Journal of Novel Applied Sciences
Available online at www.jnasci.org
©2020 JNAS Journal-2020-9-1/1-12
ISSN 2322-5149 ©2020 JNAS

ALLELOPATHY; A BRIEF REVIEW

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ABSTRACT: Allelopathy is a well known area of active research in ecology. However, its importance in agro-ecology is still underappreciated. This review sets out to address this situation and introduce this new and developing field to a wider research audience and to stimulate new research in it. The review starts with an introduction, followed by discussions of allelochemicals, the role of allelopathy in crop production, Allelopathy related problems in crop production, and Suggestions for future research. It also describes broader research into allelopathy in agriculture and the biosciences, and literature resources on the subject. We hope that it will encourage more scientists to initiate research into this exciting new field.

***Keywords*:** Allelopathy, Agro-ecology, Bio-sciences, Crop production, Ecology.

INTRODUCTION

Allelopathy is a natural phenomenon, defined as:
"The inhibition of growth in one species of plants by chemicals produced by another species"
Or, more widely:
"The biochemical interactions among all types of plants, including microorganisms"
The word allelopathy derives from two roots: allelon, meaning "of each other"; and pathos, meaning "to suffer". The "inhibitory" chemical is released into the environment by one plant, where it then affects the growth and development of its neighbors.

All living things need certain resources to live and grow, and plants require sunlight, nutrients, water, and air. The roots bring nutrients and water from the ground to the plant. The leaves absorb the energy of the sun's rays. Plants require sufficient space to meet their needs and many use allelopathic defenses to protect the space around them.

There are four major reasons why trees require their own space: fire, water, roots, and sun.

Plants need to protect themselves from harm and fire is always a threat in the wild. If trees grow too close to each another, fire can spread from one to another very easily. Trees therefore create space for themselves in order to remain safe. Water is in short supply in some areas, and reducing the number of surrounding plants increases the water available for the roots. Likewise, the amount of soil available for a plant's roots to grow in can be increased by using allelopathic defenses to kill the roots of surrounding plants. Plants also need sunlight to grow. If too many other plants are growing nearby, a plant will be shaded and less able to grow. Allelopathic defenses can be used to prevent other plants growing nearby and so help them to compete for sunlight.

There are many different types of chemical allelopathy. In one, the plant space releases growth-inhibitors from its roots into the ground to protect its immediate surroundings. New plants trying to grow near the allelopathic plant absorb those chemicals from the soil and die. In another, an allelopathic plant releases chemicals that slow or stop photosynthesis in its neighboring plants, or alter the amount of chlorophyll in their leaves, preventing them from synthesizing sufficient food so that their growth is inhibited or they die. While the term was initially coined to describe the detrimental influence of one plant upon another, it is now also used to encompass both detrimental and beneficial chemical interactions. Also, while it was initially restricted to interactions among higher plants, it is also now also applied to interactions among plants at all levels, including algae. In addition, interactions between plants and herbivorous insects or nematodes, in which plant substances attract, repel, deter, or retard the growth of attacking insects or nematodes are considered to be allelopathic. Interactions between soil microorganisms and plants can also be allelopathic in nature. Fungi and bacteria may produce and release growth inhibitors or promoters. Some soil bacteria enhance plant growth through fixing nitrogen, while others make phosphorus available to plants.

Allelopathic compounds and interactions are much more common in terrestrial plants. In aquatic situations, the chemicals released are too diluted to have significant interspecies competitive effects. In aquatic plants, allelopathic chemicals are used primarily to prevent the plant from being eaten by herbivores, rather than to compete with surrounding plants. Some scientists think that some aquatic plants can inhibit the growth of unicellular algae, but this is not generally agreed, and it is suggested that these are in fact, competitive phenomena rather than allelopathic. In allelopathy, a chemical is released by a plant into the environment, whereas in competition, one plant is merely more successful in sequestering resources such as minerals, water, space, carbon dioxide, and light than its neighbors. In the field, both allelopathy and competition usually act simultaneously. Prime examples of plants that use allelopathy to reserve their own space are black walnut trees, sunflowers, wormwoods, sagebrushes, and trees of heaven. Some pine trees are allelopathic. When their needles fall to the ground, they begin to decompose, releasing acids into the soil which keeps unwanted plants from growing near the pine tree.

Allelochemicals are the Cause of Toxicity

Allelopathy is important in sustainable agriculture, and is therefore a priority area of research in many part of the world including the USA, Canada, the European Union, Russia, Japan, Korea, Australia, Mexico, and Brazil. It is a multidisciplinary subject incorporating agriculture (agronomy, soil science, genetics/plant breeding, agroforestry, horticulture, vegetable crops, and weed, pest and disease control) as well as various biosciences (biotechnology, chemistry, biochemistry, microbiology, plant physiology, fisheries and aquaculture, and zoology).

It is interesting to note the similarities between allelopathy and the Ayurveda system of medicine, particularly with respect to pest control and the treatment of human diseases. Both systems use plants or plant extracts to control plant pests or human diseases, and the organisms under attack do not develop tolerance/resistance either to allelochemicals or Ayurvedic medicines, unlike pesticides or conventional allopathic medicines. In view of the numerous problems associated with pesticides and modern allopathic medicines, many environmentally conscious people in developed countries are turning to the use of herbal medicines for human disease control and allelochemicals for crop pest management.

Although, the impact of allelopathy on agriculture was recognized by Democritus and Theophrastus in the 5th and the 3rd Century B.C., respectively (Smith and Secoy, 1977) and by DeCandolle in 1832, most of the progress in this field has occurred during the 20th century (Rice, 1984). Since the 1960's, allelopathy has been increasingly recognized as an important ecological mechanism influencing plant dominance, succession, the formation of plant communities and climax vegetation, and crop productivity. It has been related to problems in the weed-crop interference (Bell and Koeppe, 1972), in phytotoxicity in stubble mulch fanning (McCalla and Haskins, 1964), and in certain types of crop rotations (Conrad, 1927). Rice (1984) showed that allelopathy contributed to the problem of weed seed longevity through two mechanisms: a) chemical inhibitors in the seed which prevent their decay by microbes; and b) inhibitors which keep the seed dormant, though viable for many years. Most of the allelopathic research on crops has been conducted in developed countries where mono-cropping is practiced because winters are too severe to allow the growth of a second crop within the same calendar year. However, there has been much less research in irrigated areas in the tropics and subtropics where the climate allows year round cropping and an array of crops and weeds exist together, despite the fact that allelopathy plays a greater role under these conditions. The role of allelopathy in sustainable agriculture may therefore make it an important strategy in increasing agricultural production in the 21st century.

Proof of Allelopathy

A number of studies have provided excellent evidence for allelopathy but only a few investigators have followed a specific protocol (similar to Koch's postulates for proof of disease) to demonstrate the phenomenon conclusively (Fuerst and Putnam, 1983). Proving allelopathy generally involves the following sequence of events:

i) Demonstrate the allelopathic effect using suitable controls, describe the symptoms, and quantify the growth reduction caused.

ii) Isolate, characterize and assay the allelochemicals involved. Identification of chemicals that are not artifacts is essential.

ii) Obtain toxicity with similar symptoms by adding the allelochemicals identified to the system.

iv) Monitor the release of chemicals from the allelopathic plant and detect them in the environment (soil, air, etc.) around the affected plant, and ideally in the recipient plant itself.

Allelochemicals

Organisms interact in many interesting ways. Chemicals produced by one organism that affect another organism are called allelochemicals (Barbour et al., 1980; Krebs, 1978; Ricklefs, 1979; Whittaker, 1975). Sometimes a single chemical produced by one organism is harmful to another organism but beneficial to a third. Plants of the mustard family secrete mustard oils that irritate many animals and thus prevent them from feeding on the mustard plants. Yet these same oils attract other animals that feed on mustard plants. One of the oils even stimulates germination of the spores of a fungus that is parasitic on mustard roots. We are beginning to appreciate that communities include many complex webs of chemical interactions. For example, fungi and mycelial bacteria secrete allelochemicals that are lethal to other bacteria. We have learned to use these substances in modern medicine and call them antibioticsand they are now part of the ecological interactions of humans. Allelochemicals were suspected in 19th century agriculture because of many observations of “soil sickness” of farmlands. If a piece of ground is continually cropped with one plant, the yields often decrease and cannot be improved by additional fertilizer. Fruit trees, for example, often do poorly in ground where the same species has grown before. Furthermore, it is common for one plant to harm another plant grown in its vicinity (by allelopathy). Many experiments of the type illustrated in Fig. 1 have been performed. In this experiment, one set of apple seedlings was watered with tap water, another set with water that had percolated through soil with grass growing in it, and a third set with water that had percolated through soil with nothing growing in it. Growth of the apple seedlings was apparently inhibited by something produced by the grass plants, since seedlings in the other two treatments grew much better. In a few cases, the allelochemicals have been isolated and identified. It is often difficult to be sure, however, that a particular compound isolated from the roots or leaves of one plant actually plays a toxic role in nature. It appears that juglone (5-hydroxy- naphthoquinone) from the roots and hulls of black walnut (*Juglans nigra*) is an allelopathic. It will kill tomato and alfalfa plants (up to 25 m from a walnut tree in the field) but bluegrass growth seems to be stimulated close to walnut trees. The closely related English’ walnut (*J. regia*) and the California walnuts (*J. hindsii* and *J. californica*) do not produce juglone. It is worth noting that many plants produce allelochemicals that are used as drugs in medical and veterinary practice. In fact, many early physicians (including Linnaeus) were botanists. These substances often cause changes in the physiology or behavior of the organisms that consume them. Narcotics, for example, produce drowsiness or sleep, or lessen pain. Harmful drugs are called poisons While beneficial ones are called medicines. Most exert both effects, depending on their concentration and other factors. Humans cultivate tobacco, tea, coffee, and other drug producing plants. Properly used, some of these drugs are beneficial, but we are also aware of their harmful effects. Alcohol is a waste product of yeast metabolism (fermentation) that does not help the yeast, while urine, another waste product, is often used by animals to help establish territories. Alcohol typically builds to levels that harm the very organisms that produce it. Yet it is an allelochemical and a drug. Allelochemicals are generally secondary metabolites produced by plants, and are byproducts of primary metabolic processes (Levin, 1976). They have an allelopathic effect on the growth and development of neighboring plants. Allelochemicals include: a) plant biochemicals that exert their physiological/toxicological action on plants (allelopathy, autotoxicity or phytotoxicity); b) plant biochemicals that exert their physiological/toxicological action on microorganisms (allelopathy or phytotoxicity); and c) microbial biochemicals that exert their physiological/toxicological action on plants (allelopathy and phytotoxicity. Secondary compounds are metabolically active in plants and microorganisms, and their biosynthesis and biodegradation play an important role in the ecology and physiology of the organism in which they occur (Waller and Nowacki, 1978; Waller and Dermer, 1981). Some of them accumulate at specific stages of growth, while the accumulation of others depends upon time of day or season.

Classes of Allelochemicals

Allelochemicals are biosynthesized from the metabolism of carbohydrates, fats and amino acids and arise from acetate or the shikimic acid pathway (Robinson, 1983). In his review of the potential use of allelochemicals as herbicides, Putnam (1988) listed 6 classes of allelochemicals, isolated from over 30 families of terrestrial and aquatic plants.

These classes are: Alkaloids, Benzoxazinones , Cinnamic acid derivatives, Cyanogenic compounds , Ethylene and other seed germination stimulants, and Flavonoids.

Occurrence of allelochemicals

Allelochemicals are produced in either the above or below ground parts of plants, or in both, as has been reviewed by many workers. Plant parts known to contain allelochemicals (Rice, 1974) are:

Roots:

In general, they contain fewer, and less potent or smaller amounts of allelochemicals than leaves, although the reverse may be true (Kamal., 2011; kamal and Bano., 2009; kamal and Bano., 2008; kamal and Bano., 2008).

Stems:

These contain allelochemicals and are sometimes the principal sources of toxicity (Kamal., 2011; Kamal., 2011; kamal,. 2010, kamal and Bano., 2009; kamal and Bano., 2008; kamal and Bano., 2008).

Leaves:

These are the most important sources of allelochemicals. Specific inhibitors in leaves have been demonstrated by many workers (Kamal., 2011; kamal and Bano., 2009; kamal and Bano., 2008; kamal and Bano., 2008).

Flowers/inflorescences and pollen:

Although studies on flowers or inflorescences are limited, there is growing evidence that the pollen of corn and sunflower have allelopathic properties.

Fruits:

Many fruits are known to contain toxins found to inhibit microbial growth and seed germination.

Seeds:

The seeds of many plant families or species have been found to inhibit seed germination and microbial growth.

Modes of release of allelochemicals

A major pre-requisite for successful allelopathy is that the allelochemical can be effectively transferred from the donor plant to the recipient, and the mode of transfer plays an important role in the effectiveness and persistence of allelochemicals. The donor plant generally stores these chemicals in its cells in a bound form, such as water-soluble glycosides, polymers including tannins, lignins, and salts, so that they are not toxic to it. Once the donor plant releases the allelochemicals into the environment, they may be either degraded or transformed before affecting the receiver plants, and may also become toxic to the donor (autotoxicity). The allelochemicals are cleaved by plant enzymes or environmental stress and released into the environment from special glands on the stems or leaves. First, the terpenoids, such as a-pinene, cineole and camphor, are released to the environment through volatilization. Then the water-borne phenolics and alkaloids are deployed by rainfall through leaching. Phytotoxic aglycones, such as phenolics, are released during the decomposition of plant residues in soil. Metabolites, such as scopoletin and hydroquinones, may be released into the surrounding soil through root exudates. Allelochemicals released through leachates and root exudates must be water soluble and a broad range of chemicals are involved. These processes are described in more detail below.

Volatilization

Allelochemicals may volatilize from a plant into the atmosphere. The volatile vapors may be absorbed directly from the atmosphere by plants, and the adsorbed vapors may condense in dew and fall to the ground, where they are absorbed onto soil particles and subsequently taken up by plants from the soil solution. The genera which release volatiles are: Artemisia, Salvia, Parthenium and Eucalyptus. The volatile inhibitors camphene, camphor, cineole, dipentene, a-pinene B-pinene are produced by several shrubs of the Southern California Chaparral (White *et al*., 1989). Plants rich in such compounds, release them continuously as vapors into the atmosphere. The pulverized leaves of crucifierae species *(brassica juncea, B. nigra, B. napus, B. rapa and B. oleracea)* also release volatile substances. The volatiles of *B. juncea* and *B. nigra* were most harmful to the germinating seeds of lettuce and wheat (Oleszek, 1987).

Leaching

Leaching is the removal of substances from plants by the action of water in the form of rain, dew, mist, fog, and snow. All plants seem capable of leaching, but the degree depends on type of tissue, stage of maturity, and the amount and duration of precipitation. Many allelopathic compounds, both organic and inorganic are leached, including phenolic acids, terpenoids and alkaloids. The leaching of mineral nutrients, carbohydrates and phytohormones may be beneficial for the growth of associated species, although the toxic effects have generally been studied. Most studies have focused on foliage leachates, but seed leachates may also be important. Toxin-bearing leachates are important in weed-crop associations and in plant-plant interactions in grasslands.

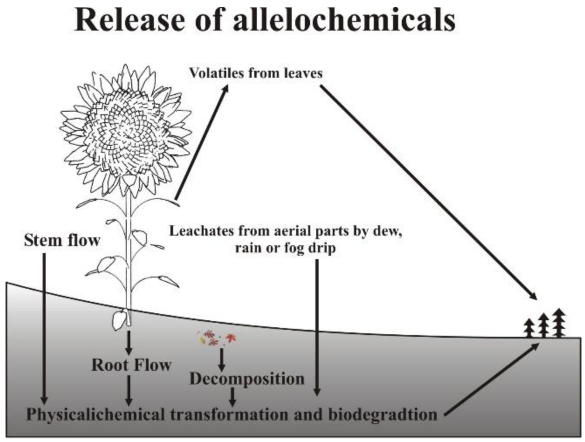

Figure 1. Possible routes of allelochemical release

Root exudates

Many compounds which may influence the growth of microorganisms and associated higher plants are exuded from the roots. The identification of allelochemicals in root exudates is difficult because they may be altered by microbial activity. Rhizosphere microorganisms in the soil environment may transform and inactivate the original exudation compounds, and in some cases may create new active allelochemicals. Exudates very according to plant species, nutrition and age, and temperature, light, microbial activity around the roots, and the soil type.

Decomposition of plant residues

The decomposition of plant residues is responsible for most of the allelochemicals added to the soil. When plants die the cell contents are released into the environment. Important variables in this process are the nature of the plant residues, the soil type, and the conditions of decomposition. Depending on the conditions, substances may be formed during the decomposition which are either highly toxic, non-toxic, or stimulatory to plants. In general, more severe and persistently toxic chemicals are produced in cold and wet soils.

Since the decomposing plant materials are never uniformly distributed throughout the soil, soil adjacent to the decomposing debris may contain more decomposition products than other areas. Therefore, as roots grow through the soil they may come into contact with patches of decomposing plant residues where they are affected by allelochemicals, while at other locations there may be no such influences (Kamal, J,. 2015). Some of the toxic effects of decomposition products on plants are: inhibition of seed germination, stunted growth, inhibition of the primary root system, increase in secondary roots, inadequate nutrient absorption, chlorosis, slow maturation, and delay or failure of reproduction.

Factors affecting production of allelochemicals

Rice (1984) listed the factors which affect the amount of allelochemicals produced: a) radiation; b) mineral deficiencies; c) water stress; d) temperature; e) allelopathic agents; f) age of plant organs; g) genetics; h) pathogens; and i) predators. All except radiation and temperature could be exploited under field conditions to improve crop productivity through better plant growth, improved crop resistance to insects/pests, and improved weed control by exploiting the smothering ability of field crops, although further research is needed.

Mode of action of allelochemicals

Allelopathic agents influence plant growth (Rice, 1984) through the following physiological processes: i) cell division and cell elongation; ii) phytohormone induced growth; iii) membrane permeability; iv) mineral uptake; v) availability of soil phosphorus and potash; vi) stomatal opening and photosynthesis; vii) respiration; viii) protein synthesis; ix) changes in lipid and organic acid metabolism; x) inhibition of porphyrin synthesis; xi) inhibition or stimulation of specific enzymes; xii) corking and clogging of xylem elements; xiii) stem conductance of water; xiv) internal water relations; and xv) other miscellaneous mechanisms.

Fate of allelochemicals

With the exception of the volatile allelochemicals, which are absorbed by plants directly from the air or as leachates (after dissolution in rain, dew, mist or snow), all other allelopathic responses occur through the soil. Potential allelochemicals must remain active in the soil to have an allelopathic effect. The biological activity, persistence, movement and fate of natural products in the soil depend upon their interaction with the soil adsorption complex, soil microbial population and soil chemical environment. Adsorbed allelochemicals may remain biologically active or be rendered inactive, depending on the nature of the adsorbing surface, but adsorbed molecules are less available to soil microbes. Some natural products/allelochemicals may become irreversibly bound in soil humic substances. Allelopathic effects in the soil therefore depend on the relative rates of addition to, and fixation of, allelochemicals in the soil.

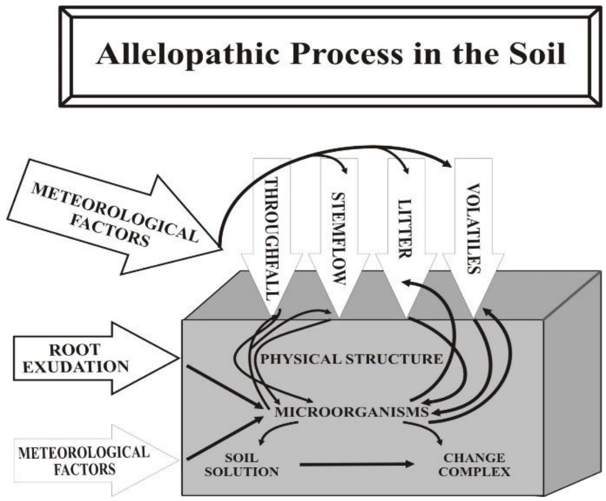

Figure 3. Allelopathic processes in soil

Crop-crop interactions

Field crops generally add phytotoxins or allelochemicals to the soil mainly through crop residues, and partly through root exudates, and the allelopathic effects of these pathways have been the most studied.

Effect of Allelochemicals

The phytotoxins from crop residues have generally negative effects on crop plants such as: a) delayed or complete inhibition of germination; b) reduced population numbers; c) stunted and deformed roots and shoots; d) reduced nutrient absorption; e) lack of seedling vigor; f) reduced tillering; g) chlorosis; h) wilting; i) predisposition to root rot; and j) seedling death (Norman, 1959; Patrick *et al*., 1963; Guenzi *et al*., 1967; Norstadt and McCalla, 1963; Toussoun *et al*., 1968; Horricks, 1969; Kimber, 1973a,b; Cochran et al., 1977; Lynch, 1977; Kuo et al., 1981; Walker and Jenkins, 1986; Waller *et al*., 1987; Oleszek and Jurzysta, 1987; Hicks *et al.,* 1988; Khaliq et al., (2004). However, the major effects of phytotoxins on crop plants are: i) inhibition of nitrification and biological nitrogen fixation; ii) predisposal to disease; and iii) inhibition or stimulation of germination, growth and yield.

Root exudates

Root exudates of crops affect the germination, growth and yield of other crop plants, and therefore play major role in crop mixtures or intercropping systems. De Candolle (1832) was the first to report harmful effects of the root exudates of one plant on the growth of another. Sorghum and maize root exudates inhibited the growth of sesame plants, preventing them being grown closer than 60 cm to live sorghum plants which release natural toxins into the soil (Fletcher, 1912; Breazeale, 1924; Hawkins, 1925; Conrad, 1927; Mckinley, 1931). Of buckwheat, alfalfa, red clover, pea, soybean, rye, vetch and blue grass, only the root exudates of buckwheat reduced the yield of tomato (Alderman and Middleton, 1925).

According to Overland (1966), barley is an excellent smother crop due to its extensive root growth and root exudates, which inhibited the germination and growth of tobacco, chick weed and shepherd’s purse. However, its root exudates had no inhibitory effect on wheat plants. Live barley root exudates contained the alkaloid ‘gramine’ and had a greater inhibitory effect than aqueous leachates of dead roots, proving the presence of active metabolic allelopathic substances. Root exudates of rice varieties ‘CB-1’ and ‘Rupsail’ inhibited the root and shoot growth of test seedlings of both these varieties, owing to the presence of phenolic compounds such as abscisic acid. The maximum release of inhibitors in root exudates occurred under climatic conditions favorable for rice growth (Sadhu and Das 1971a,b; Sadhu, 1975). Tobacco root exudates inhibited seed germination and seedling growth of maize, mustard and foxtail millet (Haq and Hussain, 1979), while that of Chinese cabbage reduced radical growth and dry matter increase of Chinese cabbage and mustard (Akram and Hussain, 1987).

Root exudates play a significant role in living plants and may inhibit or stimulate seed germination or seedling growth of associated weeds. The root exudates of rye (Borner, 1960), corn (Dzyubenko and Petrenko, 1971; Dzyubenko and Krupa, 1974), oat (Martin and Rademacher, 1960; Fay and Duke, 1977), wheat (Martin and Rademacher, 1960), sorghum (Forney *et al*., 1983; AlSaadawi *et al.,* 1985; Panasuik *et al.,* 1986), alfalfa (Abdul-Rahman and Habib, 1989), lupin (Dzyubenko and Petrenko, 1971), soybean (Massantini *et al*., 1977; Rose *et al.*, 1984), sunflower (Wilson and Rice 1968), and buckwheat (Tsuzuki, 1980) inhibited seed germination of red sorrel (Panasuik *et al*., 1986) and stimulated seed germination in witchweed (Netzy et al., 1988). Sunflower :Wilson and Rice, 1968;

Hall, 1980, Hall *et al.*, 1982, 1983; Leather, 1983a) and sweet potato (Harrison Jr. and Peterson, 1986) exudates decreased germination and growth of weeds. Growing crops of barley (Mann and Barnes, 1945, 1947; Prutenskaya, 1974; Putnam and De Frank, 1983). Rice (1964) reported that aqueous extracts of lambsquarter (*Chenopodium album* L.) and crabgrass (*Digitaria* spp.) inhibited the growth of nitrogen fixing and nitrifying bacteria. The inhibitors present in prostrate knotweed (*Polygonum aviculare* L.) inhibited the growth of *Rhizobium* and *Azotobacter* (Al-Saadawi and Rice, 1982). Aqueous extracts of *Avena ludoviciana* reduced seedling growth and nodulation in greengram (Bhandari et al. 1982). Phytotoxins produced during the decomposition of crop residues inhibited the nitrification process in the soil and biological nitrogen fixation in legumes. leaving corn residues on the soil surface increased the concentration of nitrification inhibitors (ferulic and p coumaric acids) in the soil, which decreased the population of *Nitrosomonas* and thus increased the concentration of NH_4^+ over NO_3^- compared with soil without corn residues (Lodhi, 1981). In south Taiwan, soybean planted after rice, gave higher yields when the rice residues were burnt than when they were left to decompose on the field (Asian Vegetables and Research Development Centre, 1978), because the phenolics produced by decomposing rice residues inhibited the growth of N fixing bacteria (*Rhizohium japonicum*), reduced the number of nodules, and thus decreased biological nitrogen fixation in soybean (Rice, 1971). Similarly, incorporation of vines and the storage root residues of sweet potato into the soil reduced the nodulation and nitrogen fixation of cowpea (Walker and Jenkins, 1986). In an 8-year study at Los Banos the plant stand and grain yield of successive greengram crops decreased due to allelochemical buildup in the soil which caused a multiplication of harmful soil microbes (fungi, bacteria, nematodes etc.) and accumulation of their microbial toxins harmful to greengram seed germination and seedling growth (Ventura et al. 1984) To date, 129 weed species allelopathic to crops have been indentified (Narwal, 1994b).

Weeds

Weeds have been growing alongside crops since the beginning of agriculture. Because, weeds have evolved alongside crops, or in some instances are the ancestors of cultivated crops, many crops and weeds are actually the same species. For example, the wild races of wheat, rice, barley, maize, oat, sorghum, potato, radish, cabbage, lettuce and asparagus etc., are weeds. In addition, various modem agricultural practices favor invasion by weeds: a) row sown crops leave enough inter-row space for colonization by other species; and (b) many crops are grown as monocultures. Any plant species grown alone generally fails to fully exploit its habitat. For example, it may not fully use the available sunshine because its leaf canopy develops slowly, or it may have too short a growth cycle to consume all the available water or nutrients. Weeds can therefore invade such areas and capitalize on these unused resources. Weeds cause greater losses in crop yields than either insects or plant diseases and reduce crop yields through: a) allelopathy (by the release of inhibitors from seeds, living plants and plant residues); b) competition with crops for resources (light, nutrients, water, and space); and c) providing an alternate host for insects and disease organisms. Putnam and Tang (1986) reported that a large number of weed species are allelopathic.

Weed-crop interactions

Under field conditions, weed infestation is one of the major causes of yield reduction in crops. Historically, most investigators have attributed these losses to various forms of competition between weeds and crops but allelopathic interactions between them were not considered. However, since the 1950’s, studies have shown that allelopathic interactions between crops and weeds are also partly responsible for crop yield losses. DeCandolle (1832) was the first to report the injurious effects of root exudates of Canada thistle (*Cirsium arvense* (L.) Scop.) on the growth of neighboring oat plants.

Weed residues

Weed residues may have an allelopathic effect on crop plants similar to that of crop residues, but detailed studies are lacking. Allelochemicals released from weed residues may affect crop plants in following ways: i) inhibition of biological nitrogen fixation; ii) inhibition of nutrient uptake; and iii) inhibition of seed germination, growth and yield.

Root exudates

In crop fields, weeds suppress the growth of adjacent crop plants through the excretion of inhibitory compounds in their root exudates. These compounds reduce seed germination, root and shoot growth, nutrient uptake and nodulation (in legumes). However, root exudates of Bermuda grass (*Cynodon dactylon* (L.) Pers.) and corn cockle (*Agrootemma githago* L.) stimulated the growth and yield of crops. In some weeds, the toxicity of exudates is high in the younger plants and decreases with maturity, while the reverse is true for others. The root exudates of Johnson grass, quack grass, redroot pigweed, wild oat, *Cyperus* spp., *Chenopodium* spp., *Bidens pilosa*, *Celosia argentea* and *Polygonum* spp. All caused severe reduction in the seed germination and growth of several crops.

Seed leachates/ extracts

The seeds or seed coats of certain weed species contain inhibitory compounds, which are released mainly during germination. These compounds inhibit seed germination and root and shoot growth of crops sown in their vicinity.

Volatiles

The volatiles of palmer amaranth (*Amaranthus palmeri* (L.) Wats.), mintweed (*Salvia reflexa* Hornem) and *Stevia eupatoria* had inhibitory effects on crops, while those of wild heliotrope (*Heliotropium europium*) stimulated crop growth. The volatiles released from air dried residues of *Stevia eupatoria* decreased the root elongation of white clover seedlings in a closed system (Lovett, 1982). The volatiles emitted from soil incorporated or soil surface residues severely inhibited the seed germination of carrot, tomato and onion (Bradow and Connick Jr., 1987). Mintweed is the most common weed in some countries including the USA and Australia (Holm et al., 1979). Volatiles released from its leaves retarded germination and seedling growth of wheat in a closed circulating system, and its volatiles contained monterpenes, including α-pinene, β-pinene and cineole (Lovett, 1986). Volatiles released from the dry leaves and flowers of palmer amaranth reduced seed germination in tomato, onion and carrot. The volatiles contained 2-octonone, 2-undecanone, 2-heptanone, 2-hexanone, 3-methyl-2-3 butanone, 2-pentanone, 3-hydroxy-2-butanone, and 2-butanone phytotoxins (Bradow and Connick Jr., 1987, 1988a,b). However, the volatiles from leaves, stem and seeds of wild heliotrope stimulated germination and root growth in radish and fodder bean (Grechkanev and Rodionov, 1971), (Wa,. et,. 2015), (Ahmad. et., 2004) . Weeds compete with crops for all the normal resources such as nutrients, water, space, light and carbon dioxide, or interfere with crops through the release of biomolecules into the rhizosphere. Crop production losses caused by weeds vary depending according to weed density and weed type. A variety of yield losses in wheat have been reported due to weed infestation, and may account for 15–50% of the potential yield. In severe cases, weed infestation may cause complete crop failure. Taking a minimum loss of 15%, these losses could amount to as much as nine billion Rupees per annum in Pakistan. Weeds in wheat crops are controlled by various methods mechanical and chemical. Manual and mechanical methods are weather dependent and manual methods are labor intensive as well. Both chemical and environmentally safe weed control sprays may drift and affect non-target plants, and may also contaminate soil, water, and air. Nutritive values of some crops are also affected by herbicides. Some weeds originally susceptible to herbicides, have now developed resistance. These problems demand efforts to develop alternative technologies for weed control in wheat, not only to control weeds more effectively, but also to reduce dependence on labor and weather conditions as well as to increase environmental safety. Allelopathy may offer an improved technology for this purpose. Most allelopathic compounds are phenolics, flavonoids and terpenes. These substances have selective effects depending upon their concentrations; either inhibiting or stimulating the growth of neighbors, or subsequent crops or weeds (Cheema, 1998). Weed control may be achieved by applying the residues of allelopathic weeds or crop plants as mulches, or by growing them in crop successions and leaving their residues lying on the field. By introducing an allelopathic trait into a crop cultivar, crop plants can be bred to have a competitive edge over certain weeds (Tahir et., 2018). Crop plants such as wheat, sunflower, rye, barley and cucumber have been reported to have allelopathic effects on weeds. The chief phytotoxins identified in sunflower plant residues are chlorogenic acid, isochlorogenic acid, scopolin and a suspected naphol derivative. Extracts of whole sunflower plants significantly inhibit the growth of both the radical and shoot of wheat. Some genotypes of sunflower can reduce the total weed cover by as much as 33 percent. Residues from mature sunflower crops exhibit selective effects on the germination and growth of weeds. Sunflower is the most important source of high quality vegetable oil. Being a potent allelopath in nature, its effect on subsequent crops and weed have been well studied, but very little information is available regarding its effects on wheat. Since both wheat and sunflower are important crops in Pakistan, it is important to improve our understanding of the residual interactions between sunflower, wheat and their associated weeds in sunflower/wheat cropping systems, and the effects of sunflower aqueous extracts on the germination of wheat and its major weeds. We propose to study the allelopathic effects of different sunflower plant tissues (grown with and without fertilizer) on the density and growth of weeds in the absence of wheat, and on wheat productivity, weed density and growth under two fertility conditions, using both laboratory and field experiments. Alsaadawi (1988), (Ayub et., 2015) found that water extracts and decaying residues of sunflower roots and shoots significantly reduced nitrification. In another experiment he reported that the allelopathic potential of sorghum and sunflower against nitrification may help to augment the efficiency of nitrogen application in added fertilizer (Alsaadawi, 1992), Geberiellele., et al., 2019).

IMPORTANCE OF ALLELOPATHY

The science of allelopathy is a relatively new field of study, and there is convincing evidence that allelopathic interactions between plants play a crucial role in both natural and manipulated ecosystems.

1. These interactions undoubtedly an important factor in species distribution and abundance within some plant communities,
2. Allelopathic interactions are also thought to be an important factor in the successful spread of many invasive plants, for example spotted knapweed and nutsedge

3. The brightest hope for allelochemicals is that they will act as natural weed killers or pesticides, substituting for chemicals, and promote sustainable agriculture.

3. Plants that will suppress tree growth may, in future, reduce the cost of pruning or herbicide applications in conflicts between trees and power lines.
4. Use of allelopathic cover crops for weed suppression can decrease reliance upon herbicides.
5. An understanding of plant/chemical relationships could reveal practical benefits of ,companion planting, a practical endorsed by organic gardeners, which is currently valued less than if it were based on science-based research.

Conclusions:

Allelopathy includes both inhibitory and stimulatory effects of plants on each other including micrrorganisms. It is a very wonderful natural phenomenon; its importance can be summarized as follows: it is the cheaper way of weeds control without polluting our environment.

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