Allelopathy in Agriculture

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Introduction

Allelopathy refers to any direct or indirect harmful or beneficial effect by one plant (including microorganisms) on another through production of chemical compounds that escape into the environment (Rice, 1984). Allelopathy is the indirect harmful effect through exertion of chemical substances. Allelopathy is existent in the natural ecosystem and it occurs widely in the natural plant communities. Allelopathy is possibly a significant factor in maintaining the present balance among the various plant communities. Allelopathic substance was first detected by Davis (1928) in black walnut tree (Juglans nigra) whose foliar leachate containing Juglone was found to damage germination and seedling growth of crops beneath the tree. The term allelopathy was coined by Molisch (1937) from the Greek word *allelon* meaning ‘of each other', and *pathos*, 'to suffer'. The International Allelopathy Society (IAS) has defined allelopathy as ‘to any process involving secondary metabolites produced by plants, microorganisms, and viruses that influence the growth and development of agricultural and biological systems. The history of allelopathy goes back to ca. 300 B.C.E. where, Theophrastus a student and successor to Aristotle, wrote of how chickpea "exhausts" the soil and destroys weeds. In 1 C.E., Gaius Plinius Secundus, a roman scholar and naturalist, wrote about how chickpea and barley "scorch up" corn land. He also mentioned that Walnut trees are toxic to other plants. In 1932, De Candolle suggested that the soil sickness problem in agriculture might be due to chemicals released by crop plants. Early research grew out of observations of poor regeneration of forest species, crop damage, yield reductions, replant problems for tree crops, occurrence of weed-free zones, and other related changes in vegetation.

Allelopathy has ecological significance in plant dominance, patterning of vegetation, succession, crop productivity and agroforestry systems. Besides tree species certain weeds and crop species also have allelopathic potential, which can be effectively utilized for controlling pests. The diversity of allelochemics produced by plants is vast, and chemicals range in structure from simple hydrocarbons to complex polycyclic aromatics. Many of the novel compounds isolated exhibit herbicidal activity and consequently interest exists in utilizing natural products for synthetic herbicidal template. The science of allelopathy has now reached to a stage it can be used to aid crop production that can be categorized as:

1. Avoidance of negative effects
2. Exploitation of stimulatory effects
3. Management and development of allelopathic crops to suppress weeds
4. Development of allelochemicals as herbicides or growth regulators, and
5. Combination of these approaches

An attempt has been made here to understand allelopathic interactions and their possible usage in agriculture.

Allelopathy –Basic Concepts

Although there has yet to be a true experimental separation of allelopathy from other forms of plant interactions and often create misunderstanding of interference, competition and allelopathy. Muller (1966) used plant interference including both competition and allelopathy and defined competition to mean that one plant takes up necessary substances from a habitat so as to have a harmful effect on the growth of plant that required the same substances. On the other hand, allelopathy is the process that plant releases phytotoxic compounds into the environment to inhibit the growth of plant sharing same habitat.

Grummer (1957) used four key terms to specify the inter organism relationship of allelopathic substances viz., choline, phytoncide, marasmin and antibiotic (Fig. 1). A choline is an inhibitor or toxin produced by higher plants which effects another higher plant. Terms antibiotics refers to a chemical produced by a microorganism effective against another microorganism, *marasmin* refers to a chemical produced by a microorganism and active against a higher plant and phytoncide is a substance produced by higher plants which suppresses microorganisms and macro fungi. Auto intoxication refers to one plant produces toxin substances that inhibits its own growth. Grodzinsky (1973) distinguished the excretions produced by living plants from decay products, actively excreted substances from those lost passively and volatiles from water soluble substances. Allelopathic volatiles Include phytogenic substances (volatiles originating from intact plants), phytoncides (volatiles produced by damaged or diseased plant tissue) and miasmins (volatiles produced during decomposition). Water soluble allelopathic substances include exudates (actively excreted compounds), diffuses (or passively leached substances) and saprolins (water soluble products of decomposition).

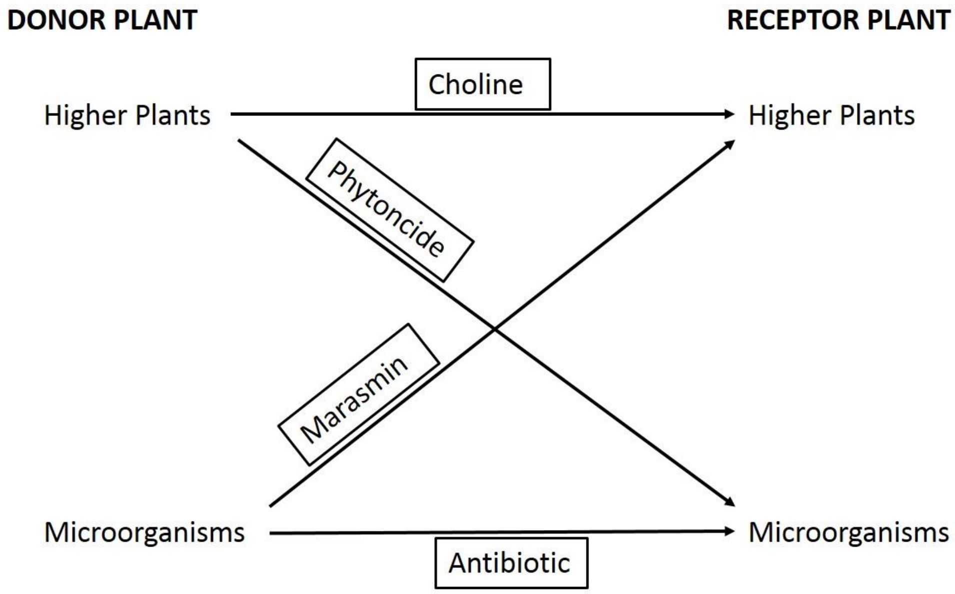

Fig. 1. Grummer's Classification of Allelopthic Substances

Ways of releasing Allelochemicals

Allelopathic chemicals are released from living plants leaves as volatiles or leachates or from roots through exudation or sloughing off of dead tissues. They may also be leached from leaf litter on the soil surface. Allelopathic chemicals are released from the plants as:

- Vapour – from root and leaf
- Foliar leachate
- Root exudate
- Breakdown/ decomposition product of dead plant parts
- Seed extract

Volatilization: Allelopathic trees release a chemical in a gas form through small openings in their leaves. Other plants absorb the toxic chemical and die.

Leaching: All plants lose leaves. Some plants store protective chemicals in the leaves they drop. When the leaves fall to the ground, they decompose and give off chemicals that protect the plant. Fall foliage tends to release more potent allelochemicals than fresh, spring foliage. Water-soluble phytotoxins may be leached from roots or aboveground plant parts or they may be actively exuded from living roots. Rye and quackgrass release allelopathic chemicals from rhizomes or cut leaves.

Exudation: Some plants release defensive chemicals into the soil through their roots. The released chemicals are absorbed by the roots of nearby trees. Exuding compounds are selectively toxic to other plants. Exudates are usually various phenolic compounds (e.g., coumarins) that tend to inhibit development.

Mode of action

The term allele-chemicals include plant bio-chemicals, micro-organisms and microbial bio-chemicals that exert allelopathy on plants. Many allelo-chemicals are strictly defense substances others are offensive compounds that act directly in weed aggressiveness, competition and the regulation of plant density. Allelo-chemicals most often impart plant resistance to insects, nematodes, and pathogens. Allelopathic compounds are synthesized above ground (stem, leaves. Inflorescence, fruits, seeds) or below ground (root, rhizome, etc.). These processes are affected by environmental factors (Saxena *et al.*, 1995). A major requisite of allelopathy is that allelo-chemical be transferred from a donor plant to receiver plant. The donor plant stores allelo-chemicals in the plant cells in a bound form, such as water soluble glycosides, polymers including tannins, lignin and salts. First the terpenoids such as α and β-pinene, cineole and camphor are released to the environment through volatilisation under drought conditions. The water borne phenolics and alkaloids are then moved out by rainfall through leaching. Next, phytotoxic aglycones (phenolics) are produced during decomposition of plant residues in the soil. Finally, many secondary metabolites such as scopoletin and hydro-quinones may be released to the surrounding soil through root exudates. Under appropriate conditions, these chemicals may be released into the environment, generally the rhizosphere. The magnitude of toxic effects largely depend upon chemicals released to the soil layer. Although more than 10,000 secondary plant products have been recorded the total number may be 400,000. Some of these chemicals or their analogues might provide important new sources of agricultural chemicals for future use. Most of these chemicals are secondary metabolites and are produced as offshoots of primary metabolic pathways. These secondary products could be classified into five major categories viz., phenyl propanes, acetogenins, terpenoids, steroids and alkaloids. It is almost impossible to enumerate each and every chemical identified as an allelo-chemical, they can be classified into the following major categories:

• Simple water soluble organic acids, straight chain alcohols, aliphatic aldehydes and ketones
• Simple unsaturated lactones
• Long-chain fatty acids and polyacetylenes
• Naphtho-quinones, anthro-quinoncs and complex quinones

The allelochemicals cause diverse types of effects on plant growth and development depending on their time of release, concentration and specificity of receptor plant. These may bring their effect through cell division and elongation; internal hormone induced growth; membrane permeability; mineral uptake; stomatal regulation; photosynthesis; respiration; protein synthesis; lipid and organic acid metabolism and inhibition or stimulation of specific enzymes.

Factors affecting Allelopathic effect

Allelopathic effects depend on a number of other factors that might be important in any given situation:

- *Varieties*: there can be a great deal of difference in the strength of allelopathic effects between different crop varieties
- *Specificity*: there is a significant degree of specificity in allelopathic effects. Thus, a crop which is strongly allelopathic against one weed may show little or no effect against another
- *Autotoxicity*: allelopathic chemicals may not only suppress the growth of other plant species, they can also suppress the germination or growth of seeds and plants of the same species. Lucerne is particularly well known for this and has been well researched. The toxic effect of wheat straw on following wheat crops is also well known
- *Crop on crop effects*: residues from allelopathic crops can hinder germination and growth of following crops as well as weeds. A sufficient gap must be left before the following crop is sown. Larger seeded crops are effected less and transplants are not affected
- *Environmental factors*: several factors impact on the strength of the allelopathic effect. These include pests and disease and especially soil fertility. Low fertility increases the production of allelochemicals. After incorporation the allelopathic effect declines fastest in warm wet conditions and slowest in cold wet conditions

Allelopathy and Cropping System Management

Allelopathy plays a significant role in deciding cropping systems and their management. Continuous monoculture in many crops causes accumulation of phytotoxins, harmful microbes or both in soil which give rise to autotoxicity and soil sickness. Hence, Crop rotations are practiced to eliminate the effects of monocultures, but a succeeding crop may be affected by the phytotoxins released by the preceding crop. In intercropping systems, the component crops may be harmful to each other. To decide an appropriate crop strategy for a particular region, it is imperative to know the allelopathic interaction among various components of the system. An account of allelopathy in some major crops is mentioned here.

Rice

In tropical and subtropical regions of the world, rice monoculture is practiced. Two or three crops of rice are being taken each year in these areas. Yield declined by 28 and 24% in second and third crops in India (Narwal, 1994), and in low-lying areas in Taiwan by 25% in second crop (Wu and Antonovics, 1979). The farmers incorporate rice stubbles in the field, and during its decomposition a great quantity of phytotoxins are released, resulting in the suppression of rice growth and yield of the succeeding crop. Aqueous extracts of rice soils were found to be phytotoxic and the phytotoxicity persisted in the soil up to 16 weeks resulting in lower tillering, plant height and yields (Chou and Chiou, 1979). The allelopathic compounds identified from decomposing rice stubbles and soil mixtures were p-coumaric, phydroxybenzoic, syringic, vanillic, o-hydroxyphenylacetic, ferulic, acetic, propionic and butyric acids (Chou and Lin, 1976; Chou, 1990). This suggests that allelopathy is partially responsible for lower yields of rice in monoculture.

Sorghum

The allelopathic influence of sorghum and its residues on crops has been observed both in monoculture and multiple cropping systems. Sorghum autotoxicity has been observed as well, and is predominant in fields where continual reduced or no-tillage cropping is practiced. The effect of a sorghum crop on succeeding crops like maize, oats, wheat and cotton has been well documented (Narwal, 1994).The adverse effect of sorghum in a continuous sorghum cropping system has been attributed mainly to accumulation of phytotoxins, possibly due to decomposition of root residues in the soil, leading to “soil sickness” (Geneve and Weston, 1988; Putnam and DeFrank, 1979).

No-till sorghum stover had little effect on stand establishment of wheat, but frequently reduced grain yield, possibly because allelopathic compounds slowly degraded and were released into the wheat rhizosphere. Prompt tillage of the mature sorghum stalks and roots resulted in initial delays in development of the following wheat crop, but did not affect grain yields, probably because allelopathic compounds eventually degraded in the soil over time (Roth *et al*., 2000). A diverse group of sorghum allelochemicals, including numerous phenolics, cyanogenic glycoside (dhurrin), and hydrophobic p-benzoquinone (sorgoleone) have been isolated and identified in recent years from sorghum shoots, roots, and root exudates. These allelochemicals, particularly sorgoleone, have been widely investigated in terms of their mode(s) of action, specific activity and selectivity, release into the rhizosphere, and uptake and translocation into sensitive indicator species. Both genetics and environment have been shown to influence sorgoleone production and expression of genes involved in sorgoleone biosynthesis. In the soil rhizosphere, sorgoleone is released continuously by living root hairs where it accumulates in significant concentrations around its roots (Weston *et al*, 2013).

Pearlmillet

Under continuous cropping of pearl millet reduced germination, poorer plant growth and declining yield have been observed (Saxena *et al*., 1995; 1996). A large amount of pearl millet residue is left in the field after harvesting is complete. In rainfed agriculture, although there is often a considerable time period between successive sowings, decomposition of residues in the soil remains incomplete. Stubble extracts of pearl millet have been found inhibitory to the seed germination and shoot growth of wheat and lentils (Narwal *et al*., 1989). Aqueous extracts of pearl millet plants at the reproductive stage were more toxic than extracts of vegetative plants to germination and seedling growth of pearl millet (Saxena *et al*., 1994).

Green gram

In northern India, two crops of green gram (*Vigna radiata*) are grown in sequence. In field studies it has been observed that plant population and yield of the succeeding green gram crop decrease by up to 50% compared with that sown after fallow or rotation with another crop (Narwal, 1994). This reduction in plant population and yield of green gram was attributed to allelopathy (Ventura *et al*., 1984). p-hydroxycinnamic acid was isolated from green gram plants and rhizosphere soil (Waller *et al*., 1995).

Wheat

Wheat contains a number of phenolic acids; the five dominant ones are ferulic, p-coumaric, syringic, vanillic and phydroxybenzoic acids. The antibiotic patulin (C7H804) produced by Penicillium urticae Baimer was found in wheat soil and the severity of phytotoxicity to winter wheat depended upon the concentration of patulin (McCalla and Norstadt, 1974). Organic solvents and water extracts of wheat soils under conventional and no-tillage contained some inhibitory compounds (Waller *et al*., 1987).

Alfalfa

Reduced yields of alfalfa are commonly associated with old alfalfa stands and where alfalfa is sown directly after an old stand is incorporated into the soil. Alfalfa produces allelopathic saponins, which might be a major cause of yield reduction in subsequent crops. As many as 40 compounds with different properties of stimulation/ inhibition are present in alfalfa plants. The plant parts differ greatly in the type and quantity of glycosides present, among which the medicagenic acid glycosides are biologically active saponins and dominant in alfalfa roots (Oleszek *et al*., 1992). Cotton was the most susceptible and wheat the most resistant to the phytotoxins released by alfalfa. Root extract of alfalfa suppressed wheat seed germination and seedling growth due to the presence of medicagenic acid glucoside (Oleszek and Jurzysta, 1987).

Sugarcane

Ratooning is a common practice in sugarcane. In every successive ratoon, the plant stand decreases by about 10% which reduces the cane yield. Phytotoxic phenolic acids (p-hydroxybenzoic, ferulic, pcoumaric, syringic and vanillic) and organic acids (formic, acetic, oxalic, malonic, tartaric and malic acids) were found in decomposing sugarcane leaves in waterlogged conditions (Wang *et al*., 1967). Higher population of *Fusarium oxysporum*, which produces fusaric acid (toxic to root and shoot growth of sugarcane), in the rhizosphere of poor ratoon cane has been observed (Chou, 1990).

Allelopathy and Crop Residue Management

It has been well known fact that incorporation of crop residues increases organic matter in the soil. Residue management is an important aspect of conservation agriculture also. Under certain situations after all the favourable conditions, a negative effect of crop residue is visible on succeeding crop. It might be due to some allelopathic effect of decomposing crop residues. The knowledge of allelopathic aspects of crop residue could be helpful in better management of crops and cropping systems.

In wet and cool soils, mulching with wheat straw reduced the seed germination of maize by 44% and growth compared with the unmulched condition due to the presence of phytotoxic compounds and patulin (Norstadt and McCalla, 1963). The aerobic decomposition of wheat straw caused stimulation of growth while anaerobic decomposition caused inhibition due to presence of acetic acid. Root and shoot growth of barley seedlings were reduced by aqueous extracts of wheat straw. Rice when grown immediately after wheat gave poor grain yields compared with rice grown one month after wheat. Wheat straw when used as mulch or incorporated into the soil reduced the plant stand, height and grain yield of soybean (Sanford, 1982; Hairston *et al*., 1987).Incorporation of rice residues in soil reduced the soybean grain yield compared with burning of residues. The yield reduction of soybean was partially due to decreased biological N fixation. The phenolic compounds from decomposing rice residues inhibited the growth of Rhizobium japonicum, causing reduced nodulation.

Rye (*Secale cereale*) residues contained vanillic, ferulic, phenyl acetic, 4-phenyl butyric, o- and p-coumaric, phydroxybenzoic, benzoic, butyric, hydrocinnamic and salicylic acids and salicylaldehyde (Chou and Patrick, 1976). The residues became phytotoxic after 10-30 days of the decomposition process. Decomposing rye residues also adversely affected its own seed germination and radicle growth (Barnes and Putnam, 1986)

Incorporation of soybean residues in soil delayed the seedling emergence of wheat and decreased its growth and yield by 19-29%. Decomposing soybean residues in association with soil micro-organisms produced inhibitory compounds, including amino acids (valine, leucine and phenylamine), organic acids and polyphenolic compounds. The phytotoxicity increased with increasing amount of soybean residues (Huber and Abney, 1986). Aqueous extracts of soybeans were also found to inhibit the seed germination of soybean, alfalfa, turnips and radishes.

Allelopathic Interactions in Agroforestry Systems

Trees are rich sources of allelochemicals which play a great role in regulating patterns of vegetation, distribution of plants in communities, nitrogen fixation, nitrification and ecosystem balance. Allelopathic properties of Eucalyptus have been widely investigated. Bund plantations of Eucalyptus proved harmful to jute, groundnuts and rice up to a distance of 15 to 20 m, chickpeas, linseed, wheat, rape and Egyptian clover up to a distance of 12 m and potatoes and wheat up to a distance of 5 to 6 m (Igboanugo, 1988, Craig and Saenalo, 1988, Kohli *et al*., 1990, Basu *et al*., 1987). The mature leaves of *Leucaena leucocephala* contain about 5% (dry weight) of mimosine. *Acacia nilotica* is widely planted for its wood and gum in dryland areas of north-west India. Large areas of cultivable land around the trees remain bare due to inhibition of growth of various agricultural crops. *Acacia nilotica* affected yields of wheat up to 4m from tree line under irrigated condition whereas under rainfed conditions *A. nilotica* showed suppression of mustard up to a distance of 26 m from the tree line (Sharma 1992, Dalai *et al*., 1992). No difference between the properties of soil beneath *A. tortilis* and *Prosopis cineraria* was found indicating that the reduction in crop growth was due to chemical inhibition (Sundaramoorthy and Kalra, 1991). The extracts of leaf and soil collected beneath the stand of *A. tortilis* exhibited inhibitory effects on germination and growth of pearl millet (Saxena and Sharma, 1996). *Prosopis juliflora* contains germination and growth inhibitors in its litter which restricts the establishment and growth of ground cover (Sankhla *et al*., 1965). Poor seed germination in wheat was observed in the zone near the trunk (up to 0.5 m from the base) beneath *Populus deltoides* (Sheikh *et al*., 1983). The extracts of fresh and partially decomposed residues of *P. deltoides* had an adverse effect on the germination of mustard and peas (Joshi and Prakash, 1992). The leaves of *P. tremuloides* contain catechol and benzoic acid, its bark contains pyrocatechol, an inhibitor of the pathogenic fungus *Hypoxylon pruinatum*, and its roots contain inhibitors of mycorrhizal fungi (Olsen *et al*., 1971).

Allelopathy and Weed Management

Weeds are an important constraint in agricultural production systems because they act at the same trophic level as the crop, capturing part of the available resources that are essential for plant growth. For these reasons, there is increasing interest in integrated weed management strategies based on a wide range of control options. There is inherent ability of many crops to suppress weeds and vice versa through a combination of high early vigor (competition) and allelopathic activity to further reduce weed interference. Allelopathy is particularly relevant for weed management strategies applied in minimum and no-till cropping systems, because weed control in such systems is particularly problematic and basically limited to the use of herbicides. Crop residues also interfere with weed development and growth through alteration of soil physical, chemical, and biological characteristics. In the case of crop residues, there are two possible sources of allelochemicals; the compounds can be released directly from crop litter or they can be produced by microorganisms that use plant residues as a substrate (Kruidhof, 2008). For effective utilization of allelopathy in weed management it is imperative to understand the allelopathic effects of weeds and crops. An account of these interactions is mentioned below:

Allelopathic effect of Weeds on Crops

A large number of weed species possess allelopathic mechanisms of plant interference which make them successful in dominating other vegetation. Allelochemicals released from weed residues may effect crop plants by inhibiting biological nitrogen fixation, nutrient uptake, or of seed germination, plant growth and crop yield. Some of the examples are mentioned here.

Agropyron repens (Quack grass), an important weed of field crops, causes serious decreases in yield of maize and potato. It interferes with uptake of manures, particularly nitrogen and potassium by maize. Ethylene generation in quack grass rhizomes due to microbial activity in soil, is responsible for allelopathic effects of the weed resulting in decrease uptake of mineral by associated crops. *Avena fatua* (Wild oat) residues inhibit germination of certain herbaceous species in shrubs stand due to an allelopathic mechanism. Growth of leaves and roots of wheat is significantly reduces by root exudate of wild oat. Decayed residues of *Cynodon dactylon* (Bermuda grass) in the field inhibits seed germination, root and top growth of barley due to allelopathic effect. *Cyperus esculentus* (Yellow Nut sedge) inhibits root and shoot growth of maize and soybean. The effect of soybean is due to the allelopathic compounds - vanillic acid, hydroxybenzoic acid in the yellow nut sedge extract. Root exudates and decaying residues of *Sorghum halepense* (Johnson grass) can inhibit both root and shoot growth. Yield reduction in corn is due to the inhibitory effect of exudates of mature *Setaria viridis* (Giant foxtail) roots and leachates of dead roots. *Impereta cylindrica* (Cogon grass) inhibits the growth tomato and cucumber. Field bindweed, Canada Thistle- release root exudates that affect seedling growth of many crops e.g. cabbage, carrot, tomato, radish etc.

Purple nutsedge (*Cyperus rotundus* L.), one of the world's worst weeds, contains phytotoxins in its tubers. Aqueous leachates of *C. rotundus* tubers completely inhibited seed germination of finger millet, wheat, sorghum and mustard. The inhibitory compounds identified were p-hydroxybenzoic, p-coumaric, caffeic, ocoumaric and ferulic acids (Leela, 1995). Tubers of yellow nutsedge (*Cyperus esculentus* L.) contained inhibitory compounds (phydroxybenzoic, p-coumaric, vanillic, syringic, ferulic acids etc.) which inhibited oats coleoptile growth and germination of sugarbeet, peas, lettuces, tomatoes and white clover (Tames *et al*., 1973). Foliage residues of yellow nutsedge were very inhibitory to the root and shoot growth of maize and soyabeans (Drost and Doll, 1980).

Parthenium hysterophorus is a troublesome weed and is responsible for allergies, contact dermatitis in humans and acute illness in cattle. The fast spread of *Parthenium* in India was possibly due to its allelopathic potential and its rapid growth habit. Allelochemicals caffeic and p-coumaric acids were reported in roots, stems, leaves, inflorescences and fruits of mature plants of Parthenium which inhibited the coleoptile growth and dry weight accumulation of seedlings of wheat (Kanchan,1975). Further, two parthenin derivatives, namely 8-hydroxyparthenin and anhydroparthenin were isolated from chloroform extracts (Das and Das, 1995). The leaf and inflorescence extracts strongly inhibited the seed germination, seedling growth, cell survival and chlorophyll content of rapeseed. Aqueous extracts were more toxic than organic or inorganic extracts.

Phytotoxicity of *Amaranthus* spp. residues on several crop species, including sorghum, cabbages, carrots and onions, has been well documented (Menge, 1988). Palmer amaranth (*Amaranthus palmeri* (L.) Warts) residues released allelochemicals through decomposition and volatilization and inhibited the growth of onions, carrots and its own plants. The residues contained the allelochemicals phytol, chondrillasterol, vanillin, 3-methoxy-4-hydroxynitrobenzene and 2, 6- dimethoxybenzoquinone. The inhibitory effects of weed residues against onion germination persisted for up to 9 weeks after soil incorporation. Soil incorporated residues inhibited carrot growth by 49% and onion by 68% and phytotoxicity persisted for 11 to 16 weeks after incorporation. Residues of *A. retroflexus* decreased the plant height, shoot and root weight, leaf area duration, leaf weight ratio and total dry matter production in maize and soyabeans. (Bhowmik and Doll, 1982). *Chenopodium album* and *C. murale* both have proved allelopathic to germination and growth in wheat, maize, chickpeas, black gram, radishes, tomatoes, sugarbeet, mustard, cucumbers, maize and soybeans (Bhowmik and Doll 1982; Goel *et al*., 1994; Mallik and Tesfai, 1988).

Impereta cylindrica inhibits the emergence and growth of an annual broadleaf weed i.e. *Borreria hispada* (Button weed) by exudating inhibitory substances through rhizomes. Living and decaying rhizomes and leaves of *Sorghum halepense* inhibit the growth of *Setaria viridis* (Giant foxtail), *Digitaria sanguinalis* (Large crabgrass) and *Amaranthus spinosus* (Spiny amaranth).

Allelopathic effect of Crops on Weeds

Growing crops can suppress the growth of certain weeds while residues of some crops inhibit the seed germination and seedling growth of weeds through release of phytotoxins. Aqueous extracts of wheat straw inhibited the seed germination and growth of several weeds (ivy leaf morning glory, velvetleaf, hemp, *Sesbania*, Japanese barnyard millet, Steinsiek *et al*., 1982). Maize cultivation considerably reduced the growth and dry matter accumulation in above ground parts of redroot pigweed. Shoot and root leachates of maize inhibited the radicle growth in barnyard grass and root leachates were also phytotoxic to *Arnaranthus leucocarpus* and *Plantago major* (Anaya *et al*., 1987). Mulches of sorghum or sudan grass applied to apple orchards in early spring reduced the weed biomass by 90 and 85%, respectively, owing to greater phytotoxin concentration in the root zone. Sorghum residues reduced the population of common purslane by 70% and of smooth crabgrass by 98% Putnam and DeFrank (1983). Soybean suppressed the plant height and dry matter of inter planted barnyard grass. Soil incorporation of ground soybean residues @ 1% (w/w) inhibited both seed germination and dry weight of velvetleaf each by 40% and that of foxtail millet by 82 and 65%, respectively (Rose *et al*., 1984). Continuous cropping of soybean for 3 years in plots heavily infested with witch weed reduced its population in the subsequent maize crop.

Coffea arabica (Coffee) release 1, 3, 7-trimethylxanthin that inhibits germination of *Amaranthus spinosus*. *Zea mays* root extracts increase catalase and peroxidase activity of the weeds which inhibit their growth. Oat, pea, wheat suppress the growth of *Chenopodium album.* Some rice genotypes have been identified with allelopathic effects on weeds.

Stimulatory Effects

Plants also produce certain chemical compounds, which have stimulatory effects on the germination and growth of other plant species. Corn roots contain a complex of stimulatory substances. The water-soluble component of these substances promote the germination of *Orobanche minor* (parasitic weed), and the ethyl soluble fraction stimulate the germination of *Striga hermonthica*, (another parasitic weed). Sorghum root produces Kinetin and certain other aminopurines, which stimulate the germination of witch weed (*Striga asiatica*), a root parasite in Sorghum.

Allelo-chemicals as Crop protectants

Management of weeds in the past has primarily been done through cultural practices and use of chemical pesticides. Improper use of pesticides caused a variety of problems depending on toxic strength. One of the problems from the excessive use of pesticides is the damage to human health and environment. Natural products of plants and microbes offer a vast array of secondary compounds with biological activity including phytotoxicity. Many of these compounds have the potential to be used directly as herbicides or as structural leads to new synthetic herbicides. Although natural compounds have made a large impact in the insecticide area, relatively few successes have been obtained with these compounds as herbicides. Degradation of natural compounds in the environment proceeds faster than that of synthetic compounds and thus reduces the environmental pollution and groundwater contamination.

Leucaena leucocephala contains mimosine and its application at the rate of 50-300 ppm killed the seedlings of Ageratum conyzoids. Natural leachates of *Vuex negudo*, a coastal vegetation in Taiwan, significantly retarded the growth of *Digiteria decumbens* growth. It leaves contained phenolic compounds and flavonoids (Chou and Yao, 1983). Therefore, rnimosine in the cultivable plants through breeding or biotechnology should be done without affecting the yield potential. Some products of microbial origin (bialaphos in Japan and collego and devine, in USA) had been commercialized. Another product of Streptomyces, aminomycin also led to the development of synthetic herbicides. The biological activities of a large number of sesqui terpenoids from *Astemisia* spp. indicated that such allele-chemicals would be a useful source of natural pesticides (Duke, 1986). Extracts of many dominant plants such as *Delonix regia*, *Digiteria decumbens, Leucaenia leucocephala* and *Vitex negundo* contain allelopathic compounds including phenolic acids, alkaloids and flavonoids that have herbicidal properties. Savard *et al*. (1997) used fusaric acid produced by a strain of *Fusarium oxysporum* for the control of the weed *Striga hermonthica*. Further, they found that no detectable toxins of concern for human health were present when fungus was cultured. These can be used as natural herbicides, fungicides, etc. which are less disruptive of the global ecosystem than are synthetic agrochemicals (Chou, 1995). Phosphinothricin (glufosinate when synthetic) a product from *Streptomyces viridochromogenes* is a successful herbicide that is environmentally and toxicologically benign (Duke and Abbas, 1985). Several herbicides been developed from toxins are presented in Table 1.

Table 1. Source of plant and microbial phytoxins with promising herbicidal activity

Phytoxin	Source	Reference
Plant toxins		
Caffiene	Coffee plant	Duke (1986)
Dhurrin	Sorghum	Putnam (1985)
Gallic acid	Spurge plant	Putnam (1985)
Juglone	Black Walnut tree	Reitveld (1983)
Phloridzin	Apple tree root	Putnam (1985)
Trimethyl xanthene	Coffee plant	Rizvi et. al. (1980)
Sesanbimide	Sesbania seeds	Staden et at. (1995)
Microbial toxins		
Anisomycin	Streptomyces sp.	Heisey & Putnam (1986)
Bialophos	Streptomyces hygroscopicus	Mase (1984)
Cercosporin	Cercospora sp.	Durbin (1981)
Herbicidins	S. saganonensis	Takiguchi et. al. (1979)
Mevinolin	Aspergillus terreus	Bach & Lichtwenhar (1983)
Patulin	Penicillium urticae	McCalla & Norstadt (1974)
Phosphinothricin	S. viridochromogenes	Duke and Abbas (1995)
Tentoxin	Alternaria alternata	Duke (1986)
Toyocamycin	S. tovocanensis	Yamada et. al. (1972)
Ziniol	Alternaria carthami	Robeson *et al*. (1984)

Extraneous application of plant and its constituents has also provided pest control against several fungal pathogens of different crops. Steamed aqueous extracts from *Achyranthus aspera, Annona squamora, Thevetia neriflia, Impatiens balsamina, Cassia fistula, Targeta erecta* had been reported to check the growth of pathogens causing blast (*Pyricularia oryzae*), brown spot (*Drechslera oryzae*) and sheath blight (*Rhizoctonia solani*) *in vitro* and *in vivo* (Mitra *et al*., 1984). Likewise, essential oil from plants *Anethum graveolens, Petroselinum crispum, Cuminum* *cyminum, Daucus carota, Ocimum adescendens* inhibited spore germination and mycelial growth of *Candida albicans, Epidermophyton floccorum, Trichophyton mentagrophytes, Aspergillus* spp., *Alternaria alternate, Curvularia* spp., *Penicillium* spp. and *Helminthosporium oryzae* (Saksena, 1984; Tewari, 1994). Purified active compounds 2-methoxy napthaquinone from *Impatiens balsamina* L., 7-hydroxyI 2,4,6-trimethoxy phenanthrene from *Diocorea rotundata*, avenacin from *Avena sativa* had been isolated and were found to be fungitoxic against *P. oryzae*, *H. oryzae* causing blast and brown spot of rice, respectively (Mitra *et al*., 1984).

Conclusion and Future Thrust

Allelopathic interactions between plants and other organisms offer alternative uses in agriculture, including decreasing dependence on synthetic pesticides for the control of weeds, diseases and insects. An allelopathic crop can potentially be used to control weeds by planting a variety with allelopathic qualities, either as a smother crop, in a rotational sequence, or when left as a residue or mulch, especially in low-till systems to control subsequent weed growth. The possible use of allelochemicals to defend crop plants against insect pests, nematodes, diseases and weeds has received considerable attention. The basic approach used in allelopathic research for agricultural crops has been to screen both crop plants and natural vegetation for their capacity to suppress weeds. To demonstrate allelopathy, plant origin, production, and identification of allelochemicals must be established as well as persistence in the environment over time in concentrations sufficient to affect plant species. In the laboratory, plant extracts and leachates are commonly screened for their effects on seed germination, with further isolation and identification of allelochemicals from greenhouse tests and field soil confirming laboratory results. Interactions among allelopathic plants, host crops, and other non-target organisms must also be considered. Furthermore, allelo-chemistry may provide basic structures or templates for developing new synthetic herbicides/ pesticides. Incorporation of allelopathic traits from wild or cultivated plants into crop plants through traditional breeding or genetic engineering methods could be the future line of work in allelopathy research. This area of technology is in its infancy and, although complex, represents a new frontier for agricultural scientists.

REFERENCES

Anaya, A.L., Ramos, L., Hernandez, J.G. and Cruz, R. 1987. Allelopathy in Mexico. In: *Allelochemicals: Role in Agriculture and Forestry* (Waller, G.R. Ed). American Chemical Society pp. 89-101.Washington DC, USA,

Bach, T.J. and Lichtenhaler, H. K. 1983. Inhibition by mevinolis of plant growth, sterol formation and pigment accumulation. *Physiology Plantarum* **59**: 50-60.

Barnes, J.P. and Putnam, A.R. 1986. Evidence for allelopathy by residues and aqueous extracts of rye (*Secale cereale*). *Weed Science* **34**:384-390.

Basu, P.K., Kapoor, K.S., Nath, S. and Banerjee, S.K. 1987. Allelopathic influence: an assessment on the response of agricultural crops growing near Eucalyptus tereticornis. *Indian Journal of Forestry* **10**: 267-271.

Bhowmik, P.C. and Doll, J.D. 1982. Corn and soybean response to allelopathic effects of weed and crop residues. *Agronomy Journal* **74**: 601-606.

Chou, C.H.1990. The role of allelopathy in agroecosystems: studies from tropical Taiwan. In: *Agroecology: Researching the Ecological Basis for Sustainable Agriculture*. (Gliessman, S.R. Ed.) pp. 104-121. Springer-Verlag, New York, USA.

Chou, C.H. and Chiou, S.J. 1979. Autointoxication mechanism of *Oryza sativa* II. Effects of culture treatments on the chemical nature of paddy soil and on rice productivity. *Journal of Chemical Ecology* **5**: 839-859.

Chou, C.H. and Lin, H.J. 1976. Autointoxication mechanism of Oryza sativa I. Phytotoxic effects of decomposing rice residues in soil. *Journal of Chemical Ecology* **2**:353-367.

Chou, C.H. and Patrick, Z.A. 1976. Identification and phytotoxicity activity of compounds produced during decomposition of corn and rye residues in soil. *Journal of Chemical Ecology* **2**: 369-387.

Chou. C. H. and Yao, C. 1983. Phytochemical adaptation of coastal vegetation in Taiwan. I. Isolation, identification and biological activities of compounds in *Vitex negundo*. *Botanical Bulletin of Academia Sinica* **24**: 155-168.

Craig, I.A. and Saenalo, M. 1988. Effects of paddy bund planted Eucalyptus trees on the performance of field crops. Working paper No. 1, Nearad Project, The Phar, Khon Kaen, Thailand.

Dalai, M,R., Dahiya, D.S., Sarmah, M.K., Narwal, S.S.1992. Suppression effects of arid-zone trees on plant stand and growth of crops. In: *Proceedings of the First National Symposium. Allelopathy in agroecosystems*. (Tauro, P., Narwal, S.S. Eds.) Indian Society of Allelopathy pp. 132-135. Hisar, India,

Das, B. and Das, R. 1995. Chemical investigation in *Parthenium hysterophorus* - an allelopathic plant. *Allelopathy Journal* **2**: 99-104.

Drost, D.C., Doll, J.D.1980. The allelopathic effect of yellow nutsedge (*Cyperus esculentus*) on corn (*Zea mays*) and soybeans (*Glycine max*). *Weed Science* **28**:229-233.

Duke, S.O. and Abbas, H. K. 1995. Natural Products with Potential Use as Herbicides. In: *Allelopathy, Organisms, Processes and Applications*. (Inderjit, K. M. M., Dakshini and F. A. Einhellig. Eds.) ACS Symposium Series **592**: 348-362. *American Chemical Society*, Washington DC.

Duke. S. O. 1986. Naturally occurring chemical compounds as herbicides. *Reviews in Weed Science* **2**: 15-14.

Durbin. R. D. 1981. Toxins in Plant Disease. New York: Academic Press.

Geneve, R. L. and Weston, L. A. (1988). Growth reduction of eastern redbud (*Cercis canadensis* L.) seedlings caused by interaction with sorghum-Sudan grass hybrid (sudex). *Journal of Environment and. Horticulture*. 24–26.

Goel, U., Saxena, D.B., Gupta, A.K.1994. Allelopathic potential of *Chenopodium album* L. *Allelopathy Journal* **1**: 105-113.

Grummer, G. 1957. Vzaimnol vliyanic Rastenii: Allelopatiya. Moscow, USSR: Izd-vo Inostrannyaya Literatura.

Hairston, J.E., Sanford, 1.0., Pope, D.F. and Horneck, D.A.1987. Soybean-wheat doublecropping: implications from straw management and supplemental nitrogen. *Agronomy Journal* **79**: 281-286.

Heisey, R.M. and Putnam, A. R. 1986. Herbicidal Effects of Geldanamycin and nigericin, antibiotics from Streptomyces hygroscopicus. *Journal of Natural Products* **49**: 859-865.

Huber, D.M. and Abney, T.S. 1986. Soybean allelopathy and subsequent cropping. *Journal of Agronomy and Crop Science* **157**: 73-78.

Igboanugo, A.B.I. (1988). Effects of some eucalypts on yields of *Vigna unguiculata* L. Walp., Zea mays L. and Sorghum bicolor L. *Agriculture, Ecosystems and Environment* **24**: 453-458.

Joshi, P.C. and Prakash, O. (1992). Allelopathic effects of litter extract of some tree species on germination and seedling growth of agricultural crops. In: *Proceedings of the First National Symposium. Allelopathy in Agroecosystems (Agriculture & Forestry)* (Tauro, P., and Narwal, S.S. eds.) pp. 127-128. Indian Society of Allelopathy, Hisar, India.

Kanchan, S.D.1975. Growth inhibitors from *Parthenium hysterophorus* Linn. *Current Science* **44**: 358-359.

Kohli, R.K., Singh, D. and Verma, R.C. (1990) Influence of eucalyptus shelterbelt on winter season agroecosystems. *Agriculture, Ecosystems and Environment* **33**: 23-31.

Kruidhof, H.M. 2008. Cover crop-based ecological weed management: Exploration and optimization. Ph.D. thesis. Wageningen Univ., Wageningen, the Netherlands.

Leela, D. 1995. Allelopathic effects of purple nutsedge (*Cyperus rotundus* L.) tubers on growth of field crops. *Allelopathy Journal* **2**: 89-92.

Mallik, M.A.B. and Tesfai, K. 1988. Allelopathic effect of common weeds on soybean growth and soybean-Bradyrhizobium symbiosis. *Plant and Soil* **112**: 177-182.

Mase, S. 1984. Meiji Herbiace (MW-801, SF-1293) (common name: bialaphos). A new Herbicide, *Japan Pesticides Information*. **45**: 27-30.

McCalla, T.M. and Norstadt, F.A.1974. Toxicity problems in mulch tillage. *Agriculture and Environment* **1**: 153-174.

Mitra, S.R., Chaudhury, A and Adithyachaudhary, N. 1984. Production of anti-fungal compounds by higher plants - a review of recent researches. *Plant Physiology and Biochemistry* **11**: 53 – 57.

Molisch, H. 1937. Der Einfluss einer Pflanze auf die andere- Allelopathie Fischer, Jena.

Muller, C.H. 1966. The role of chemical inhibition (allelopathy) in vegetation composition. *Bulletin of the Torrey Botanical Club* **93** (5): 332-351

Narwal, S.S. 1994. Allelopathy in Crop Production. Pp.288 Scientific Publishers, Jodhpur, India.

Narwal, S.S., Singh, A., Singh, I. and Gupta, K. 1989. Allelopathic effects of stubble extract of pearl millet on seed germination and seedling growth of wheat, barley, lentil, chickpea and taramira. *Indian Journal of Ecology* **16**: 127-131.

Norstadt, F.A. and McCalla, T.M. (1963). Phytotoxic substances from a species of *Penicillium*. *Science* **140**:410-411.

Oleszek, W. and Jurzysta, M. 1987. The allelopathic potential of alfalfa root medicagenic acid glycosides and their fate in soil environments. *Plant and Soil* **98**: 67-80

Oleszek, W., Jurzysta, M., Ploszynski, M., Colquhoun, I.J., Price, KR. and Fenwick, G.R. 1992. Zahnic acid tridesmoside and other dominant saponins from alfalfa (*Medicago sativa* L.) aerial parts. *Journal of Agriculture and Food Chemistry* **40**:191-196.

Olsen, R.A., Odham, G. and Lindeberg, G.1971. Aromatic substances in leaves of *Populus tremula* as inhibitors of mycorrhizal fungi. *Physiologia Plantarum* **25**: 122-129.

Putnam, A. R. and Defrank, J. 1979. Use of Allelopathic Cover Crops to Inhibit Weeds. In: IX International Congress of Plant Protection. pp. 580–582. Burgess Publishing Co., Minneapolis, USA.

Putnam, A.R. and DeFrank, J. 1983. Use of phytotoxic plant residues for selective weed control. *Crop Protection* **2**: 173-181.

Reitveld, W.J. 1983. Allelopathic effect of juglone on germination and growth of several herbaceous and woody species. *Journal of Chemistry & Ecology* **9**: 259-308.

Rice, E.L. 1984. Allelopathy. 2nd Edition. Pp. 422 Academic Press, New York.

Rizvi, S.J.H., Mukherjee, D. and Mathur, S. N. 1980. A Possible New Source of Natural Herbicide. *Journal of Experimental Biology*. **18:** 77-78.

Robeson, D.J., Strobel, G. A. Matusrnoto, C. K., Fischer. E. L., Chen. M. H. and Clardy, J. 1984. Alteichin: an unusual phytotoxin from *Alternaria eichornae*, a fungal pathogen of water hyacinth. *Experientia* **40**: 1248-1250.

Roth, C. M., James, P. S. and Gary, M. P. 2000. Allelopathy of sorghum on wheat under several tillage systems. *Agronomy Journal* **92**:855–860.

Saksena, N. 1984. Comparative Evaluation of some Essential Oils for their antifungal activity against some dermatophytes. *Indian Perfumer* **28**: 35-37.

Sanford, J.O. 1982. Straw and tillage management practices in soybean-wheat double-cropping. *Agronomy Journal* **74**: 1032-1035.

Sankhla, N., Baxi, D. and Chatterjee, U.N.1965. Eco-physiological studies on arid zone plants. I. Phytotoxic effects of aqueous extracts of Mesquite, *Prosopis juliflora* D.C. *Current Science* **34**:612-614.

Savard, M.E., Miller, J.D., Ciotola, M. and Watson. A. K. 1997. Secondary Metabolites produced by a strain of *Fusarium oxysporum* used for *Striga* control in West Africa. *Biocontrol Science and Technology* **7**: 61-64.

Saxena, A. and Sharma, A.K. 1996. Allelopathic potential of Acacia tortilis in agroforestry systems in arid regions. *Allelopathy Journal* **3**: 81-84.

Saxena, A. Singh, D.V. and Joshi, N.L. (1994). Autotoxicity of pearl millet in relation to different crop growth stages. In: *International Symposium on Allelopathy in Sustainable Agriculture, Forestry and Environment*. (Narwal, S.S., Tauro, P., Dhaliwal, G.S., Jai Prakash Eds.) pp. 40, Indian Society of Allelopathy, Hisar, India,

Saxena. A., Singh D.V. and Joshi. N.L. 1995. Allelopathic Effects of Pearl Millet as Influenced by Stage of Crop Growth. *Annals of Arid Zone* **34**: 293-296.

Saxena. A., Singh D.V. and Joshi. N.L. 1996. Allelopathy in agroecosystems. *Field Crop Abstracts* **49** (10): 891-899.

Sharma, K.K. 1992 Wheat cultivation in association with Acacia nilotica (L.) Willd ex. Del. field bund plantation - a case study. *Agroforestry Systems* **17**:43-51.

Sheikh, M.I., Cheema, A. and Raza-ul-Haq (1983) Effect of poplars on the yield of wheat at Changa Manga irrigated plantation. *Pakistan Journal of Forestry* **33**: 201-207

Staden, J. van, Grobbelaar, N. and Van Staden, J. 1995. The Effect of Sesbanimide and Sesbania seed extracts on germination and seedling growth of a number of plant species. *Environmental and Experimental Botany* **35**: 321-329.

Steinsiek, J.W., Oliver, L.R. and Collins, F.C. 1982. Allelopathic potential of wheat (Triticum aestivum) straw on selected weed species. *Weed Science* **30**: 495-497.

Sundaramoorthy, S. and Kalra, A. 1991. Allelopathic potential of *Acacia tortilis* plantation in Indian desert. *Annals of Arid Zone* **30**: 259-266.

Takiguchi, Y., Yoshikawa H., Terahara, A., Torikata, A. and Terao, M. 1979. Herbicidins F and G: two new nucleoside antibiotics. *Journal of Antibiotics* **32**: 857-867.

Tames, R.S., Gesto, M.D.V., Vieitez, E.1973. Growth substances isolated from tubers of *Cyperus esculentus* var. aureus. *Physiologia Plantarum* **28**:195-200.

Tewari, S. N. 1994. Botanicals in Allelopathic March - A current review and thrust for future. In: *Allelopathy in Agriculture and Forestry* (Narwal. S. S. and Tauro. P.) pp. 229-243. Scientific Publishers, Jodhpur, India

Ventura, W., Watanabe, I., Komada, H., Nishio, M., de la Cruz, A. and Castillo, M. 1984. Soil sickness caused by continuous cropping of upland rice, mungbean and other crops. *IRRI Research Paper Series* **99**: 1-13.

Waller, G.R., Krenzer, E.G., Jr., McPherson, J.K. and McGown, S.R. (1987). Allelopathic compounds in soil from no tillage vs conventional tillage in wheat production. *Plant and Soil* **98**: 515.

Wang, T.S.C., Young, T.K. and Chuang, T.T. (1967). Soil phenolic acids as plant growth inhibitors. *Soil Science* **103**: 239-246.

Weston, Leslie A., Ibrahim S. Alsaadawi and Scott R. Baerson 2013. Sorghum Allelopathy—from ecosystem to molecule. *Journal of Chemical Ecology* **39**:142–153

Wu, H.P. and Antonovics, J.1979. Regional distribution of rice yields in Taiwan 1965-1976. *Botanical Bulletin of Academia Sinica* **20**: 18.

Yamada, O., Kaise, Y., Futatsunga, F., Ishida, S., Ito, K., Yamamoto, H. and Munakata, K. 1972. Studies on Plant Growth Regulating Activities of anisomycin and toyocomycin. *Agricultural and Biological Chemistry* **36**: 2013-2015.