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Allelopathic Herbicide Approach to Biological Control of Weeds

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Fungal pathogens are beginning to be preferred as weed biological control agents because of their simplicity and efficacy. The classical approach using exotic fungal pathogens ensures permanence and economy. The mycoherbicidal approach using indigenous and exotic fungi ensures immediate and complete control against many hard-to-control weeds. A knowledge of the disease cycle, degree of pathogenicity, host-specificity and endemicity is essential for the screening of such pathogens. Inhibitory effects of crop plants on weeds are exploited as another potential tool in weed biological control programmes. Screening for allelopathic types of crops, selecting and transferring allelopathic mechanisms into cultivars and utilising rotational and companion crops in cropping systems are some of the possible approaches towards the allelopathic herbicidal strategy. Integration of allelopathic herbicides with other classical weed biological control methods seems to ensure economy as well as environmental safety.

Introduction

Weeds can be defined as competitive, pernicious and persistent plants growing where they are not wanted. Weeds become so abundant and pose a serious threat as weedy pests when introduced from a different geographical region without their natural enemies–insects and pathogens (Thakur 1984).

Huffaker (1964) defined biological control of weeds as the "action of parasites, predators or pathogens in maintaining another organism's population density at a lower average than would occur in their absence." Therefore biological control of weeds aims at the reduction of weed density to sub-economic level by the introduction of insects, plants and diseases (Thakur 1984).

Of all natural enemies, insects have received greatest attention as biological agents for the control of weeds. Biological control of weeds by insects has been attempted only when all cultural and chemical methods prove ineffective and expensive (Thakur 1984).

The increasing global awareness of environmental hazards caused by chemical weedicide usage has generated a renewed interest in biological control techniques. In the new arena of co-operative research involving plant pathology and weed science, certain fungi are more efficacious than chemicals as weed killers.

Mycoherbicides

In recent years, plant pathogens, especially fungi, have been deliberately used as biological control agents. These are used either as sole agents or as part of a complex with other organisms. It may be because fungi are numerically more important, have a well defined taxonomy and in many cases their host specialisation and specificity are known (Templeton *et al.* 1979).

There are 2 strategies–classical and bioherbicidal–for the control of weeds using fungal pathogens as biological control agents. The classical tactic involves the importation of the pathogen from the area of co-evolution with its host and its release into a new geographical region where the host has become a weed (Templeton *et al.* 1979).

The classical biological control tactic has been successful. In Australia, rush skeleton weed, *Chondrilla juncea* L. (Asteraceae), in wheat has been controlled by the introduction of *Chondrilla* rust fungus, *Puccinia chondrillina* Bubak & Syd. (Uredinales) from the Mediterranean (Cullen 1976). In Florida, water hyacinth, *Eichhornia crassipes* (Mart.) Solms-Laubach (Pontederiaceae) has been controlled by a native but geographically restricted species, *Cercospora rodmanii* Conway (Hyphomycetes) (Charudattan *et al.* 1976), and also by a foreign rust (Charudattan *et al.* 1976). Indigenous *Cercospora* are not comparable with chemical weedicides in its effect, but timely applications of this pathogen have reduced water hyacinth biomass (Conway and Freeman 1976).

In Hawaii, the Hamukua pa-makani weed, *Agerarina riparia* (Regel) R. King & H. Robinson (= *Eupatorium riparium* [Regel]) (Asteraceae) in the mountain ranges has been controlled by the introduction of *Cercosporella ageratinae nomen nudem* (*C. adenophorum* Spreng.) (Trujillo and Obrero 1976). In Chile, blackberries, *Rubus constrictus* Lef. et M. and *Rubus ulmifolius* Schott. (Rosaceae), have been suppressed by the introduction of the autoecious blackberry rust, *Phragmidium violaceum* (Schultz) Winter. (Uredinales) from Europe (Oehrens 1977).

Classical weed control with fungal pathogens is comparable to biological control with insects and many of the principles apply to both. The use of exotic pathogens in the classical approach has potential for controlling alien weeds (Templeton *et al.* 1979).

The permanence, environmental safety and economy of the classical strategy warrant further research to evaluate pathogens. Most of the obligate fungi, particularly rusts used in classical biological control are very specific or have narrow host ranges. Therefore there is a need to screen plant families related to the weed–the control target (Templeton *et al.* 1979). Classical biological control operates too slowly to reduce pests below economic thresholds (Ridings *et al.* 1976).

The bioherbicidal tactic involves the application of microbes as herbicides to target weeds in a manner similar to chemical herbicides (Daniel *et al.* 1974, Freeman *et al.* 1976, Ohr 1974). Fungal pathogens applied as sprays that uniformly kill or suppress weed growth are called mycoherbicides. The mycoherbicidal tactic involves releasing massive quantities of fungal inoculum on weeds at strategic stages in their life cycle, preferably when temperature and moisture are optimum for disease development (Templeton *et al.* 1976).

Exotic as well indigenous fungi have the potential for use as mycoherbicides for the control of both alien and indigenous weeds. The mycoherbicidal tactic has been effective in controlling annual weeds in annual crops, range and aquatic weeds when chemical weedicides cannot be used (Templeton *et al.* 1979) and also for perennial weeds in orchards (Ridings *et al.* 1976).

The mycoherbicidal tactic has been greatest potential where specificity, immediacy and completeness of control are paramount. Mycoherbicides have been employed successfully against many weeds. Northern jointvetch weed, *Aeschynomene virginica* (L.) B.S.P. (Fabaceae) and winged water primrose weed, *Jussiaea decurrens* (Walt) D.C. (Onagraceae) of rice and soybean crops have been controlled by host specific strains of *Colletotrichum gleosporioides* (Penz.) Sacc. (Coeolmycetes) (Daniel *et al.* 1973,1974). Strains of *Phytophthora citrophthora* (R.E. & E.H. Smith) Leonian (Peronsporales) have been employed for the control of strangler vine, *Morrenia odorata* Lindle (Asclepiadaceae), a serious weed in Florida citrus (Ridings *et al.* 1976). The oat wilt fungus, *Ceratocystis fagacearum* (Bertz) Hunt, was found to be a selective silvicide (French and Schroeder 1969). A serious pasture weed, *Acacia glauca* L. (Mimosaceae), has been controlled by injecting a spore suspension of *Cephalosporium* sp. (Gupta & Lamba 1978).

Alternaria eichhorniae Nagraj & Ponappa (Hyphomycetes) has been reported to be an effective biological control agent for water hyacinth (Nag Raj and Ponnappa 1970, Kaiser Jamil *et al.* 1982, Kaiser Jamil and Jyothi 1990). A leaf spot pathogen, *C. rodmanii*, has been successfully employed for the suppression of water hyacinth in Florida (Conway 1976). The potent activity of *C. rodmanii* under field conditions led to the development of a wettable powder formulation of the pathogen (Charudattan 1982).

Recently, many mycoherbicides have been isolated and registered under different trade names for use against economically important weeds. The mycoherbicide "Devine®" has been developed from *Phytophthora* spp. for controlling *M. odorata*. An isolate from the pathogen *C. gleosporioides*, registered under the name "Collego®", selectively controls *A. virginica* in rice and soybean. The mycoherbicide "CASST" from *Alternia cassiai* Jurair & Khan (Hyphomycetes) has shown great promise as biological control agent against *Cassia obtusifolia* L. (Caesalpiniaceae) in Mississippi. Applying spore formulations of this pathogen to seedlings in the first leaf safe ensures 80% control. Another promising mycoherbicide, "Bio Mal®" has been developed from *Colletotrichum gleosporioides* f. sp. *malvae* for the control of round leaved mallow (*Malva pusilla*) (Sakhuja & Kaur 1990).

So far, mainly indigenous fungi have been selected as mycoherbicides. Indigenous fungi produce endemic disease of their hosts. Application of indigenous fungi in massive inoculations as mycoherbicides compensates for natural constraints to their epidemic development. As mycoherbicides, they kill 95-100% of the weeds. Epidemics of this magnitude are normally prevented by natural constraints. An understanding of the natural constraints on epidemic development of pathogens is essential for the selection of pathogens as biological control agents (Templeton *et al.* 1979). Study of the disease cycle of the northern jointvetch anthracnose disease has revealed that poor inoculum production and poor dissemination of inoculum are the 2 important natural constraints that sustain the disease at endemic level. Environmental factors, spatial isolation of the host and host resistance are the other constraints (TeBeest *et al.* 1978).

Biological control using fungal pathogens is economical and offers a permanent solution with minimal disturbance of non-target organisms (Bennett 1968). The development of pathogens as mycoherbicides depends on finding pathogens that are strongly and selectively pathogenic to major weeds and are ecoclimatically suitable for the target area. Integration of mycoherbicides into weed management seems to have great potential for solving weed problems.

Allelopathy

Another spectacular means of weed biological control involves the use of crop plants with allelopathic potential–allelopathic herbicides. In many ecosystems plants form pure stands or as individuals spaced in rather specific densities. These dispersion patterns could have been caused by a combination of factors including allelopathy (Putnam 1985).

Many plants show clear zones of inhibition into which no alien plant can invade. *Eucalyptus* spp. (Myrtaceae), *Pinus densiflora* Siebold & Zucc. (Pinaceae), and *Platanus occidentalis* L. (Platanaceae) seem to exert selective herbicidal influence on herbaceous vegetation in their immediate vicinity (Rice 1974). Pure strands of black mustard, *Brassica nigra* (L.) Koch (Brassicaceae) in annual grasslands were attributed to germination inhibitors released from the plants (Muller 1969). These observations provide agronomists hope that similar results could be exploited with crops, especially to achieve weed-free stands of crops using allelopathy (Putnam and Duke 1978). Allelopathy has been documented for a number of important crop plants (Putnam and Duke 1974). Allelopathy refers to the detrimental effects of higher plants of one species (donor) on the germination, growth or development of another (receptor) species (Putnam and Duke 1978). Inhibitory effects of crops on weeds could be as important as the reverse response (Bell and Koeppe 1972). The potential of allelopathy as a mechanism of weed control has been recognised by many ecologists (Altieri and Doll 1978).

Allelopathy differs from other mechanisms of interference in that the detrimental effect is exerted through the release of chemicals by the donor (Putnam and Duke 1978). Allelopathy has been implicated in weed/crop interference (Rice 1974, Altieri and Doll 1978), in orchard replanting (Borner 1959) and in forest regeneration (Horsley 1977). Several researchers have identified the chemicals involved in allelopathy (Davis 1928, Gray and Bonner 1948). The chemical inhibitors were secondary compounds (Chandramohan *et al.* 1973). Those implicated as effective allelopathic agents include phenolics, coumarins, terpenoids, flavanoids alkaloids, cyanogenic glycosides and glucosinolates (Harborne 1972, Whittaker and Feeny 1971).

Allelochemicals are considered the by-products of metabolism or waste products shunted into vacuoles to prevent autotoxicity and are present in virtually all plant tissues (Putnam 1985). These chemicals are allelopathic only when circumstances favour their accumulation. They may be released in a variety of ways such as volatilisation, root exudation, leaching from aerial portions of plants and decomposition of plant residues. Therefore the allelopathic properties are the secondary effects of secondary compounds (Whittaker 1970). Genetic regulation of allelochemicals has been shown by Putnam and Duke (1974). Certain genetic strains of *Cucumis sativus* L. (Cucurbitaceae) and *Avena sativa* L. (Poaceae) have been shown to reduce weed growth (Fay and Duke 1977; Lockerman and Putman 1978).

Artemisia (Muller *et al.* 1964) (Asteraceae), *Salvia* (Muller 1965) (Lamiaceae) and *Eucalyptus* (del Moral and Muller 1970) release volatile terpenoids. *Chenopodium album* L. (Chenopodiaceae) exudes toxic levels of oxalic acid from roots (Caussanal and Kunesch 1979). Leachates from the leaves of *Chrysanthemum* (Turkey 1966) and *Camelina alyssum* (Burst.) (Brassicaceae) (Grummer and Beyer 1960) are toxic. After plant death, toxins may be released directly by leaching of litter or by microbial degradation of the plant tissues. Production of toxins by microbial action from the residues of *Sorghum halepense* (L). Pers. (Poaceae)and *Prunus* spp. (Rosaceae) has been reported (Abdul-Wahab and Rice 1967).

Plants vary in their production of allelochemicals depending upon the environment in which they are grown and the stresses that they encounter. Long days seem to enhance the production of phenolics and terpenes in a variety of plants (Rice 1974). Deficiencies of Ca, Mg, N, P, K, S and Bo have been reported to enhance the concentration of chlorogenic acid and scopolin in a variety of plants (Rice 1974). In sunflower, the combination of drought stress and nitrogen deficiency produced approximately a 15-fold increase in chlorogenic and isochlorogenic acids (del Moral 1972). The implications from these findings is that inhibitor production can be enhanced by exerting the proper stress on plants (Putnam 1985).

Allelochemical Mode of Action

The mode of action of herbicides (natural and synthetic) has received attention. There is evidence that allelochemicals can alter the rate of ion uptake by plants. Salicylic and ferulic acids inhibited K^+ uptake by oats at lower pH (Harper and Balke 1981). Coumarin has been shown to block mitosis is onion roots (Cornman 1946). Volatile terpenes from *Salvia leucophylla* (L.) are potent inhibitors of mitosis in cucumber seedlings (Muller 1965). Several allelochemicals have been shown to activate indole acetic acid (IAA) oxidase and thereby inhibit extension growth. Monohydroxy benezoic acids are stimulatory to IAA oxidase (Lee and Skoog 1965). Scopoletin causes a reduction in photosynthesis in tobacco, sunflower and pigweed (Einhellig *et al.* 1970). Several compounds isolated from soils inhibit respiration in roots. Juglone causes 90% reduction in the respiration of corn roots after one hour exposure (Koeppe 1972). Volatile terpenes from *Salvia* spp. reduce respiration in mitochondria isolated from oats and cucumber (Muller *et al.* 1969). Root secretions of crops inhibit catalase and peroxidase activities in red root pig weed (Dzubendo and Petrenko 1971). Tannins inhibit the activity of peroxidase, catalase, cellulase, amylase and polygalacturonase (Rice 1974). Inhibition of key enzymes necessary for seed germination could provide an effective herbicidal mode of action. Germination of weed seed is inhibited by a variety of secondary compounds (Lehle and Putnam 1983, Williams and Hoagland 1982, Evanari 1949).

Application of Allelopathy

Allelopathy has great potential to be used as a method of weed biological control. One approach in weed management is to screen for allelopathic types in crop germplasm collections. The cultivars that are grown commercially may not have the required allelopathic potential because the selection of these plants for other desired characteristics could have resulted in the elimination of the allelopathic attributes. The allelopathic attributes are more likely to occur in crop predecessors that have developed in phytocoenosis and evolved in the presence of allelopathic and competitive influences from other species (Putnam 1985). Superior weed suppressing types have been reported by researchers. They include cucumber (Putnam and Duke 1974), oats (Fay and Duke 1977), sunflower (Leather 1983) and soybean (Rose *et al.* 1983).

One more approach to weed management is to select allelopathy and to transfer this character into cultivars by either conventional breeding or genetic transfer. Crop cultivars may be developed that would release kolines or other natural herbicides to provide satisfactory weed control (Putnam 1985). Production of kolines by many forest trees and the influence of kolines on the species' density and distribution have been reported (Rice 1974).

Another approach is to utilise companion plants that are selectively allelopathic to weeds but do not interfere with the growth of crops (Grant and Sallans 1964). A variety of agroecosystem weeds has been completely suppressed by rye, *Secale cereale* L. (Poaceae) and its residues (Putnam and De Frank 1983; Barnes and Putnam 1983).

Allelopathic plants could be used as rotational crops in a cropping sequence to provide toxicity to weeds by exudation or upon decay of their residues. Residues of sorghum, wheat, barley and oats can suppress certain weeds (Putnam *et al.* 1983).

Allelopathic plants provide a tactic for weed management in aquatic systems. *Eleocharis coloradoencis* (Arnes.) (Cyperaceae) has been reported to displace *Potamogeton* (Potamogetonacaea) and *Elodea* (Hydrocharitaceae) in canals (Yeo and Fisher 1970). The allelopathic potential of *Eleocharis* is attributed to the phytotoxic compound dihydroactinidiolide (DAD) isolated from it (Frank & Dechoretz 1980).

Research should be directed towards evolving methods to increase weed seed decay. The selection of a microorganism able to destroy weed seed is one posssible approach in weed biological control (Putnam 1985).

Conclusion

It may be practical in the future to capitalise on allelopathy to combat weed problem in agroecosystems (Putnam 1985) and in aquatic ecosystems (Szezenpanski 1977).

The present trend to "integrated control" aims at adopting all the available methods of control. Integration of allelopathic herbicides with other weed biological control tactics seems to have a great potential for solving weed problems. Allelopathic herbicides seem to have an exciting prospect as a new approach to biological weed control.

References

Abdul-Wahab, A.B. and E.L. Rice 1967. Plant inhibition by Johnson grass and its possible significance in old-field succession. *Bulletin of the Torrey Botany Club* **94**:486.

Altieri, M.A. and J.D. Doll. 1978. The potential of allelopathy as a tool for weed management in crop fields. *Pest Articles and News Summaries* **24**:495-9.

Barnes, J.P. and A.R. Putnam. 1983. Rye residues contribute weed suppression in no-tillage cropping systems. *Journal of Chemical Ecology* **9**:1045-50.

Bell, D.T. and D.E. Koeppe. 1972. Noncompetitive effects of giant foxtail on the growth of corn. *Agronomy Journal* **64**:321-2.

Bennett, F.D. 1968. Insects and mites as potential controlling agents of water hyacinth (*E. crassipes*). *Proceedings of the British Weed Control Conference* **9(2)**:832-9.

Borner, H. 1959. The apple replant problem. I. The excretion of phlorizen from apple root residues. *Contributions of the Boyce Thompson Institute* **20**:39-40.

Caussanel, J.P. and G. Kunesch. 1979. Qualitative and quantitative study of growth inhibitors in root exudates of common lambsquarters (*Chenopodium album* L.) at the beginning of its flowering on hydroponic culture and under controlled conditions. *Z. Pflanzenphysiol.* **93**:229-34.

Chandramohan, D., D. Purushothaman and R. Kothandaraman. 1973. Soil phenolics and plant growth inhibition. *Plant and Soil* **39**:308-405.

Charudattan, R., D.E. McKinney, H.A. Cordo, and A. Silveria-Guido. 1976. *Uredo eichhorniae*, a potential biocontrol agent for water hyacinth. *Proceedings of the IV International Symposium on Biological Control of*

Weeds, 30 August-2 September 1976, Gainesville, Florida. Freeman, T.J. (ed.). University of Florida, Institute of Food and Agricultural Science, Gainesville, pp 210-3.

Charudattan, R. 1982. *Biological Control of Weeds with Plant Pathogens.* John Wiley, New York.

Conway, K.E. 1976. Evaluation of *Cercospora rodmanii* as a biological control of water hyacinths. *Phytopathology* **66:**914-9.

Conway, K.E. and T.E. Freeman. 1976. The potential of *Cercospora rodmanii* as a biological control for water hyacinths. *Proceedings of the IV International Symposium on Biological Control of Weeds,* 30 August-2 September 1976, Gainesville, Florida. Freeman, T.J. (ed.). University of Florida, Institute of Food and Agricultural Science, Gainesville, pp 207-9.

Cornman, I. 1946. Alteration of mitosis by coumarin and parascorbic acid. *American Journal of Botany* **33:**217.

Cullen, J.M. 1976. Evaluating the success of the programme for the biological control of *Chondrilla juncea* L. *Proceedings of the IV International Symposium on Biological Control of Weeds,* 30 August-2 September 1976, Gainesville, Florida. Freeman, T.J. (ed.). University of Florida, Institute of Food and Agricultural Science, Gainesville, pp 117-21.

Daniel, J.T., G.E. Templeton, R.J. Smith Jr. and W.T. Fox. 1973. Biological control of Northern joint vetch in rice with an endemic fungal disease. *Weed Science* **21:**303-8.

Daniel, J.T., G.E. Templeton and R.J. Smith Jr. 1974. Control of *Aeschynomene* sp. with *Colletotrichum gloeosporioides* Penz. f. sp. *aeschynomene. United States Patent No.* **3, 849, 104.**

Davis, R.F. 1928. The toxic principle of *Juglans nigra* as identified with synthetic juglone and its toxic effects on tomato and alfalfa plants. *American Journal of Botany* **15:**620-5.

del Moral, R. 1972. On the variability of chlorogenic acid concentration. *Oecologia* **9:**289-91.

del Moral, R. and C.H. Muller. 1970. The allelopathic effects of *Eucalyptus canaldulensis. American Midland Naturalist* **83:**254-60.

Dzubenko, N.N. and N.I. Petrenko. 1971. On biochemical interaction of cultivated plants and weeds. *In: Biochemical and Physiological Bases for Plant Interactions in Phytocenosis.* Grodzinsky, A.M. (ed.). Naukova Dumka, Kiev, 2.

Einhellig, F.A., E.L. Rice, P.C. Risser and S.H. Wender. 1970. Effects of scopoletin on growth, CO_2 exchange rates, and concentrations of scopolin, and chlorogenic acid in tobacco, sunflower and pigweed. *Bulletin of the Torrey Botany Club* **97:**22-30.

Evanari, M. 1949. Germination inhibitors. *Botanical Review* **15:**153-9.

Fay, P.K. and W.B. Duke. 1977. An assessment of allelopathic potential in *Avena* germplasm. *Weed Science* **25:**224-5.

Frank, P.A. and N. Dechoretz 1980. Allelopathy in dwarf sipkerush (*Eleocharis coloradoensis*). *Weed Science* **28:**499-507.

Freeman, T.J., R. Charudattan and K.E. Conway. 1976. Status of the use of plant pathogens in the biological control of weeds. *Proceedings of the IV International Symposium on Biological Control of Weeds,* 30 August-2 September 1976, Gainesville, Florida. Freeman, T.J. (ed.). University of Florida, Institute of Food and Agricultural Science, Gainesville, pp 201.

French, D.W. and D.B. Schroeder. 1969. Oak wilt fungus *Ceratocystis fagacearum,* as a selective silvicide. *Forest Science* **15:**198-201.

Grant, E.A. and E.G. Sallans. 1964. Influence of plant extracts on germination and growth of eight forage species. *Journal of the British Grasslands Society* **19:**191-5.

Gray, R. and J. Bonner. 1948. An inhibitor of plant growth from the leave of *Encelia farinosa. American Journal of Botany* **35:**52-5.

Grummer, G. and H. Beyer. 1960. The influence exerted by species of *Camelina* on flax by means of toxic substances. *In: The Biology of Weeds.* Blackwell, Oxford, pp. 153-7.

Gupta, O.P. and P.S. Lamba. 1978. *Modern Weed Science.* Today and Tomorrows Printers and Publishers, New Delhi.

Harborne, J.B. 1972. *Phytochemical Ecology.* Academic Press, London.

Harper, J.R. and N.E. Balke. 1981. Characterisation of inhibition of K^+ absorption in oat roots by salicylic acid. *Plant Physiology* **68:**1349-57.

Horsley, S.D. 1977. Allelopathic interference among plants. II. Physiological modes of action. *Proceedings of the Fourth North American Forest Biology Workshop.* Wilcox, H.E. and A.F. Hamer (eds.). College of Environmental Science and Forestry, Syracuse, New York.

Huffaker, C.B. 1964. Fundamentals of biological weed control. *In: Biological Control of Insect Pests and Weeds.* DeBach, P. (ed.). Chapman and Hall, London.

Kaiser J. and K.N. Jyothi. 1990. Biological control of *Eichhornia crassipes* (Mart.) Solms. *Indian Review of Life Science* **10:**83-6.

Kaiser J., V. Vinay Kumar and G. Thiagarajan. 1982. Biology and Biocontrol agents of *Eichhornia crassipes. Proceedings of the Indian Academy of Parasitology* **3:**80-2.

Koeppe, D.E. 1972. Some reactions of isolated corn mitochondria influenced by juglone. *Physiologia Plantarum* **27:**89-91.

Leather, G.R. 1983. Sunflowers (*Helianthus annus*) are allelopathic to weeds. *Weed Science* **31:**37-42.

Lee, T.T. and F. Skoog. 1965. Effects of hydroxybenzoic acids on indole acetic acid inactivation by tobacco callus extracts. *Physiologia Plantarum* **18:**577-80.

Lehle, F.R. and A.R. Putnam. 1983. Allelopathic potential of sorghum (*Sorghum bicolor*): Isolation of seed germination inhibitors. *Journal of Chemical Ecology* **9:**1223-5.

Lockerman, R. and A.R. Putnam. 1978. Field evaluation of allelopathic cucumbers as an aid to weed control. *Weed Science* **27:**54-9.

Muller, C.H. 1965. Inhibitory terpenes volatilised from *Salvia* shrubs. *Bulletin of the Torrey Botany Club* **92:**38-41.

Muller, C.H. 1969. Allelopathy as a factor in ecological process. *Vegetatio* **18:**348-9.

Muller, C.H., W.H. Muller and B.L. Haines. 1964. Volatile growth inhibitors produced by shrubs. *Science* **143:**471-8.

Muller, W.H., D. Lorber, B. Haley and K. Johnson. 1969. Volatile growth inhibitors produced by *Salvia leucophylla*: Effect of oxygen uptake by mitochondrial suppressions. *Bulletin of the Torrey Botany Club* **96:**89.

Nag Raj, T.R. and K.M. Ponnappa. 1970. Blight of water hyacinth caused by *Alternaria eichhorniae* sp. nov. *Transactions of the British Mycological Society* **55:**123.

Oehrens, E. 1977. Biological control of the black berry through the introduction of rust, *Phragmidium violaceum*, in Chile. *Plant Protection Bulletin* **25:**26.

Ohr, H.D. 1974. Plant disease impact on weeds in the natural ecosystem. *Proceedings of the American Phytopathological Society* **1:**181-9.

Putnam, A.R. 1985. Weed allelopathy. *In*: *Weed Physiology Vol. 1: Reproduction and Physiology.* Duke, S.O. (ed.). CRC Press, Florida.

Putnam, A.R. and J. De Frank. 1983. Use of phytotoxic plant residues for selective weed control. *Crop Protection* **2:**173-80.

Putnam, A.R. and W.B. Duke. 1974. Biological suppression of weeds: Evidence of allelopathy in accessions of cucumber *Science* **185:**370-5.

Putnam, A.R. and W.B. Duke. 1978. Allelopathy in agroecosystems. *Annual Review of Phytopathology* **16:**431-9.

Putnam, A.R., J. De Frank and J.P. Barnes. 1983. Exploitation of allelopathy for weed control in annual and perennial cropping systems. *Journal of Chemical Ecology* **9:**1001-7.

Rice, E.L. 1974. *Allelopathy*. Academic Press, New York.

Ridings, W.H., D.J. Mitchell, C.L. Shoulties and N.E. El-Ghel. 1976. Biological control of milk weed Vine in Florida citrus groves with a pathotype of *Phytophthora citrophora*. *Proceedings of the IV International Symposium on Biological Control of Weeds*, 30 August-2 September 1976, Gainesville, Florida. Freeman, T.J. (ed.). University of Florida, Institute of Food and Agricultural Science, Gainesville, pp. 224-40.

Rose, S.J., O.C. Burnisde, J.E. Specht, J.H. Williams and B.A. Swisher. 1983. Competition and allelopathy of soybean (*Glycine max* [L.] Merr.) cultivars to weeds. *Weed Science Society of America* (Abstract*)* **16:**24-31.

Sakhuja, S. and S. Kaur. 1990. Mycoherbicides. *The Botanica* **40:**74-8.

Szczenpanski, A.J. 1977. Allelopathy as a means of biological control of water weeds. *Aquatic Botany* **3:**193-4.

TeBeest, D.O., G.E. Templeton and R.J. Smith Jr. 1978. Temperature and moisture requirements for development of anthracnose of northern jointvetch. *Phytopathology* **68:**389-92.

Templeton, G.E., D.O. TeBeest and R.J. Smith Jr. 1976. Development of an endemic fungal pathogen as a mycoherbicide for biocontrol of northern joint vetch in rice. *Proceedings of the IV International Symposium on Biological Control of Weeds*, 30 August-2 September 1976, Gainesville, Florida. Freeman, T.J. (ed.). University of Florida, Institute of Food and Agricultural Science, Gainesville, pp 214-20.

Templeton, G.E., D.O. TeBeest and R.J. Smith Jr. 1979. Biological weed control with mycoherbicides. *Annual Review of Phytopathology* **17:**301-5.

Thakur, C. 1984. *Weed Science.* Metropolitan Book Company (P) Ltd, New Delhi.

Trujillo, E.E., F.P. Obrero, 1976. *Cephalosporium* wilt of *Cassia surattensis* in Hawaii. *Proceedings of the IV International Symposium on Biological Control of Weeds*, 30 August-2 September 1976, Gainesville, Florida. Freeman, T.J. (ed.). University of Florida, Institute of Food and Agricultural Science, Gainesville, pp 217-20.

Turkey, H.B. Jr. 1966. Leaching of metabolites from above ground plant parts and its implications. *Bulletin of the Torrey Botany Club* **93:**385-6.

Williams, R.D. and R.E. Hoagland. 1982. The effects of naturally occurring phenolic compounds on seed germination. *Weed Science* **30:**205-9.

Whittaker, R.H. 1970. The biochemical ecology of higher plants. *In*: *Chemical Ecology*. E. Sondheimer and T.B. Simeone (eds.). Academic Press, New York.

Whittaker, R.H. and P.P. Feeny. 1971. Allelochemics: chemical interaction between species. *Science* **171:**757-8.

Yeo, R.R. and T.W. Fisher. 1970. *Progress and Potential for Biological Weed Control.* Weed Science Society of America, Champaign, Illinois, 688 p.