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INTERACTION BETWEEN HERBICIDES AND NEMATODE DISEASES— A REVIEW

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This review documents reports of herbicides interaction with nematodes of higher plants. Changes in the incidence of plant diseases may result from the application of herbicides through the effect they have on the pathogen, the host or microorganisms in the environment. Herbicides belonging to different chemical groups were found to increase or decrease nematode diseases of many plants. The mechanism involved in this phenomenon are discussed and examples are given. The control of disease, either by combined application of herbicides and nematicides or by using different methods of application, are discussed.

Keywords : Herbicides; Nematode disease; Mechanism.

Introduction

Use of herbicides in addition to fertilizers and new high yielding crop varities have increased food production all over world. During chemical revolution in last decade, more than 150 herbicides are used as arsenal to kill undesirable plants and every year new improved herbicides are added to the existing list. Knowledge in the field of chemistry and biology and familiarity with reaction of plants to phytotoxic agents is essential before recommending chemical on large scale. Effect of herbicides vary from species to species and they may affect the entire plant or only a particular organ. Their common action includes growth inhibition, foliar chlorosis, necrosis and reduccd cuticle formation as well as organelle and membrane modifications.

In addition to specific function of these herbicides, they have a wide range of effect on pests, soil properties and microenvironment of the plant. These 'nontarget activity' of these compounds received great attention during last decade, where these compounds either alone or in combination with other pesticides are used to control pathogens. Information on the effect of herbicides on plant disease have been published by Altman and Campbell (1977); Bollen (1979); Fletcher (1960); Franklin (1970) ; Katan and Eshel (1973); Kavanagh (1969, 1974); Papavizas and Lewis (1979) ; Putnam and Pennes (1974) ; Rodriguez-Kabana and Curl (1980) and Van deer Zeep (1970). However, there is no separate and informative review on the effect of herbicides in relation to nematode diseases, where much information had been published during the last few years. In this review, information is provided in three separate headings: Effect of herbicide alone, herbicide plus growth regulators and herbicide plus nematicide on their effect on nematode infested plants.

Herbicide

Herbicide may affect plant parasitic nematodes directly by contact or indirectly by causing physiological changes in their food plants, by eliminating food plants or by making the plants toxic (Franklin, 1970). Many reports have been published showing effect of these compounds on the development, growth and reproduction of nematode in various plant species (Kochba and Samish, 1971; Peacock, 1963; Webster, 1967). Chemical names of herbicides (Table I) and their mode of action on different host plants are mentioned (Table 2).

Direct effect of herbicide on nematode—There is very little information on the direct effect of herbicides on nematodes. Soaking stem nematodes for 5 hrs in 2,4–D at concentration up to 0.5 mg/100 ml, had no effect on their ability to reproduce, however, ten times this concentration inhibited reproduction, although movement appeared unaffected (Webster and Lowe, 1966). When root-knot nematode larvae were soaked in 10% maleic hydrazide for up to 48 hrs, only about half of them were subsequently able to enter host roots, but those that did so, developed normally (Davide and Triantaphyllou, 1968).

Herbicide aminotriazole was found to be active against *Acrobloides buetshlii*—with 50% mortality at a concentration of 184 ppm and almost total mortality in 600 ppm (Frey, 1979). Reduction in *Meloidogyne incognita* larval emergence was noted in eggs treated with herbicide EPTC as compared to TOKE–25 and Lasso (Mathur *et al.*, 1980).

Effect of herbicides on nematode infested plants–Many herbicides were Used alone to study their effect on nematode infested plants. After 8 months of spray of 2, - on nematode susceptible and resistant oats infested with *Ditylenchus dipsaci*, revealed greater number of nematode population in the sprayed than in unsprayed plants (Webster, 1967). Increase in population with 2, 4–D in the case of *Ditylenchus dipsaci*, *Pratylenchus penetrans* and *P. zeae* (Krusberg and Blickenstaff, 1964) and in *Aphelenchoides ritzemabosi* (Webster and Lowe, 1966) was recorded in tissue culture studies. Blake (1969) pointed out that herbicides that kill bananas infested with rootburrowing nematodes, leave the roots and rhizomes still succulent and able to provide food for the nematodes for many months.

Application of EPTC to tomato reduced populations of the reniform nematode attacking them (Rao and Prasad, 1969, 1972), while 2, 4–D helped in increasing it. Use of paraquat plus linuron to limited weed growth in the tree rows coupled with a permanent cover of creeping red fescue between the rows reported to be an effective way of retarding increases of *Pratylenchus penetrans* numbers in peach orchards (Marks *et al.*, 1973).

Vernolate, applied as a preplant soil treatment to Florunner peanuts did not affect gall density (No. gall/g root fresh wt) of *Meloidogyne arenaria* (Rodriguez–Kabana *et al.*, 1977). However, gall density was increased 16—22% in pots treated with 1—8 mg EPTC /Kg soil and was suppressed 17—25% in response to rates of 12,16 and 20 mg/Kg soil. In another study, influence of herbicides and mono–and multicopping sequences on population densities of nematode species common in corn, cotton, peanut, and soyabean fields in the southeastern United States was observed for 4 years (Johnson *et al.*, 1975) and results showed that the application of herbicide did not significantly affect nematode population densities.

Azides as herbicides—Azides are well known enzyme inhibitors and the herbicidal properties of azides were investigated earlier (Hill *et al.*, 1953 ; Todd and Clayton, 1956). The number of rootknot larvae and ring nematodes in the soil at harvest time of peanut increased significantly with azide concentrations of 10 and 15 lb/acre (Rodringuez–Kabana *et al.*, 1972). Sodium azide applied alone was found somewhat nematicidal, but when applied in combination with carbofuran, reduced the efficacy of the nematicide (Overman, 1973).

Effect of Cycloate on nematode— Cycloate is effective as selective herbicide when it is incorporated into the soil immediately before planting (Thomson, 1976). Cycloate added to *Heterodera schachtii* infested soil enhanced cyst development/g root on *Beta vulgaris* and larvae/g of root in *B. patellaris* and *B. procumbens* at 4, 10 and 16/ug (a. i.) /g of soil respectively (Abivardi and Altman,1978a). Higher concentration of nematode/g root in plants growing in cycloate amended soil may be attributed to factors such as fewer roots available for penetration, possible effects of cycloate on egg hatch, greater attraction of nematodes to roots,and increased susceptibility of roots to larvae penetration (Abivardi and Altman 1978a).Increase in nematode/g root in treated plants may be due to : 1 . delay in maturation of sugarbeet seedlings stressed by cycloate(Wheeler, 1975); 2. the increased penetration of the nematode to the young seedlings (Johnson and Viglierchio, 1969) ; 3 . on release of glucose to soilplant interface by seedlings growing in herbicide–amended soil (Altman, 1972) and on hatch stimulating activity of sugars (Wallace, 1956).

Foliar spray of herbicides– Herbicides were used to break the life cycle of the nematode *Angvina agrostis* by preventing bentgrass *Agrostis tenuis* from flowering for one season. The more effective herbicide were maleic hydrazide (8 & 16 lb/ac), dalapon (5 lb/ac) and aminotriazole (5 & 10 lb/ac) sprayed in solution at 100 US gal/ac. (Apt *et al.*, 1960; Courtney *et al.*, 1962). Chloremequat applied to potato plants inoculated with both *Verticillium dahliae* and potato cyst nematode *(Heterodera rostochiensis)* dimin-

Table 1. Chemical names of some of the herbicides/nematicides mentioned in text.

Common Name	Chemical Name
Alachlor	2–chloro-2' ,6'-diethyl-N- (methoxymethyl) acetanilide
Alar	2, 2, dimethyl hydrazied ammonium succinic acid
Aldicarb	2-methyl-2(methylthio)-propionaldehyde–O–(methyl carbamoyl) oxime
Aminotriazole	3-amino–s–triazole
BAS 083	1, 1-dimethylpiperdinium chloride
Benefin	N–butyl-N-ethyl-a, a, a trifluoro-2, 6-dinitro-p–toluidine
	5–Bromodeoxyuridine
Carbofuran	2,3-dihydro–2,2-dimethyl-7–benzofuranyl methylcarbamate
CCC	2–chloroethyl, trimethyl ammonium chloride
Chlorpropham	isopropyl–m-chlorocarbanilate
Cycloate	S-Ethyl N-ethylthiocyclohexanecarbamate
2, 4–D	(2, 4-dichlorophenoxy) acetic acid
Dalapon	2, 2-dichloropropionic acid
DBCP	1, 2-dibromo–3-chlorpropane
Disulfoton	O, O-diethyl S-(2–(ethytio) ethyl) phosphorodithioate
EPTC	S–ethyl–N, N-dipropylthiocarbamate
Ethoprop	O–ethyl S,S–dipropyl phosphorodithioate
Fensulfothion	O,O-dimethyl O-(U-nitro-m-tolyl) phosphorodithioate
Glyphosate	N-[phosphonomethyl] 1-methoxy-1-methylurea
MBR–(P)	Methyl bromide chloropicrin
MCPB	4-[(4-chloro-O-tolyl) oxy] butyric acid
Metribuzin	4-amino-6-6-butyl-3-(methylthio),1,2,4-triazin-5-(4H)-one
MH	1, 2-dihydro–3,6-pyridazinedione
Oryzalin	3, 5-dinitro-N,N-dipropyl sulfanilamide
Paraquat	1,1 '–dimethyl–4, 4 ' –bipyridiniumion
Phorate	O, O-diethyl S–(ethythio)–methyl phosphorodithioate
TOKE	2, 4–dichlorophenyl, 4–nitrophenyl ether
Trifluralin	a, a, a–trifluoro–2, 6-dinitro–N,N–dipropyl–p-toluidine
Vernolate	S-propyl dipropylthiocarbamate
Vydate	Methyl N' , N'-dimethyl-N- [(methylcarbamoyl) oxy]—1 —thioxamidate

ished infestation by both pathogens (Corbett and Hide, 1969). Chloremequat also greatly decreased the number of stem nematode in oats (Trudgill and Webster, 1967). Foliar application of herbicides EPTC, glyphosate and oryzalin on soybean infested with *M. incognita* modified the root-knot numbers before host phytotoxicity occurs. Dip treatments of tomato roots with oryzalin or 5-bromodeoxyuridine at concentration below 50 μg/ml showed significant reduction in nematode development (Osman and Viglierchio, 1981).

Effect of Combination of Herbicides and Nematode—In some cases a combination of herbicide was found more effective in controlling nematode than either treatment alone. Treatments with the herbicides chlorpropham, DCPA and EPTC alone or in combination with *M. hapla* significantly reduced the growth of both nematode-resistant and susceptible alfalfa (Griffin and Anderson, 1979). Combination of trifluralin soil treatment and *M. hapla* inoculation reduced growth of tomato or alfalfa more than either treatment alone (Griffin and Anderson, 1978).

Oryzalin and BAS 083 reduced root—knot infection in tomato roots when applied respectively as soil drench at 20 ppm and 10,000 ppm (Orum *et al.*, 1979). They explained reduced infectivity of larvae with BAS 083 by the observation that treated plants had fewer lateral roots than did control plants, and hence fewer sites for penetration by the nematode. Reduction in lateral roots also mean that BAS 083 was active in the pericycle of the root, where lateral roots are initiated (Orum *et al.*, 1979).

Herbicide and Growth Regulators

Use of herbicides and plant growth regulators in agriculture is widespread because of their selective phytotoxicity and activity in retarding or promoting growth. But sometimes, their effects are unusual on plants as they may cause a plant to become either more susceptible or resistant to a disease organism (Katan and Eshel, 1972).

Host-Pathogen Response—Poor giant cell development with degenerate female were noted in root-knot infected tobacco plants sprayed with maleic hydrazide 7 days after infestation (Nusbaum, 1958). Increased number of males, reduced galling and giant cell was reported in MH treated plants (Davide and Triantaphyllou, 1968). Small giant cells with fewer nuclei were observed in morphactin treated plants then on control (Orion and Minz, 1971). Oryzalin acted on cotton roots inoculated with *Meloidogyne incognita* through inhibition of giant cell development in root, confined larval penetration to the area just behind root tips and prevent growth and development of nematode. However, herbicide DCPA prevented larval penetration by producing a mechanical barrier to the larvae by thickening the cell walls of the epidermal tissue (Romney *et al.*, 1974).

Increase or decrease in numbers

Table 2. Action of herbicide alone and in combination with nematodes

Herbicide	Nematode	Mode of Action	Result*	Reference
Aminotriazole	*Acrobelvides buetschlii*	Total mortality	+	Frey, 1979
Aldicarb	*H. glycines on soybean*	Increase nematode population	—	Schmitt *et al.*, 1983
Aldicarb + Cycloate	*H. schachtii* on Beta	Reduce growth of sugarbeet	—	Abivardi & Altman, 1978b
Alachlor + Phena-miphos	*H. gtycines*	Increase Juvenile hatch	—	Bostian *et al.*, 1984a
Cycloate	*H. schachtii*	Enhance cyst development on Beet	—	Abivardi & Altman, 1978a
Chloremequat	*H. rostochiensis*	Decrease infestation on potato	+	Corbett & Hide, 1969
Chloremequat	Stem Nematode	Decrease nematode on Oat	+	Trudgill & Webster, 1967
Chloropropham + DCPA + DPTC	*M. hapla*	Reduce the growth of Alfalfa	—	Griffin & Anderson, 1979
2, 4—D	Stem Nematode	Inhibit Reproduction	+	Webster & Lowe, 1966
2, 4—D	*Dityienchus dipsaci*	Increase population on oat	—	Webster, 1967
2, 4—D	*Ditylenchus Pratylenchus Penetrans P, zeae*	Increase Nematode population	—	Krusberg & Blickenstaff, 1964
2, 4—D	*Aphelenchoides ritzemabosi*	Increase in Nematode population	—	Webster & Lowe, 1966

2, 4—D	Reniform Nematode	Increase Nematode population	—	Rao & Prasad, 1969
EPTC	—do—	Decrease Nematode Population	+	Rao & Prasad, 1972
EPTC	*M. arenaria* on Peanut	Gall density increased	—	Rodriguez-Kabana *et al.*, 1977
Vernolate	—do—	No effect on gall density	±	
EPTC	*M. incognita*	Inhibit larval emergence	+	Mathur *et al.*, 1980
EPTC & Vernolate	*M. arenaria*	Gall density reduced at higher rate	+	King *et al.*, 1977
Fensulfothion + Alachlor or Vernolate	*H. glycines* on soybean	Increase in Nematode population	—	Schmitt & Corbin, 1981
Phorate + Alachlor or Metribuzin	—do—	—do—		—do—
Kinetin	Root-knot on tomato	Loss of resistance to nematode	—	Dropkin *et al.*, 1969
MH	Root-knot	Prevent entry in host roots	+	Davide & Triantaphyllou 1968,
MH Dalapon aminotriazole	*Anguina agrostis*	Break life cycle of Nematode	+	Apt *et al.*, 1960, Courtney *et al.*, 1962
MH	Root-knot on tobacco	Poor giant cell (G. C.) development, with degenerate female	+	Nusbaum, 1958

Contd............

Herbicide	Nematode	Mode of Action	Result *	Reference
MH	Root-knot	Increase number of male, reduce galling & G.C.	+	Davide & Triantaphyllou, 1968
MH	Root-knot on tomato	Reduction in number of galls	+	Mjuge & Viglierchio, 1975
Morphactin	Root-knot	Small G.C. with fewer nuclei	+	Orion & Minz, 1971
Oryzalin or 5-bromo deoxy uridine	Root knot on tomato	Reduce nematode development	+	Osman & Viglierchio, 1981
Oryzalin & BAS 083	Root-knot	Reduce infection	+	Orun *et al.*, 1979
Oryzalin	Root knot on cotton	Inhibit G. C. formation & development of nematode	+	Romney *et al.*, 1974
DCPA		Prevent larval penetration by mechanical barrier	+	
Paraquat+Linuron	*Pratylenchus penetrans* in peach	Decrease nematode population	+	Marks *et al.*, 1973
Potassium azide	Root-knot & Ring nematode on Peanut	Increase in no. of nematode	—	Rodriquezkabana *et al.*, 1972
Phenamiphos	*H. glycines*	Less penetration in root	+	Bostian *et al.*, 1984b
Phenamiphos+Alachlor	—do—	More penetration in root	—	
Trifluraln	*M. hapla*	Reduce the growth of alfalafa and tomato	—	Griffin & Anderson, 1979

* Positive (+), Negative (—), No effect (±).

of nematodes was reported when treated with different growth regulators. 2, 4-D sprayed on oats increased the rate at which stem nematode multiplied and made variety Manod, susceptible which is usually resistant (Webster, 1967). *Aphelenchus ritzemabosi* multiplies on lucerne plants but does so faster in lucerne callus induced by 2, 4-D (Webster and Lowe, 1966). Loss of resistance to nematode infection in tomato, when applied with kinetin (Dropkin *et al.*, 1969) and reduction in the number of knots on tomato plants treated with MH (Mjuge and Viglierchio, 1975) was reported.

Herbicide and Nematicide

Little information is available on the effects of pesticide combinations on nematode control.There are reports that a nematicide mixed or used in combination with fugicides and/or herbicides resulted in significant differences in nematode control compared to the ne--maticide alone (Birchfield and Pinckard, 1964; Brodie and Hauser, 1970; Broide *et al.*, 1968; Schmitt and Corbin 1981; Bostian *et al.*, 1984). Both positive and negative findings were reported on the role of herbicides in combination with nematicides,

Negative Effect of Herbicide- It was demonstrated by Johnson *et al.*, (1975) that herbicides were not nematicidal A Combination of cycloate with aldicarb resulted in a significantly reduced growth of both sugarbeet cultivars and *Beta pattellaris* (Abivardi and Altman, 1978b). In North Carolina, treatment with fensulfothion + alachlor or vernolate, phorate + alachlor or metribuzin resulted in greater nematode population densitis than no treatment or treatment with fensulfothion alone or phorate alone (Schmitt and Corbin, 1981). They reported that herbicide used in some treatments were stimulatory, yet appeared to control nematodes in other treatments. Number of *H. glycines* at harvest were greater in plots treated with aldicarb than in those treated with ethoprop or phenamiphos (Schmitt *et al.*, 1983). Increased juvenile hatch of *H. glycines* was observed when treated with phenamiphos (0.5 μg/ml) + alachlor (0.063, 0.125 or 1.0 μg/ml) over that of untreated control in *in vitro* study. Phenamiphos (1.0 μg/ml) alone and in combination with alachlor (1.0 μg /ml) suppressed hatch for 21 days and juvenile survival for more than 21 days.

The application of herbicides, nematicides and inoculant had no significant effect on yield, sound mature kernels or other extract of 'Starr' pea nuts and nematode infestation was low and did not affect yield (Walker *et al.*, 1976). Cotton seedlings under stress from root-knot nematode infestation were susceptible to further injury by the additon of preplant incorporated and preemergence herbicides (Orr, 1974).

Positive effect of herbicides— A preplant incorporated tank mix application of Fumazone 86E nematicide and Treflan herbicide was an effective method for nematode control in soybean (Norris *et al.*, 1974). *Meloidogyne arenaria* root gall density was increased over that in control at lower rates and reduced at higher rates of the herbicides EPTC and Vernolate (King *et al.*1977).Increase growth of cotton seedlings was observed when phorate and disulfoton were applied with trifluralin as compared with trifluralin alone (Arle, 1968).

Little information is available on influence of nematodes and weeds in the production of vagetable crop under the film mulch, trickle irrigation system. Reduced nematode population was observed by soil treatment with an organic phosphate or carbamate nematicide-herbicide-fungicide combination (MHF), DD-MENCS, MBR-P, ethoprop, carbofuran and sodiumazide plus ethoprop or carbofuran. Growth and yield was found greater when nematodes and weeds were controlled (Johnson *et al.*, 1981).Peach tree mortality was reduced to 29% by preplanting plus postplanting applications of DBCP and herbicidal weed control (Wehnut *et al.*, 1980). However, preplanting application of nematicides alone did not effectively reduce tree mortality or increase yield.

The results of the role of fertili zers, plant hormones, herbicides in comparison with nematicides on the activity of citrus nematode population indicated that Vydate, Giberellic acid, Alar, Dowpon-S, superphosphate and Nemacur gave high potency in controlling citrus nematode (Salem *et al* . , 1983). The number of mature soybean cyst nematode recorded from Treflan treated soil were not different from the number of check but the root system was much more deteriorated (Riggs and Oliver, 1982). Increased growth of blueberry in plots treated with nematicides + herbicides was reported to be due to reduction in *Pratylenchus penetrans* and weed control since increased growth was obtained in plots treated only with herbicides (Elliott *et at* . , 1982) . A detailed four-year experiment to study the effects of a nematicide (ethoprop) and various herbicides vs cultivation on nematode population densities and the effects of nematodes on yields of crops in intensive cropping system in the southeastern coastal plain of the United States was performed (Johanson *et al.*, 1983). Herbicides frequently increased populations of *Pratylenchus* spp. on corn and *Macroposthonia ornata* on peanuts and corn and decreased populations of *Meloidogyne* spp. on corn; *Paratrichodorus minor*, on corn, soybeans and peanuts.

Different herbicidal behaviour were reported on nematodes. Myers (1973) found that organic phosohates and organic carbamates affected nematode reproduction rather than viability. Concentration of aldicarb (O.OI mg/ml in sand column) disrupted the male sensory system of *Heterodera schachtii* so that it could not find females (Hough and Thomason, 1975). Application of vernolate, trifluralin or metribuzin with aldicarb improved the nematicide effectiveness by reducing cyst production and nematode fecundity on soybean infected by *H. glycines* (Kraus *et al.*, 1982).

In general, following major herbicidal effects lead to decreased in disease: (i) direct toxic effect on parasite; (ii) decreased in rate of hatching; (iii) inhibition of giant cell development; (iv) prevention of laval penetration by producing a mechanical barrier to the juvenile; (v) by reducing rate of reproduction.

Increased attack of pathogen by herbicide alone or in combination may be due to : (i) increase in hatching and reproduction of pathogen; (ii) reduction of microflora competing with potential pathogen; (iii) decrease in host defence to the pest.

However, additional studies are needed to understand complex mechanisms going on in soil as well as to show overall effects of these intricate interactions in nematode protection programs.

Conclusion

Worldwide increase in the use of herbicide for more agriculture production has diverted attention of scientist to find out their applicability in large scale. More information is needed to solve mechanism of action and intricate interaction between host-pathogens–herbicide in the complex soil system. Many pesticides were found toxic to mammals, so great care is necessary before introducing new herbicide in market. The possible side effects of herbicides must be explored, explained and eveluated. It is found that herbicide changed the metabolism of the host, their susceptibility and defence mechanism, which lead to crop plant being more susceptible.

Use of herbicide in combination with other pesticides will be an answer to control many pests at the same time and cooperative efforts of various specialists is necessary in integrated pest management program. Developing countries of the world are not using these pesticides because of their high cost, where yield of crop plants is reduced by 15—40% by pest disease and weeds. Cheap chemicals with easy way of applications will help farmers of developing countries to use these pesticides. Mixing of herbicides with other chemicals must be done with care to prevent crop injury. Sometimes different combination of organic compounds applied to a crop acts in an unexpected manner. More research is essential to understand mechanism of interactions of these chemicals with host-pathogen and soil.

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