadirachta indica* (margosa) with several crop plants in India reduced the populations of at least six genera of plant-parasitic nematodes on tomato, eggplant, cabbage and cauliflower. In studies conducted by Rangaswamy *et al.* (1993) total insoluble polysaccharides, proteins and nucleic acids were maximum in tomato, moderate in *Brassica juncea* and least in *Tegates putala*. From these observation it is concluded that *T. patula* was highly resistant, *B. juncea* moderately resistant and tomato highly susceptible to *Meloidogyne incognita*.

It must be remembered, however, that allelochemicals would, at least in part be present in adsorbed and bonded form in soils, and that the effect of these chemicals upon plant growth would not be the same in the soils as it would be in nutrient solutions. The ultimate aim is to develop new herbicide molecules similar to allelochemicals, which possibly will be less dangerous to the environment (Mikulas *et al.*, 1990). The two ways by which the principal of allelopathy can be used as potential weed control options are breeding commercially acceptable cultivars with allelopathic traits and the development of botanical herbicides from allelochemicals (De Datta and Baltazar, 1996). Conditions that lead to the formation of high concentrations of phytotoxic decomposition products may, therefore, be more common than is generally realized, and not necessarily confined to waterlogged soils.

A major criticism of the work on phytotoxicity relates to their existence, effectiveness and importance under field conditions.

a in the soil we are dealing with dynamic systems, where all effects are transitory, where production, transformation and destruction of these substances go hand in hand.
b Good detection procedures are required.
c Ideally, the methods should reflect the ecological conditions of the soil as encountered by the plant.
d Residues are unevenly distributed. Therefore, the soil environment must not be regarded as a uniform medium but composed of a large variety of microhabitats with a point-to-point variation of microbial activities, solutes and diffusion patterns.
e Research on phytotoxins production must be superimposed on this system and interpretations should bear this in mind. We must now visualize the existence of a variety of microhabitats within the soil gross environment. Each micro habitat has its own activity and sphere of influences. There are many questions relating to conditions in the field. How many are produced, the sequence of production, concentration gradients, levels necessary for phytotoxicity and the nature of the chemical.

It is evident that although studies of this nature involve great technical and interpretative difficulties, it is an exciting field, and the indications are that the biological consequences of decomposition of plant residues in soil are immense and most phases of plant development are affected.

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