ALLELOPATHY

DEFINITION

Allelopathy is derived from the Greek words allelon "to each other" and pathos "to suffer". It therefore translates literally as mutual suffering. It can be defined as any direct or indirect effect by one plant, including micro-organisms, on another through the production of chemical compounds that escape into the environment and subsequently influence the growth and development of neighbouring plants. It includes both inhibitory and stimulative reciprocal biochemical interactions. Chemicals found to inhibit the growth of a species at a certain concentration may stimulate the growth of the same species or another at a lower concentration. Allelopathy differs from competition in that the latter is involved in the removal or reduction of some factor(s) (e.g. water, nutrients, and light) from the environment that is required by some other plant sharing the habitat. Allelopathy is significant for weed-desired plant ecology in three aspects: (1) as another factor affecting changes in weed composition (2) as another source of weed interference with growth of desired plants and yield, and (3) as a possible tool in reducing losses of desired plants from weeds.

TYPES OF ALLELOPATHY

1. TRUE TYPE

The release into the environment of compounds that are toxic in the form in which they are produced.

2. FUNCTIONAL TYPE

The release into the environment of a substance that is toxic as the result of transformation by micro-organisms.

Allelochemicals/allelopathic compounds/phyto-toxins, in general, the isolated chemical inhibitors include simple phenolic acids, coumarins, terpenoids, flavonoids, alkaloids, cyanogenic glycosides, glucosinolates. Concentration of these compounds is more important than their specific chemistry. Greater quantities are produced under more light quantity, intensity, duration, mineral deficiency, drought stress, cool temperature and with growth regulator such as 2,4-D and maleic hydrazide. Infection of some plants by pathogens and attack by insects cause considerable increases in concentrations of phenolic compounds. Also, plants during the peak of the growing season could be expected to produce more allelo chemicals than those same plants earlier or later in the growing season.

ALLELOPATHY AND SUCCESSION

The production of plant toxins is an important factor of succession which brings about the replacement of dominants and other species. Annual plants with little necessity for nitrogen and phosphorus grow first on barrens (the first stage). These plants make their own life impossible by the auto toxic substances they excrete.

The second stage is occupied by annual grasses not inhibited by the toxic substances exerted by first stage annual plants and tolerant to conditions of low nutrition. Herbaceous plants of the first and the second stages have inhibitory actions to nitrogen fixation of soil micro-organisms and a slowing down of the progress of secondary succession. Then gradually annual grasses are replaced by perennial plants not excreting toxic substances (Aldrich and Kremer, 1998).

RELEASE OF ALLELOCHEMICALS/MODES OF ENTRY INTO THE ENVIRONMENT

Unless allelochemicals are released into the environment at a time when they can exert an effect, they can not be of any use. That is, if the allelochemicals are not released from the plant that produces it, obviously it can have no effect on other plants. If the allelochemicals are released to the soil environment at the end of a growing season, only to be dissipated before the start of next growing season, they may will have no effect. There are many ways of their release:

1. DISCHARGE OF VOLATILE CHEMICALS FROM LIVING PLANT PARTS

This mode of entry of allelochemicals into the environment is common under arid or semi arid conditions. However, certain temperate plants emit volatile organic compounds from their vegetative residues e.g. *Amaranthus* spp. Volatile allelochemicals include low molecular weight hybrocarbons, aldehydes and alcohols.

2. LEACHING OF WATER-SOLUBLE TOXINS FROM ABOVE-GROUND PLANT PARTS

Rainfall, irrigation water, or dew may transport, or leach, allelochemicals that are subsequently deposited on other plants or on the soil. Leaching of plant residues on or in the soil may also transport allelo chemicals into the environments.

3. EXUDATION OF WATER-SOLUBLE TOXINS FROM BELOW-GROUND PLANT PARTS

Compounds exuded from roots include the hydroxamic acids of rye and the benzoquinone sorgoleone exuded from grain sorghum (Aldrich and Kremer, 1998).

4. RELEASE OF TOXINS FROM LITTER OR LITTER DECOMPOSITION

Once these allelo chemicals are released into the immediate environment, they must accumulate in sufficient quantity to affect other plants, persist for some period of time, or be constantly released to have lasting effects.

ALLELOPATHY IN AGRICULTURE

The worldwide associations of certain weeds within a crop ecosystem suggest that crops biochemically promote certain weeds and inhibit others. Allelopathy can be used in agriculture in several ways.

1. Cultivars may be developed that would release kolines as natural herbicides, to provide satisfactory weed control.
2. Planting strips of species which actively release substances toxic to weeds but not to the crops. For example rye.
3. The use of a rotational crop that is incorporated as green manure may also provide toxicity to the weeds. e.g. Rye.
4. The utilization of mulches that suppress weed growth via allelopathy in annual and perennial crop ecosystems e.g. Rye.
5. Application of plant residues having allelopathic chemicals can also be made e.g. alfalfa, sorghum, sunflower, rye, barley etc.
6. Extracts from plant parts containing high concentrations of weed inhibitors can be sprayed.
7. Development of cropping systems which discourage weed establishment.

FACTORS IFLUENCING ALLELOPATHY (Kumar and Jugannathan, 2003)

A) PLANT FACTORS

i. **Plant population.** Higher the number of target species lower will be concentration of allelochemicals available to each target species and thus reducing the effect of allelopathy.

ii. **Life cycle.** The relative timing of crop sowing and weed emergence is an important factor in determination of crop losses due to weeds. Crop yield losses are less if weeds emerge after the crop is sown and complete their life cycle before the crop does.

iii. **Plant age**. The release of allelochemicals by weed plants starts when they attain a particular age. Kanchan and Jayachandra (1979) reported that maximum release of allelochemicals from roots of *Parthenium hysterophorus* occurred at the rosette and flowering stages.

vi. **Plant habit**. Plant habit is an important factor in the determination of allelopathic potential of weed species. For example, perennial weeds often present allelopathic interference to associated crop plants by their continuous presence and cyclic replenishment of allelochemicals in the rhizosphere.

v. **Plant habitat**. Habitat in which the donor plants thrive has a significant effect on the expression of allelopathy. For example, compared to uncultivated soil cultivated soil, had higher values of allelopathy when particular weed dominates the habitat.

B) SOIL FACTORS

The isolation and identification of allelochemicals from weed plants with biological activity does not demonstrate that these allelopathic compounds actually interfere the target crop plants. Because the fate of allelopathic compounds during their flow from roots of host plants to roots of target plants is influenced by the physiochemical and biological properties of soil.

i. **Influence of Physico-chemical properties**. Physico-chemical properties of soil such as soil texture, pH, organic carbon, soil nutrients, inorganic ions and solute potential are found to affect the quantity and quality of allelochemicals and thus their allelopathic effect.

ii. **Influence of biological properties**. Soil micro organisms also play an important role in allelopathy because they have the potential to modify effects of allelochemicals. Soil organisms can degrade allelopathic compounds producing either less toxic or more toxic by-products. They can influence the availability of soil nutrients, which may further influence the fate of allelopathic compounds. They can also influence the release of allelochemicals bound to soil particles..

C) STRESS FACTORS

Various biotic and abiotic stresses influence the expression of allelopathy. There is an increased production of allelopathic chemicals with an environmental stress. Weidenhamer (1996) suggested that environmental stress due to moisture, nutrient and temperature, pathogens, plant density, light and organics influence the leaching of allelopathic compounds. After entering into the soil environment the availability, persistence and fate of allelochemicals are influenced especially by physico-chemical properties of soil and soil microorganisms.

MECHANISM OF ACTION OF ALLELOCHEMICALS

1. INTERFERENCE WITH CELL ELONGATION

Allelochemicals play an important role in the regulation of plant cell growth and there are many reports on the interference of allelochemicals with cell elongation and cell division (Rice, 1984, Ortega *et al*., 1988).

2. INTERFERENCE WITH PHOTOSYNTHESIS

Several research workers reported reduction in photosynthesis due to allelochemicals. However, Inderjit and Dakshini (1992) observed a significant increase in net photosynthetic rate, stomatal conductance and stomatal cavity,

CO_2 concentration in asparagus grown with *Pluchea lanceolata* amended soil compared to those grown with *P. lanceolata* free soils. They further suggested that this might be due to quantitative and qualitative differences in allelopathic compounds or to species specific responses.

3. INTERFERENCE WITH RESPIRATION

The different processes of respiration such as O_2 uptake, oxidation of NADH, ATP production, electron transport and dark CO_2 production are found to be influenced by allelopathic compounds. While most of the processes of respiration are inhibited by allelopathic chemicals, stimulation was also observed in some studies (Ortega *et al.* 1998).

4. INTERFERENCE WITH MINERAL ION UPTAKE

The influence of allelochemicals on mineral ion uptake by affected plants is reported to be consistently concentration dependent besides specificity of ion and species. Alsaadwai and Co-workers (1986) reported that syringic, caffeic and protocatchuric acids lower the uptake of N, P, K, Fe and Mo in cowpea (*Vigna sinensis*); however, Mg uptake was not influenced.

5. INTERFERENCE WITH PROTEIN AND NUCLEIC ACID METABOLISM

Protein synthesis and RNA and DNA metabolism was reported to be interfered by many allelopathic compounds. Cameron and Julian (1980) reported that cinnamic and ferulic acids at 50 uM concentrations, reduced protein synthesis in lettuce seedlings.

WEEDS ALLELOPATHIC TO WEEDS

Allelopathic effects of weeds on weeds were demonstrated by Begum and Hussain (1980) working with aqueous shoot extract, root exudates, soil extract and soil (seed bed) bioassay of *Panicum antidotale* Retz. on *Cenchrus ciliaris, Lolium multiflorum* and *Panicum antidotale* itself (Table-38) Study showed that all the extracts, exudates and soil bed bioassay inhibited not only germination and root growth of *C. ciliaris* but also that of other two species except that germination of *Lolium multiflorum* was not affected by soil extract of *P.antidotale*. Subsequent work by Inam and Hussain (1988) showed that *Medicago sativa, Rumex dentatus, Cynodon dactylon, Vicia faba, Cannabis sativa* and *Coronopus didymus* growing within thickets of *Silybum marianum* exhibited poor biomass under field conditions (Table-39). Work by Hussain and Abidi (1991) indicates more inhibitory effect of shoot leachate of *Imperata cylindrica* on germination and radicle growth of *Dichanthium annulatum* and *Medicago polymorpha* than root leachate (Table-40).

Reduction in fresh weight, dry weight of shoots, roots, nodules as well as number of nodules of *Medicago polymorpha, Medicago minima* and *Melilotus indica* (Table-41) due to allelopathic effect of *Imperata cylindrica* was reported by Hussain and Abidi (1991).

Table-38 Effect of Aqueous Shoot Extract, Root Exudates, Soil Extract and Soil bed Bioassay of *Panicum antidotale* Retz. on Weed Species

Shoot extract	Germination (%)		Radicle growth (cm)	
Species	Control	Test	Control	Test
Cenchrus ciliaris	66	3	0.61	0.31
Lolium multiflorum	68	6	0.46	0.01
Panicum antidotale	30	6	0.13	0.02
Root exudates				
Cenchrus ciliaris	23	10	0.12	0.04
Lolium multiflorum	80	53	0.32	0.16
Soil extract				
Cenchrus ciliaris	24	4	0.16	0.008
Lolium multiflorum	78	78	1.5	1.19
Panicum antidotale	30	14	0.13	0.05
Soil bed bioassay				
Cenchrus ciliaris	40	23	0.26	0.11
Lolium multiflorum	83	20	1.03	0.14
Panicum antidotale	53	23	0.14	0.09

Begum and Hussain (1980)

Table-39 Fresh and Dry Weights of different Ssecies growing with (Test) or without (Control) the Dominance of *Silybum marianum*

Test species	Fresh weight(g)		Dry weight(g)	
	Control	Test	Control	Test
Medicago sativa	6.76	4.53	2.89	1.30
Rumex dentatus	37.44	23.68	5.57	3.22
Cynodon dactylon	1.58	0.65	0.85	0.30
Vicia faba	20.04	10.66	8.66	4.06
Cannabis sativa	39.84	7.48	15.37	2.36
Coronopus didymus	21.96	1.12	6.49	0.20

Inam and Hussain (1988)

Table-40 Effect of Natural Rain Leachate of *Imperata cylindrica* on the Germination and early growth of weeds

Weed	Distilled water		Direct rain water		Shoot leachate		Root leachate	
	G (%)	RL (cm)	G (%)	RL (cm)	G (%)	RL (cm)	G (%)	RL (cm)
Dichanthium annulatum	96	1.66	94	1.6	60	1.15	78	1.08
Medicago polymorpha	80	1.20	78	1.12	70	0.61	76	0.79

Hussain and Abidi (1991)

G = Germination

RL = Root length

Table-41 Effect of *Imperata cylindrica* on the Fresh, Dry Weight and Nodulation of Three Leguminous Weed Species

	Medicago polymurpha		*Medicago minima*		*Melilotus indica*	
	Control	Test	Control	Test	Control	Test
Shoots						
Fresh weight per plant (mg)	1140	840	950	780	3720	2200
Dry weight per plant (mg)	280	190	230	134	600	290
Roots						
Fresh weight per plant (mg)	59	44	45	29	180	150
Dry weight per plant (mg)	26	10	19	9	100	59
Nodules						
Number	10.60	5.50	7.88	4.95	26.50	13.11
Fresh weight per plant (mg)	6.68	4.83	5.11	3.99	17.59	10.89
Dry weight per plant (mg)	1.83	0.21	1.22	0.51	7.25	5.10

Hussain and Abidi (1991)

ALLELOCHEMICALS IN WEEDS

Inam and Hussain (1988) identified P. hydroxybenzoic, Caffeic, Syringic acids, P. coumaric, Chlorogenic and Ferulic acid in shoots of *Silybum marianum*. In addition to above stated allelochemicals Hussain and Abidi (1991) recorded vanillic acid in *Imperata cylindrica*. Vanillic, P-hydroxybenzoic and salicylic acids were identified as allelochemicals in *Argemone mexicana* by Begum and Shaukat (1999).

WEEDS ALLELOPATHIC TO CROPS

Allelopathy may be a factor in weed interference with desired plants in two respects: (1) in inhibiting germination and seedling establishment and (2) in inhibiting growth of the desired plant. Aqueous extracts from shoots and roots, root exudates, soil beneath the *Cenchrus ciliaris* (Tables-42,42a&42b) invariably reduced germination and radicle growth of *Pennisetum americanum* and *Brassica campestris* (Hussain and Anjum, 1981). *Silybum marianum* rain leachates did not effect the germination of mustard, cucumber and wheat but reduced the radicle growth (Table-43). Whereas, soil extract inhibited germination of mustard and wheat, and root growth of mustard, cucumber and sorghum (Inam and Hussain, 1988). Alam *et al.* (1990) reported 31% reduction in seed germination of wheat at 2% level of leaf extract of *Cyperus rotundus*. The shoot and root lengths increased at levels of 0.5 and 1.0% level of leaf extract compared to control. However, the growth in both cases was decreased beyond the level of 1 %(Table-44)

Convolvulus arvensis established and grew rapidly in wheat fields. Experiment revealed that dry powder material of root and shoot of *C. arvensis* mixed with soil inhibited germination, root length, dry weight. 1000- Kernel weight and grain yield of wheat (Table-45). The shoot material was more allelopathic than the root material (Rehman *et al.* 1992). Allelopathy of *Melilotus indica* towards wheat was shown by using seeds of *M. indica* (Table-46). There was no effect of weed seeds on the germination of wheat but shoot and root length was reduced (Alam and Khan, 2002). Alam and Islam (2002) stated that leaf extract, stem extract and root extract of *Chenopodium murale* decreased germination, shoot length (except root extract) and root length of rice (Table-47). Inhibitory effect of aqueous extract of *Cyperus rotundus* and *Echinochloa crus-galli* (Table-48) on germination, plumule and radicle growth of maize was reported by Hamayun *et al.* (2005). *Echinchloa crus-galli* was found to be more allelopathic to maize than *C. rotundus*.

Table-42 Effect of Shoot and Root Aqueous Extracts of *cenchrus Ciliaris* on Germination and Root Growth of Crop Plants

Treatment	*Pennisetum americanum*		*Brassica compestris*	
	Germination (%)	Root length (cm)	Germination (%)	Root length (cm)
Control	98	4.42	96	0.62
Shoot extract	64	1.4	34	0.20
Root Extract	92	3.3	70	0.41

Hussain and Anjum (1981)

Table-42a Effect of *Cenchrus ciliaris* Soil on Germination and Root Growth of Crop Plants

Treatment	*Pennisetum americanum*		*Brassica campestris*	
	Germination %	Root length (cm)	Germination %	Root length (cm)
Control	96	2.02	92	1.58
Soil extract bioassay	80	1.32	76	1.08
Control	96	2.20	98	1.67
Soil bed bioassay	76	1.02	58	0.87

Hussain and Anjum (1981)

Table-42b Effect of Root Exudates of *Cenchrus ciliaris* on Germination and Root Growth of Crop Plants

Treatment	*Pennisetum americanum*		*Brassica campestris*	
	Germination %	Root length (cm)	Germination %	Root length (cm)
Control	94	1.12	90	0.93
Root exudates	90	0.92	72	0.67

Hussain and Anjum (1981)

Table-43 Effect of Natural Rain Leachates from Shoots and Soil Extract of *Silybum marianum* on Germination and Growth of Test Species

RAIN LEACHATES

Test species	Germination (%)		Radicle growth (cm)	
	Control	Test	Control	Test
Mustard	30.00	30.00	1.31	0.46
Cucumber	96.00	96.00	9.41	2.94
Wheat	98.00	98.00	3.98	2.82
Sorghum	86.00	70.00	6.94	2.78
Soil extract				
Mustard	40.00	26.00	1.91	0.05

Cucumber	96.00	96.00	4.13	3.71
Wheat	86.00	72.00	1.20	6.90
Sorghum	84.00	84.00	4.58	4.04

Inam and Hussain (1988)

Table-44 **Effect of Purple Nutsedge (*Cyperus rotundus* L.) Leaf Extract on Germination and Seedling Growth of Wheat**

Level of leaf extract (%)	Germination (%)	Shoot length (cm)	Root length (cm)
0.0	96	7.92	6.89
0.5	88	11.65	8.36
1.0	78	10.84	7.56
1.5	78	7.57	5.52
2.0	66	5.27	4.11

Alam *et al.* (1990)

Table-45 **Allelopathic Effect of Dry Powdered Material of Shoots and Roots o Convolvulus *arvensis* on Germination, Growth and Yield of Wheat**

Treatment	Germination %)	Root length (cm)	Dry weight (g)	1000-kernel weight (g)	Yield per plant (g)
Shoot powder	9.51	20.54	22.17	40.24	8.81
Root powder	9.58	23.42	24.35	40.26	10.01
Control	9.76	39.15	25.76	41.13	11.36

Rehman *et al.* (1992)

Table-46 **Effect of Seeds of *Melilotus indica* on Germination and Seedlin Growth of Wheat**

Treatment	Germination (%)	Shoot length (cm)	Root length (cm)
Control	90	6.18	9.80
Weed seed	90	2.63	1.39

Alam and Khan (2002)

Table-47 Effect of Aqueous Extract of Leaf Stem and Root of *Chenopodium murale L.* on Germination and Seedling Growth of Rice

Treatment	Germination (%)	Shoot length (cm)	Root length (cm)
Leaf extract	72	2.44	2.09
Control	95	4.39	9.67
Stem extract	83	3.81	3.56
Control	93	4.12	9.54
Root extract	85	4.22	5.67
Control	97	3.74	7.84

Alam and Islam (2000)

Table-48 Allelopathic Effects of *Cyperus rotundus* and *Echinochloa crus-galli* on Seed Germination, Plumule Length and Radicle Length of Maize (*Zea mays* L.)

Treatments	Weed added (g)	Extract duration (hr)	Seed germination (%)	Plumule length (cm)	Radicle length (cm)
0 (Check)	-	-	96	0.76	3.96
CSC_1T_1	5	6	94	0.212	2.83
CSC_1T_2	5	12	96	0.212	3.01
CSC_2T_1	10	6	100	0.094	2.43
CSC_2T_2	10	12	82	0.052	1.94
CRC_1T_1	5	6	92	0.038	2.45
CRC_1T_2	5	12	76	0.156	2.19
CRC_2T_1	10	6	94	0.698	3.72
CRC_2T_2	10	12	92	0.034	2.12
ESC_1T_1	5	6	92	0.114	2.44
ESC_1T_2	5	12	66	0.114	2.22
ESC_2T_1	10	6	88	0.158	1.54
ESC_2T_2	10	12	66	0.030	1.56

ERC_1T_1	5	6	100	0.130	2.98
ERC_1T_2	5	12	98	0.248	3.27
ERC_2T_1	10	6	90	0.106	2.08
ERC_2T_2	10	12	88	0.168	2.34
LB(Check)	-	-	86	2.91	5.86
$LBCSC_3T_2$	0.5	12	80	1.98	3.96
$LBESC_3t_2$	0.5	12	92	1.402	4.04
SLB(Check)	-	-	96	2.204	5.09
$SLBCSC_4T_2$	1.0	12	92	1.89	4.77
$SLBESC_4T_2$	1.0	12	92	2.098	4.69

Hamayun *et al.* (2005)

Abbreviations used in the Table

C: *Cyperus rotundus*

S: Shoots

C_2: 10 grams

T_1 : 6 hrs.

SLB: Sand+Litter bed

E: ***Echinochloa crus-galli***

R: Rhizomes

C_3: 0.5 grams

T_2 :12 hrs.

C_1: 5 grams

C_4: 1.0 grams

LB: Litter bed

CROPS ALLELOPATHIC TO WEEDS

Crop residues, leachates or extracts either can inhibit or promote germination and growth of weeds. Cheema *et al.*, (1988) conducted a laboratory experiment and found that aqueous extract of wheat straw reduced the germination, growth of *C. arvensis* and only germination of *D. aegyptium* (Table-49). In another study Cheema *et al.* (1990) found that incorporation of wheat roots + wheat straw (surface or incorporated) was more successful practice in suppressing weed growth than other wheat residues (Table-50).

An increase in population of *Melilotus parviflora* and *Medicago hispida* with sorghum roots or whole sorghum incorporation in wheat particularly with increasing rate of fertilizer (Table-51) was reported by Ahmad *et al.* (1994). Density of *Rumex dentatus*, *Convolvulus arvensis*, *Chenopodium album*, *Anagallis arvensis*, *Phalaris minor* and *Cyperus rotundus* was reduced. Anwar *et al.* (2003) reported that an increase in concentration and number of application of sorghum extract (Table-52) reduced the number and dry weight of weeds accordingly.

Table-49 **Effect of Wheat Straw Aqueous Extract on the Germination, Shoot and Root Length of *Convolvulus arvensis* and *Dactyloctenium aeygptium***

C. arvensis

Extract (% v/v)	Germination(m^{-2})		Shoot length (mm)		Root length (mm)	
	Lab.	Pot	Lab.	Pot	Lab.	Pot
0	95.00	100.00	137.40	40.28	73.60	311.8
25	82.50	85.00	122.40	35.44	69.09	300.29
50	77.50	82.00	122.70	35.48	66.66	289.64
75	60.00	80.00	120.40	35.40	62.94	287.55
100	37.50	72.50	86.60	32.05	56.02	286.22
Dactyloctenium aegyptium						
0	73.05	62.25	10.29	-	5.91	-
25	67.50	55.00	11.12	-	4.91	-
50	45.00	46.25	10.12	-	5.29	-
75	37.50	38.45	12.29	-	6.04	-
100	37.50	27.50	10.75	-	5.50	-

Cheema *et al.* (1988)