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Allelopathy in ecological sustainable organic agriculture

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CONTENTS

ABSTRACT

To make our modern agriculture successful, the use of new agricultural technology in a short span of 35-40 years have caused havoc by contaminating our soil, environment and food with toxic pesticides residues. Modern agriculture is exploitive of growth resources and has caused very serious problems such as environmental pollution through (i). contamination of underground drinking water resources, food and fodder with pesticides and nitrates, which are harmful to human beings and livestock, (ii). poor soil health/ soil Sickness leading to low soil productivity and (iii). poor quality of life. These problems may be overcome with the adoption of Organic Agricultural practices. The definition of Organic Agriculture used in this paper is "*Organic Agriculture consists of those practices, which reduces the use of outside inputs viz., fertilizers and pesticides etc on the farm*". Therefore, various types of allelopathic strategies may be used for (a) maintenance of soil fertility (use of crop rotations, Biological Nitrogen Fixation, crop mixtures, crop residues and leaf litter etc.), (b) weed management (cover crops, crop residues as mulches, intercropping, crop rotations, phytotoxic or allelopathic varieties and natural herbicides etc.), (c) insects pest management (cropping systems, resistant varieties, insecticidal allelochemicals etc.), (d) nematodes management (plant materials, oilseed cakes, nematicidal compounds etc.), (e) diseases management (cropping systems, crop residues, organic amendments etc.) and (f) use of allelochemicals as growth regulators. Therefore, research efforts are needed to utilise inhibitory allelopathic effects of plants for natural control of crop pests (weeds, insects, nematodes, pathogens), so that use of present pesticides could be minimized or eliminated for developing Sustainable Organic Agriculture, keeping the environment clean for our future generations and reducing the cost of Organic food.

1. INTRODUCTION

Allelopathy consists of two Greek words ‘Allelon’ means each other and ‘Pathos’ means harmful. The term was coined by Prof. Hans Molish, German Botanist in 1937. In past, the definition of Allelopathy has been changes several times. Acccording to the latest definition of International Allelopathy Society (1996), Allelopathy refers to any process involving secondary metabolites produced by plants, microorganisms, viruses, fungi that influence the growth and development of agricultural and biological systems.

The indiscriminate use of new agricultural technology [agrochemicals (fertilizers, pesticides etc.) and multiple cropping in irrigated areas], for the success of modern agriculture has (i) made our soils sick, (ii) caused environmental pollution, (iii) development of resistance in pest (weeds insects, pathogens etc) and (iv) toxic residues in our food. The new technology in a short span of 35-40 years have caused these major problems, which have severely deteriorated our soil health, human and livestock health, environment and quality of life. This indicates the new technology is not sustainable over long periods. Modern agriculture is exploitive of growth resources and has caused various problems such as environmental pollution through (a) contamination of underground drinking water resources with pesticides and nitrates, (b) contamination of food and fodder with residues of pesticides, nitrates and antibiotics, (c) both 'a' and 'b' cause harm to farm workers and livestock (108), (d) poor soil health and soil productivity and (e) poor quality of rural life. There is growing evidence that grain yields of cereals in cereal based rotations in modern agriculture cannot be sustained at the current levels e.g. rice-wheat rotation. In the last 16 years, there is a decline of 25-30% in the grain yields of both rice and wheat in Philippines, Indonesia, India and Pakistan, despite the use of recommended cultural practices (108). Therefore, the recent emphasis in agriculture has shifted from a primary goal of maximizing yields over the short term, to a sustainable productivity over long periods of time and conserving natural resources. The knowledge of ecological interactions occurring within an agroecosystem and the sustainable functioning of the system as a whole has become the overall approach. Sustainability can be achieved in an agriculture, that is ecologically sound, resource conserving and not environmentally degrading. Therefore, several definitions of organic agriculture are available, but for this lecture, the ecological sustainable agriculture means that "farmer grow the crops with the resources available on the farm, reduces dependence on off-farm inputs viz., fertilizers and pesticides etc and maintains soil productivity and clean environment over a long period of time". Hence, farmer conserves the resource base to minimize artificial inputs from outside the farm and manage pests (weeds, insects, nematodes, pathogens) through internal regulating mechanisms based on ecological principles and processes (133). Thus, Sustainable Organic Agriculture strives for the integrated use of a wide range of pests, nutrients and soil management technologies (108). In the last few years, some good books on similar aspects have been released (47,90, 93,108).

All plant spp. and their residues produce secondary metabolites called allelochemicals. Although allelochemicals are produced by all plant parts, but the leaves and roots are mainly responsible for their production and release. The Organic Agriculture maintains diversity of plant spp. on the farm, through various types of multiple cropping systems viz., mixed cropping, crop rotations etc., hence, allelopathy assumes great significance. Allelopathy may be used to increase crop production through avoidance of negative impacts, exploitation of stimulatory effects, management and development of allelopathic crops and varieties to suppress pests (weeds, insects, nematodes, pathogens) and use of allelochemicals as pesticides and growth regulators (38).

The productivity of monoculture declines after few years mainly due to build up of pests and soil sickness etc. These problems could be overcome through the adoption of crop rotations and intercropping systems, which exert detrimental effects on the pests (weeds, insects, nematodes, pathogens) through various chemical interactions (Allelopathy) and cause physical hindrances to restrict movement of pests. Likewise, the bio-diversity provided by crop mixtures has a smothering effect on pests and diseases. These indirect synergistic effects also contribute to higher productivity in crop rotations and intercropping systems. If these effects are utilized properly it is possible to reduce the use of chemical pesticides and herbicides in Organic Agriculture.

This paper reviews the allelopathic effects in crop production and the possible use of multiple cropping systems, plant residues, plants and varieties rich in allelochemicals to control pests and supplement nitrogen requirement through Biological Nitrogen Fixation by legumes, which may be used to develop truly Sustainable Organic Agriculture.

2. SOIL FERTILITY

In tropical and sub-tropical countries of the World, climate is suitable for round the year cropping. Therefore, in assured irrigated or high rainfall areas, farmers grow 2-4 crops in a calendar year in multiple cropping systems (MCS). The properly planned MCS (crop rotations, crop mixtures, intercropping) aims at making ecological sustainable agriculture successful, has little harmful impact on environment conditions and maintains soil productivity over a long period of time. They maintain soil fertility, keep the pest under check and reduce soil sickness problem. Both the crop rotations and intercropping systems or crop mixtures through inclusion of legumes maintains or improves soil fertility.

2.1. CROP ROTATION

A well planned crop rotation maintains and even improves the soil fertility, prevents the build up of pest and soil sickness as compared to monoculture (8). If scientifically sound crop rotations are followed, they provide sustainability to agriculture through reducing the requirement of chemical nitrogenous fertilizers and thereby decreasing environmental pollution by substituting them with biologically fixed nitrogen of legumes.

2.1.1. Biological nitrogen fixation

2.1.1.1. Legumes

In the past when chemical fertilizers were not available, biological nitrogen fixation (BNF), fallowing and application of farmyard manure were the only practical steps to maintain soil fertility and to provide essential nutrients to the crops. Even today in dryland areas receiving less than 300 mm annual rainfall, the farmers do not apply chemical fertilizers or manures due to uncertainty of crop production. In such regions, legumes are the major component of cropping systems, which through BNF maintains soil fertility and also provide protein rich diet to the people and nutritious feed to the livestock. In irrigated areas, continuous cropping of cereals necessitates the use of large quantities of nitrogenous fertilizers resulting in the development of undesirable soil properties and contamination of underground water resources. Under such conditions, the inclusion of legumes in the cropping system and the use of Blue green algae (Azolla) is imperative, as organic nitrogen from BNF may be more suitable than fertilizer nitrogen, because it is released gradually to become available at a time when conditions are favourable both for microbial activity and plant growth. In ecological sustainable farming, legumes should alternate nitrogen demanding crops-ideally it should be possible to meet the farm's nitrogen requirements from well designed crop rotations (67) as they fixed upto 450 kg N/ha/yr (103). In sequential cropping, the legumes are generally used as green manure, forage and for grains. As such, their nitrogen contribution varies and follows the order: green manure > forage legume > grain legume, provided that factors governing BNF are similar. However, the allelopathic weeds reduce the N_2 fixation in legumes, hence, weeds must be controlled for more BNF.

The beneficial effect of preceding legumes on the succeeding non-legumes is exerted through the transfer of nitrogen and other nutrients. In crop rotation, nitrogen transfer takes place through decomposition of legumes residues and mineralization of organic nitrogen. The mineralised forms of nitrogen are then absorbed by the succeeding crop. The quantity of nitrogen transferred depends upon the total quantity fixed and the end use of legume i.e. green manure, forage or grain crop, residues removed/added to soil and other factors.

In tropical and subtropical countries, green manuring is generally known to farmers and is practiced wherever, facilities are available. However, green manuring is getting less and less popular with the advent of modern farming. In the irrigated belts of India, continuous cropping of cereals is adopted and green manure crops seldom find a place in the cropping system. This has caused serious soil health problems. For green manuring, fast growing legume crops are grown and incorporated *in situ* before flowering for quicker decomposition and mineralisation of plant nutrients, so that these becomes easily available to the succeeding crop. Two types of practices are followed: (a) growing of legumes especially for green manuring and (b) incorporating residues of grain legumes after the harvest of seeds at maturity. This difference causes variation in the beneficial effects of green manuring.

Therefore to reduce environmental pollution from nitrogenous chemical fertilizers, the inclusion of legumes (grain legumes, forage legumes, green manure crops) in annual crop rotations is necessary. Since forge and green manure legumes provide more nitrogen to the crop than grain legumes, hence, these should be preferably included in crop rotations.

2.1.1.2. Blue green algae

In rice fields, a small fern called Azolla *(Anabena azollae)* covers the water surface but does not harm the crop growth. It fixes upto 120 kg atmospheric N/ ha in the leaves and the nitrogen becomes available to the rice crop after its soil incorporation and decomposition. In Philippines, 100 days old azolla produces 57 t fresh weight/ha, which yields more than 120 kg N/ha (66). In one whole year, it may fix upto 400 kg N/ ha i.e. more than tropical and subtropical legumes and thus offers opportunity to substitute inorganic fertilizers.

2.2. CROP MIXTURES OR INTERCROPPING

In terms of land use, growing of crops in mixtures is more productive than growing them separately (146); hence, it is practised traditionally in parts of Asia, Africa and Latin America. Interest in cereal-legume intercropping system is also developing in temperate and warm regions of Australia and U.S.A. because of higher grain yields, greater land use efficiency per unit land area and the improvement of soil fertility through BNF and nitrogen extretion from the legume component (146). In South American countries like Mexico etc., the interplanting of maize, bean and squash in the same planting hole is very ancient practice (48). In such soils of poor fertility, the cultivation of cereals + legumes together improves both total yields and reduces the nitrogen requirement of cereal component. In maize + cowpea mixture, 30% nitrogen taken up by the maize is obtained from the legume (2). Besides, the legume biomass may be used as mulch/green manure. Many legume spp. such as velvet bean *(Mucuna pruriens), Sesbania* spp. and *Tephrosia* spp. are used in many countries to conserve soil, improve soil fertility through BNF and as green manure crops. Hence, it also offers scope for developing energy efficient ecological agriculture (97).

2.2.1. Nitrogen transfer

It has been shown that N fixation is the source of transferred N. In intercropping systems, the transfer of nitrogen from legume to non-legume component occurs through root exudates (current transfer), via VAM (vesicular-arbuscular mycorrhizae) connections or through decomposition and mineralisation of N from fallen leaves and dead roots and nodules (residual transfer). The root exudates of legumes contain various nitrogenous components which are directly absorbed from the rhizosphere by intermingled roots of non-legume component. The residual transfer also occurs in intercropping systems, provided that non legume component grows for more than 80 days after the harvest of legume, so that nitrogen is mineralised from legume residues e.g. cowpea/ greengram/ clusterbean/ blackgram +sugarcane intercropping etc.

The direct/ current transfer of nitrogen from forage legumes to companion grasses occurs in mixed pasture swards (95). Eaglesham *et al.* (37) confirmed the current transfer of nitrogen from cowpea to maize in cowpea + maize intercropping system using N_{15}. Using replacement series designs, Patra *et al.* (99) have reported substantial transfer of nitrogen from legume component to the associated cereal in wheat + chickpea and maize + cowpea intercropping systems both in green house and field studies.

Estimates of residual transfer of nitrogen from legumes + sugarcane intercropping system are not available. However, results of studies on residual effects of legumes + cereal intercropping on succeeding crops are available. Nair *et al.* (87) found a mean wheat yield increase of about 30% after a maize + soybean intercropping and after maize + cowpea the yield increase was 34% when compared to wheat after sole maize. Singh *et al.* (129) estimated the nitrogen benefits to wheat of various preceding legume intercrops. When comparing wheat after sole sorghum, with wheat after intercrops, he obtained nitrogen fertilizer equivalents of 3, 31, 46, 40 and 54 with soybean, greengram, cowpea (grain), groundnut cowpea (fodder), respectively.

Besides VAM mediated transfer of phosphorus from a non-legume to the legume crop has also been documented.

2.3. BIOMASS

Soil fertility management in ecological sustainable agriculture gives much reliance on the use of biomass (crop residues and other organic wastes) to maintain the status of organic matter in the soil and to meet the nutrients requirement of the crops. The crop residues release allelochemicals through volatiles, leaching and during microbial decomposition. The production of allelochemicals in soil affects germination, growth and yield of crops depending on plant residue type, amount, depth of placement and length of decomposing period. The allelochemicals may either be inhibitory or stimulatory to the succeeding crops (116,141).

2.3.1. Crops residues

Plant residues when recycled, improve the physical, chemical and biological properties of the soil. A surface mulch of plant residues ameliorates the microclimate, reduces runoff and soil erosion and makes tillage easier. In Asia, the availability of plant residues has, of late, increased substantially due to adoption of multiple cropping, reduced tillage, stubble mulch agriculture and combine harvesting of grain crops.

Few studies on stimulatory effect of legumes crop residues have been reported. For example, chopped alfalfa added to soil stimulated the growth of tomato, cucumber, lettuce and several other plants (117). The stimulatory allelochemical was identified as triacontanol. Gill *et al.* (45) have also reported stimulatory effect of mungbean, sesame and soybean residues on wheat, chickpea and lentil at lower concentration. Improvement in corn yields following legume crops has also been reported (105,135).

2.3.2. Tree litter

Trees form a major component of integrated ecological farming. They perform productive and protective functions in the agroecosystem. Most of the mature trees produce substantial quantity of litter, whose proper management is essential in organic agriculture. Trees due to their deep root system have the capability to improve physico-chemical condition of soil and extract nutrients from deep layers and return them to the surface through litter fall. In general, most of the litter falls underneath tree canopy.

Like crop residues, the litter of some tree species also stimulates the growth of associated crops. For example, corn, bean, black raspberry and quince *(Cydonia oblonga)* grew better within the root zone of the walnut trees than outside (28). *P. roxburghii* field soil increased the growth of blackgram (131) and dried residues of *Glyricidia maculata* significantly promoted the growth of tomato seedlings (20). Likewise, a marked increase in the productivity of pigeonpea, sesame, castor and sorghum under leucaena tree (128a) and beneficial effects of eucalyptus on sorghum (56) were also reported.

3. WEED MANAGEMENT

There are about 250 major weed species in agriculture and many of them have allelopathic properties, which reduce crop growth and yield (102). Continuous use of herbicides for weed control has created many problems including their persistence in soil, contamination of environment, crop injury, increase in herbicide-resistant weed population, etc. Hence, non-chemical methods of weed control are preferred. in ecological agriculture. Among different non-chemical methods of weed control, allelopathic suppression of weeds through the use of allelopathic plants in crop rotations and of phytotoxic mulches in soil fertility management is very effective (89).

3.1. COVER CROPS AND RESIDUE MULCHES

For weed management in ecological sustainable agriculture, the use of phytotoxic mulches and cover crops is very effective. Allelochemicals significantly contribute to weed suppression when planted no-till into residues of cover crops or previous crop residues. Cover crops of wheat, barley, oats, rye, grain sorghum and Sudan grass have been used effectively to suppress broad leaf weeds (73,125,126).

The suppressive effect of allelochemicals of rye mulch on weeds in the field is outstanding. Chou and Patrick (22) identified nine acids from ether extract of decaying rye residues in soil. Phenylacetic, 4-phenylbutyric, vanillic, ferulic, *p*-coumaric, *p*-hydroxybenzoic, *o*-coumaric and salicylic acids, all inhibited the growth of bioassay plants. Shilling *et al.* (125-127) found that β-phenyllacetic acid (PLA) and β-hydroxybutyric acid (HBA) from rye residues provided 20 to 60% inhibition of common lambsquarters and red root pigweed in no-till planted soybean, sunflower and tobacco. Barnes *et al.* (12) isolated two hydroxamic acids, 2-4 dihydroxy-1,4 (2H)- benzoxazine-3-one (DIBOA) and 2(3H)-benzoxazolinone (BOA) with phytotoxicity on a large number of weed test plants. Further, they also reported that a mulch of 40 days old spring planted rye reduced 69% weed biomass. Muraleedhaeran *et al.* (86) isolated a microbially transformed allelochemical, 2-2--epidioxy-1, I-azobenzene (2, "2-oxo-1- 1" azobenzene) (AZOB) from a soil supplemented with 2 ($3H^+$)-benzoxazolinone (BOA). AZOB was more toxic to curly cress and barnyard grass than DIBOA or BOA. Although there were no detectable amounts of the biotransformation product in soil under rye residues, the implications of such phytotoxic biomagnification of allelochemicals may explain allelopathic weed suppression under field conditions.

Discoveries concerning microbial transformation of certain allelochemicals from wheat and rye residues may be significant in increasing phytotoxicity of such materials to weeds. Liebel and Worsham (73) reported that ferulic acid released during the decomposition of wheat and rye residues in the presence of prickly sida seed carpels was decorboxylated by a bacterium living on the seeds to a styrene derivative, 2- methoxy-4-ethenylphenol. The styrene was more phytotoxic to prickly sida than ferulic acid and controls this weed in natural conditions under wheat and rye mulch.

In field experiments, residues of sorghum, sunflower, rapeseed, wheat and pea at five tonnes ha^{-1} selectively toxified broad-leaved and grass weeds. The response of wild oats was of particular interest. Field pea and wheat residues significantly stimulated wild oat germination and growth. The germination and growth of other grass weeds was, however, significantly inhibited by all types of residues (110). It is possible that the stimulatory compound(s) produced from wheat residues could be employed to counter the discontinuity of germination in wild oat, facilitating a more complete kill by subsequent adoption of an appropriate cultural practice.

Putnam and DeFrank (112) tested residues of several fall and spring planted crops for weed control in Michigan, USA. The plants were desiccated by the herbicides or by freezing. Wheat and rye residues reduced weed growth by upto 88%. Mulches of sorghum or Sudan grass applied to apple and cherry orchards in early spring reduced weed biomass by 90% and 85%, respectively. In a three years series of field experiments, sorghum residues reduced population of common purslane by 70% and smooth crabgrass by 98%.

Sunflower has a pronounced allelopathic effect on germination and growth of many other plants. Consequently, it strongly influences the patterning of the surrounding vegetation (116). It was observed that decomposition of sunflower residues significantly reduced the total number of weeds especially the dicotyledonous ones. In a 5-years field study with oats and sunflower grown in rotation, the weed density was significantly less than in control plots with oats only (70). In sunflower-wheat rotation field trials, sunflower decreased the density and dry weight of wild oat and *Cirsium arvense* in the following wheat crop (18). Similarly, sunflower reduced the population of associated weed *Trianthema portulacastrum* by 75% at flowering and 96% at maturity stage and of *Parthenium hysterophorus* by 56 and 84%, respectively. The indication was that allelopathic material was released by the roots of sunflower. The maximum inhibition was in BSH-l variety followed by MSFH-l, Co-2 and EC-68415 in descending order (32). Likewise, preceding crop of sunflower reduced the population of broad leaf weeds such as *Cleome viscosa* and *Corchorus trilocularis* and sedges like *Cyperus iria* in succeeding crop (109).

Narwal *et al.* (92) observed suppression by pearlmillet of the weed density and growth in the succeeding sorghum crop. *Brassica campestris* also reduced the weed density in the same field in the following year owing to inhibitory effect of its residues and volatile excretions from the leaves on the germination and growth of other plants. This crop is used for weed control by the Tarahumara Indians in North Mexico (19).

Residual effects on weeds have also been reported for *Tagetes patula* L., beans, corn, cassava (6); sunflower, sweet potato, sorghum and soybean (39); forage sorghum, Sudangrass hybrid (42); sorghum, barley, oats, wheat and rye (111); crimson clover and hairyvetch (144), fescue (104), alfalfa (1) and cucumber (76).

3.2. INTERCROPPING

The mixing or intercropping of plant species with different growth habits and morphology e.g. melons + plantains provides effective weed control (94). Likewise, undersowing of wide row crops like maize with clover or other species with spreading nature control weeds (142). Bantilan *et al.* (11) reported that in maize crop, mungbean provides more weed suppression than peanut and ascribed it to more rapid early growth and uniform canopy structure in mungbean. Among mungbean cultivars, the more prostrate ones were more suppressive.

The farmers in south eastern Mexico, interplant squash in maize/cowpea fields for effective weed control (71). The squash plant suppresses weeds through shade effect and selective allelochemical inhibition. Here the peasants also grow *Stizolobium pruriens* legume with maize to control weeds (49). Grechkanov and Rodionov (53) reported benefits from mixing 1-2 kg seed ha^{-1} of wild heliotrope *(Heliotropeum europeum* L.) with several legumes. This plant not only reduced weeds by 30 to 70% but also controlled other pests.

Expression of allelopathy in fields through plant to plant interactions has also been observed. Joshi and Mahadevappa (62) and Mahadevappa and Kulkami (78) found that *Cassia sericea,* a leguminous plant, effectively controlled the parthenium weed in the fields through allelopathic activity. Bansal (10) showed that buttercup's *(Ranunculus* sp.) weed species, which cause severe infestation and suppression of wheat in mid-hill conditions of Himachal Pradesh, India could be effectively controlled by planting linseed with wheat.

In a three-year field study, barley, rye and *Vicia faba* were planted in monoculture after the harvest of summer crop. These crops grew during the winter season and were ploughed in the soil in the month of March or early April. Thereafter, summer vegetables were planted by the end of May. Barley and *V. faba* and rye + *V. faba* offered almost complete weed control and the latter was most effective. It was attributed to the release of allelochemicals from root exudates during crop growth and from decomposing crop residues (46).

3.3. CROP ROTATIONS

Some weeds species are specific to some crops. Such species are: wild oat and downy brome in wheat; barnyardgrass, foxtail, sandbur and fall panicum in corn/sorghum; cocklebur and valvetleaf in soybean; field bindweed, pricky sida, spurred amoda, sicklepod and silvershade in cotton (140). In these cases, crop rotation is the most effective and economical control method. Only those crops which can compete effectively against weeds are included in such rotations. Fields with summer annual weed problems are rotated with winter grain crops; likewise, fields with troublesome winter annual weeds are rotated with spring or summer crops (145). In common poppy infested fields, rotation with wheat was less effective, while rotation with oat effectively controlled its population possibly due to allelopathic effect of oat. The poppy seeds germinated in oat field but failed to reach maturity (67).

3.4. PHYTOTOXIC VARIETIES

There is variation in the content of allelochemicals in various crops. In addition, the crop varieties also differ in the exudation or excretion of allelochemicals which may affect the degree of weed control. Fay and Duke (39) screened 3000 accessions of oat germplasm for their ability to exude scopoletin, a compound with growth inhibiting properties. Twenty five accessions exuded more scopoletin from their roots than a standard oat cultivar 'Garry'. Four accessions exuded up to three times as much scopoletin as 'Garry' oats. When one of these was grown in sand culture for 16 days with a wild mustard, growth of the mustard was significantly less than when the weed was grown with 'Garry' oats. Moreover, plants grown in close association with toxic accessions exhibited severe chlorosis, stunting and twisting indicative of chemical effects rather than competition.

Dilday (34) reported that 347 accessions of rice out of 16134 from 99 countries showed allelopathic activity against five aquatic weeds viz. ducksalad, signal grass, redstem, flatsedge and barnyard grass. Some of the accessions repelled weeds and maintained weed free area upto a radius of 12-25 cm from their base. Since rice is planted in rows at spacings of 10-25 cm, allelopathic activity would overlap the space between the rice plants or rows leading to control of these problem weeds in rice. Dilday *et al.* (35) further reported that out of the tested accessions, 347, 161 and 6 accessions demonstrated allelopathic activity to ducksalad, purple ammannia and broadleaf signal grass, respectively. Some accessions from India and Bangladesh also exhibited allelopathic activity to barnyard grass and *Cyperus iria.*

Narwal *et al.* (92) screened 13 genotypes of pearlmillet and found that HHB-67 and 8800 4A x 833-2 had greatest suppression effect on weeds particularly *T. portulacastrum,* the major weed of irrigated crops in Haryana, India. Sarmah *et al.* (122) determined the suppression effect of 11,10 and 8 accessions of *Brassica juncea, B. napus* and *B. carinata,* respectively, on winter weeds of north-west India under field conditions. They observed that RH-8689, RH-8605 and RH-8693 of *B. juncea,* HNS- 8902 and HNS-11-1 of *B. napus* and BCCN-5 genotype of *B. carinata* had more smothering effect on weeds compared to their other genotypes.

Superior genotypes for weed control have also been reported in cucumber (113), oats (41,70), sunflower (70) and soybean (80). It appears possible, therefore, to breed allelopathic genes into standard cultivars to aid in weed control.

3.5. NATURAL HERBICIDES

Growing awareness about the environmental and public health problems linked with the excessive use of plant protection chemicals in agriculture has stimulated interest in the search for new selective, easily degradable and environmentally safe herbicides. The ability of some natural plant compounds to effectively inhibit the development of other plants has suggested that they may be used as herbicides. Besides, recent advances in the microbial and plant biochemistry have stimulated scientific interest in the possible role of secondary plant metabolites and microbial toxins as herbicides.

Among the plant products as herbicides, juglone, isolated from walnut tree has been found effective against redroot pigweed, velvetleaf and barnyard grass (124,132,143). Caffeine derived from coffee showed considerable selectivity in inhibiting germination of *Amaranthus spinosus* L. at a concentration that has no effect on blackgram (118,119). Strigol, a sesquiterpenoid derivative from cotton roots is a potent germination stimulant of witchweed *(Striga asiatica* L. Kuntz), an obligate parasite of maize, sorghum (24) and *Orobanche minor* (132).

Dhurrin (sorghum); gallic acid (spurge); Phlorizin (apple root); trimethylxanthene (coffee) and cinch (eucalyptus) are some other important plant products having promising herbicidal activity. The commercialization and marketing of "Herbiacae" the herbicide from microbial natural product bialaphos in Japan (54) has opened up a new era in weed management. Other microbial phytotoxins found to suppress weed growth include anisomycin, tentoxin, biopoloroxin, herbimycin etc.

3.6. TREE FARMING

Very little information is available on this aspect, but it offers scope owing to availability of large quantity of tree litter during leaf fall. It may play a major role in agroforestry systems. It has been observed that in poplar *(Populus deltoides)* based agrisilviculture system, the field remains almost free from weeds during the winter season. It may be due to physical barrier on account of leaf fall at the time of germination of winter weed seeds and the release of catechol and benzoic acid inhibitors during the fast decomposition of th; leaf litter. About 30% less weed population was recorded in wheat grown in the alleys of *Dalbergia sissoo* as compared to control plots (88).

Allelochemicals from eucalyptus could be successfully exploited for the control of noxious weeds. Oils from *Eucalyptus citriodora* and *E. globulus* completely reduced the germination of *Parthenium hysterophorus* seeds and affected the growth of mature weed plants. Similarly, the oils and other chemicals of eucalyptus checked the rooting potential of *Lantana camara* weed (65).

4. NEMATODES MANAGEMENT

The root-knot nematode *(Meloidogyne)* is ranked as number one among the ten most important phytoparasitic nematode genera with wide geographical distribution, phytophagous food habit and infecting over 2200 plant species (123). Owing to the high cost, uncertain availability, problems of application and phytotoxicity of plant protection chemicals as well as the environmental and health hazards associated with the use, other approaches to nematode management, including allelopathy, appear to be potential alternatives for ecological agriculture.

4.1. PLANT MATERIAL AS NEMATOCIDES

Chopped mature dried residues of lespedeza, alfalfa, oats and flax when incorporated @ 25 tonnes ha^{-1} into fields infested with *Meloidogyne incongnita,* significantly reduced the incidence of rootknot in tomato (60). The ploughing of rye crop in the infested soil effectively checked the *Pratylenchus penetrans* and the effect was identical to D.D. fumigation (85). The soil amended with cotton waste, lucerne pellets and lucerne hay showed reduced incidence of *Tylenchulus semipenetrans* (79). Rice straw @ 22.5 or 44.75 tonnes ha^{-1} reduced the population of *Belonolaimus longicaudatus* and other plant parasitic nematodes (137). Johnson (59) observed 75-90% reduction in root-knot incidence in potted tomato grown in soil mulched with flax, lucerne or orchard grass residues. Prasad *et al.* (107) found that wheat straw and neem cake + NPK gave maximum reduction in the plant parasitic nematodes associated with wheat and mungbean. Mishra and Prasad (83) reported good reduction in *M. incognita* incidence in tomato through application of wheat straw and paddy husk.

The oil extracts from the seeds of *Argemone mexicana* weed, when applied @ 0.2% as soil drench or foliar spray, reduced root-knot nematode infestation of okra and increased plant growth. The oil showed systematic effect and the foliar spray proved more effective than soil drench (26). *Azolla pinnata,* a biofertilizer, suppressed the infestation of *M. incognita* in okra (136). Species of polygonum weed have also been found effective in controlling nematodes (120).

Sukul (134) has recommended the planting of some trees like *Anthocephalus cadamba* Mig., *Azadirachta indica* A. Juss., *Eucalyptus*, *Tectona grandis* L. and *Pongamia glabra* Vent. along roads, river banks and forests for the collection and field application of their leaves to control nematodes. Mishra and Mojumdar (82) have reported that neem *(Azadirachta indica)* seed kernel is more toxic followed by its seed and seed coat. They found that addition of decomposed *A. indica* seed, seed kernel and seed coat drastically reduced the root-knot nematode population in soil and increased the yield of mungbean. Mulching with green leaves of *Pongamia* and *A. indica* reduced root-knot nematode infestation of mulberry plants infield experiments (52). The leaves of Ieucaena and *A. indica* after a fixed period of degradation also control root-knot nematodes (58,98).

4.2. OIL SEED CAKES AND BY-PRODUCTS

It is a common practice among vegetable and fruit growers to use oil seed cakes as a source of plant nutrients and to control nematodes. The application of neem, castor, mustard and rocket salad oil seed cakes suppressed the population of root-knot nematode and the reniform nematode (*Rotylenchulus reniformis*) in okra and improved the plant growth and water absorption capacity of its roots (7). Mainpueira, a sub product in the production of cassava flour, proved effective against *M. incognita* under green house conditions as well as in the field (43,106). The citrus fruits canning factory waste used as soil amendment gave good control of tomato nematodes (9). The use of cassava root peeling and locust bean husk as soil amendments reduced root-knot of sugarcane and increased its growth (121).

4.3. NEMATICIDAL ALLELOPATHIC COMPOUNDS

Bhatti and Nandal (14) have reviewed the information on nematicidal substances (allelochemicals). Only a few allelochemicals have been isolated, elucidated and characterized against plant nematodes. Terthienyl isolated from marigold exhibited strong nematicidal properties under laboratory conditions. It, however, failed to suppress nematode population under field conditions even at 200 ppm (139). Cucurbitacin that accumulate in bitter cucumber genotypes repelled more juveniles of *M. incognita* from infecting them than did the non-bitter genotype and the cucurbitacins were implicated with such repellent actions (55).

The compounds isolated from tobacco (nicotine), jackbean (phytolectins) and *Ocimum sanctum* (eugenol) have been found to reduce *M. incognita* infestation of host plants including tomato and okra (3,4,26,29). Juices from numerous plants or their parts and extracts with organic solvents or root exudates contain nematicidal compounds (30,51,116).

5. INSECTS PEST MANAGEMENT

Most pests spp. are naturally regulated by various ecological processes viz., competition for food or by predation and parasitism by natural enemies. Their population is stable and the damage caused is relatively insignificant in most cases. Conversely modern high input farms are planted with uniform varieties, well watered and fertilized i.e. providing ideal conditions for pests attack, for which farmers use pesticides. Pesticides may be dangerous to human and livestock health and damage the natural resources, cause pest resurgence by killing the natural enemies of target pests, can produce new pest, which were not pest in the past e.g. whitefly in cotton. Pests become resistant to pesticides so necessitating their further applications and lastly they do not provide lasting control, hence, have to be repeatedly applied. To overcome such problems, farmers are advised to use wide range of technologies based on ecological processes of predation, competition and parasitism to control pests more effectively than pesticides alone. Besides the use of Integrated Pest Management practices, not only reduces the pests population to satisfactory level, but also are sustainable and non-polluting. In ecological sustainable agriculture, insect control with non-chemicals can be achieved through the use of cropping systems, insect pest resistant varieties and antibiotic allelochemicals of plant origin.

5.1 CROPPING SYSTEMS

5.1.1. Crop rotation

In crop rotations, maximum use of those crops which reduce pests infestation should be encouraged. The approach is to rotate non-host crops with susceptible crops in sequence. Non-host crops reduce the pests population to very low level and then susceptible crops may be grown. The non-host crops provides a break, disrupting the relationship between a pest or pathogen and its host.

In crop rotation, the best results are usually achieved when botanically unrelated crops are rotated. For example, in upland rice-corn-cowpea-fallow rotation, corn and cowpea are unrelated, have different growth habits and attract different pests. Soil insects such as wire worm *(Elateridae)* and white grubs usually have a wide range of hosts, which restricts the choice of crops in rotation on the same land. Rotation of about 4 years duration, under host free conditions is usually necessary to reduce the pest population to a tolerance level (44).

5.1.2. Crop mixture/intercropping

When different crops are grown together as in mixed cropping or intercropping, the pests recognise a suitable crop either by sight or smell. In such a situation, it is possible to confuse the pests by adopting suitable structuring of the crop components.

The crop mixtures/intercropping are also very useful to reduce the pests infestation through (a) release of repellent allelochemicals as volatiles, (b) different plant spp. confuse the insect pests and (c) the various plant spp. provide a physical barrier to the movement of insect pests etc. A large number of small farmers in tropical and sub-tropical countries rely on this system. In Latin America, 60% maize is grown with beans and generally rice, cotton, beans and cassava are grown in mixtures. Generally, more diverse the agroecosystem, the less will be abundance of herbivore pests. Mixtures of cabbage + tomato, reduces the colonization of diamond backmoth, while maize + beans/squash mixtures have the same effect on chrysomelid beetles. Besides, the odours of some plants can also disrupt the searching behaviour of pests. Grass borders repel leaf hoppers from beans and the chemical stimuli from onions prevent carrot fly from finding the carrots. Alternatively, one crop in mixture may act as a trap or decoy crop the "fly paper effect". Strips of alfalfa interspersed in cotton fields in California attract and trap *Lygus* bugs. The loss in alfalfa yield, offsets the cost of alternative control methods for cotton. Similarly, crucifers interplanted with beans, grass, clover or spinach are damaged less by cabbage maggot and cabbage aphids. There is less egg laying on the crucifers and the pests are subjected to increased predation (108).

5.2. RESISTANT VARIETIES

The presence of antibiotic metabolites in some plants makes them comparatively more resistant to the common insect pests. The resistant varieties identified in rice, wheat, maize, sorghum, cotton and alfalfa are being used for breeding commercial varieties. Pathak and Dale (100) have isolated some antibiotic metabolites such as saponins, phenolic acids, 6-MBOA, DIMBOA, gossypol, quercetin and 2-tridecanone. Rao (115) while screening 17 chilli genotypes, found that the pod borer resistant variety 'Loc' had the highest content of total phenols (0.61 %) while the susceptible genotypes ‘Tetraold’ and 'Lanka-l ' had the least amount (0.31 %).

5.3. INSECTICIDAL ALLELOCHEMICALS

Many locally available plants have pesticidal properties and are used to repel, deter or poison pests due to presence of pesticidal allelochemicals. Many of these kills only pests and not the predators, degrade rapidly so do not contaminate environment. Increasingly scientists are determining the mechanisms of such practices. The role of plant allelochemicals in plant-insect interactions has received considerable attention in recent years. The allelochemicals are used in pest control as repellents, antifeedants, growth disrupters and toxicants. Allelochemicals commonly found in plants are toxic amino acids, protease inhibitors, alkaloids, cyanogenic glycosides, phenols, tannins, lignins, flvonoids, toxic lipids, glucosinolates, terpenoids, saponins and phytohaemagglutinins.

Among tree species, neem *(A. indica)* has received substantial attention during the pest decade particularly for insect pest control. It has been an age old practice in rural India to mix dried neem leaves with stored grains or to place them among warm clothes to repel-insects. Butterwoth and Morgan (16) isolated a substance 'azadirachtin' from neem seed that inhibited feeding in desert locust. Since then many azadirachtin based insecticides have been formulated and found effective against insects. The azadirachtin based formulations viz. Azadirachtin, Neemark, Achook, Margoside, Nimbicidine, Repelin, Parasmani, Jawan, Sukrima, Neem oil, Neem gold, Nocilneem, Neemata-2100 and

Neemrich-l and II have been found effective against cotton bollworm (33,96); castor semilooper (63); white fly of cotton (128) and rice hispa *(Dicladispa armigera* (31).

6. DISEASES MANAGEMENT

6.1 CROPPING SYSTEMS

Continuous cultivation of same or related crops leads to perpetuation and build up of soil pathogens which gradually increase the disease intensity. Crop rotation is one of the natural methods of disease prevention especially when botanically unrelated crops are included as they are affected by different pathogens. Crop rotation helps to control many soil borne diseases such as mosaic, wilt of legume crops (pigeonpea, pea, chickpea) and linseed, red rot and wilt in sugarcane, ergot and smut in pearlmillet, leaf smut and bunt in rice, bunt and molya disease in wheat and barley and root rot in vegetable crops. Chohan (21) observed that crop rotation was particularly effective in lowering the population of soil borne pathogens.

The mixtures of different crop species provide buffer against losses from diseases by delaying the onset of disease, reducing spore dissemination and/or modifying microenvironmental conditions. In soil borne pathogens some plant conditions may enhance soil fungistatis and antibiosis through indirect effects on soil organic matter content. The presence of immune or resistant plants in mixed cropping systems impedes the spread of pathogens and increases the separation between susceptible plants. Larios and Moreno (68) documented evidence of disease buffering in various intercropping systems.

6.2. CROP RESIDUES

Many plants produce chemicals either prior to or after infection by certain pathogens which render the plants resistant to diseases (116). The first scientific report on the benefits of plant and other organic materials in disease control appeared 50 years ago. They included reports on control of potato scab, wheat take all and root rot of cotton with various organics (25). In Texas, grain sorghum is a popular alternate crop with cotton. Sorghum provides 20-25 tonnes ha^{-1} of residue. This residue on incorporation in soil, controls root-rot in the subsequent crop of cotton. Green manuring with clover also controls this fungus (77). Soybean residue incorporated in soil before planting of potatoes, controlled the potato scab due to antibiotic production by *Bacillus subtilis,* a bacterium antagonistic to *Streptomyces scabies* which cause potato scab. Volatile compounds released during decomposition of crop residues also deserve attention because of their influence on plant pathogens (74). Various aldehydes from decomposing alfalfa may stimulate the germination of micro sclerotia *Verticillium dahliae* and *Sclerotium rolfsii,* followed by lysis causing a net reduction in the population of these two fungi. Crucifer residues emit sulphur containing volatiles during decomposition that are inhibitory to *Aphanomyces euteiches* and may reduce the root rot of peas caused by this fungus (72).

Although residues incorporated in adequate amounts and at the right time are generally suppressive to root diseases, they may also increase some diseases. Plant residues may be colonied by a pathogen which uses them as energy source. Residues may also produce certain phytotoxic decomposition products that may predispose roots to infections. Such phytotoxins have been reported to increase the susceptibility of certain tobacco cultivars to black root-rot (101); cotton plants to root rot caused *by Theilaviopsis basicola* (75), bean to root-rot (138); sugarcane to pythium root-rot (114) or cause injury to plant roots and thereby open the way for secondary root decay (17,23).

6.3. ORGANIC AMENDMENTS ETC

Among the common organic amendments, neem seed and cake have been found effective against many plant diseases like rice bacterial blight (40); rhizome rot of ginger (36) and other diseases caused by *Rhizoctonia solani, Macrophomina phaseolina, Fusarium solani* and *Phytophthora capsici* (130). Addition of cotton cake @ 15 9 kg-1 soil reduced the incidence of seedling blight of eucalyptus from 80 to 27% owing to release of inhibitor chemicals (64).

Some neem derivatives like Neemta-2100, Neemark, Nimbicidine, Sukrina, Neemoil and Jawan have been found effective against yellow mosaic virus of horsegram. Powdery mildew fungi has also shown sensitivity to Neemta-2100, Neemark and Nimbicidine (61).

7. ALLELOCHEMICALS AS GROWTH REGULATORS

Growth regulators are exogenous non-nutrient substances that manipulate growth, development and composition of plants and functions by interaction with the endogenous phytohormones groups. Their action include growth retardation, flower induction, hastening of maturity or senescence and stimulating biomass production etc. Allelochemicals provide a promising source for new growth regulating compounds viz., agrostemin, triacontanol and brassinolide, which have received maximum attention.

Bioprodukt (15) summarized Yugoslavian work showing that 100 g agrostemin per hectare through seed treatment or foliar spray hastened germination and increased yields of wheat, maize, sunflower and sugarbeet by 10, 15, 15 and 10%, respectively. It also enhanced the oil content of sunflower by 4%. It has proved beneficial to vegetables, flowers, fruits, pastures and forest species.

Triacontanol, a 30-carbon primary alcohol, was isolated as a growth promoting compound from alfalfa. Its foliar applications increased the yields in cucumber, carrot, rice, corn, soybean and others. Inconsistent results, perhaps due to accumulation problems and to method, rate and time of application, reduced its efficacy (69). Extensive work has been done on evaluation of brassinolide, a steroid isolated from rape *(Brassica napus* L.) pollen as a yield stimulant. Brassinolide and several analogues have been synthesized (81) but they are too expensive for use in field crops. All the bioregulators have shown increase in yields of major crops. However, inconsistency in performance between the locations, genotypes and spraying dates, besides difficulties in formulations, has hindered their commercial use.

8. CONCLUSIONS

The crop, weed and tree residues constitute the major source of organic matter in the soil. They also release numerous organic and inorganic compounds in the soil. These compounds (allelochemicals) are generally inhibitory to the growth of other crops/trees depending on the residue amount, length of decomposition period and type of residue. However, some plant residues especially legume residues like alfalfa, mungbean, soybean and leucaena stimulate the growth of crops. In addition to this, plant residues through the release of allelochemicals and biotransformation products decrease the incidence of pests (weeds, nematodes, insect pests and diseases). Intercropping and use of phytotoxic crop varieties and natural herbicides are effective methods of non- chemical weed control in ecological sustainable agriculture. Plant diseases including those caused by nematodes and infestation by insect pests in agriculture could be successfully controlled through the use of organic amendments, allelopathic compounds and crop varieties rich in allelochemicals content. In view of the practical significance of allelopathy in ecological sustainable agriculture, research efforts are needed to make use of the inhibitory allelopathic effects of plants for natural control of crop pests and diseases.

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