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Effects of Pesticides (Herbicides) on Soil Microbial Biomass - A Review

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Abstract: There are different factors that affect soil microbial biomass, including: soil factors (such as soil physical and chemical properties), soil environmental factors (such as temperature, moisture, pH etc.), and soil management factors (such as use of chemical fertilizers, heavy metals, pesticides, addition of organic matter, cultivation and crop rotation, seasonal variation, tillage, land use etc.). This review is mainly focusing on the pesticides particularly herbicides as a factor affecting the microbial biomass in different soils. The influence of herbicides on microbial biomass in different soils under different conditions has been reviewed. Herbicides have various effects associated with the type of herbicides, the concentration of the herbicides, the type of soils, and the conditions of the experiment (temperature, moisture, and the time of incubation etc.). The significance of these effects has been discussed.

Key words: Herbicides, Microbial biomass, Soils

Introduction

Herbicides: Chemicals for crop protection and pest control known collectively as pesticides are being increasingly used to ensure the production of adequate supplies of food, fiber, and protection of human and livestock health. However, the use of pesticides is not free from problems. Pesticide residues may constitute a significant source of contamination of air, water, soil and food, which could become a threat to the continued existence of many plant and animal communities of the ecosystem (Khan, 1980).

Herbicides are one of the major groups of pesticides, which provide a tool which man can use to promote and sustain his preferred status on earth in a number of ways. They contribute to the increased and economical production of plant and animal products, to minimize human toil in agricultural production, and to the positive management of our environment for the maximum benefit mankind. Weeds have been a persistent problem in rice since the beginning of settled agriculture. For Asia as a whole, weeds cause an estimated 10-15% reduction in rice yields-equivalent to about 50 million tons of rough rice annually (Pingali and Roger, 1995).

In 1932, people discovered selective organic herbicide, used it as a contact herbicide for the control of broad-leaf weeds in cereals. In the beginning of 40's, chemist synthesizes 2,4-D it has the selective biological action and its salts and esters are systemic herbicides. After 50 age, most organic compounds such as triazines, carbamates, thiocarbamates, ureas have been used as herbicide. In China, herbicides were first introduced in the mid-1960s and are now used on 30-40% of total rice area (Naylor, 1996).

Asia now accounts for a vast majority of the global rice herbicide market. Japan alone accounts for more than 50% of the value of all herbicides sold for rice production (Shibayama, 1996). Other countries in Asia also are beginning to buy larger amounts of herbicides and more expensive products as their economies grow. Taken together, the Asian rice economies excluding Japan bought almost US $ 300 million of herbicides in 1993, more than twice the amount sold in the United States, and almost five times the amount currently sold in Europe (Naylor, 1996).

Pesticide persistence in the soil: Regardless of the method of application, either as direct applications, from fall-out from aerial spraying, in rain or dust or from plant or animal remains, large amounts of pesticides ultimately reach the soil. As a result, world soils are accumulating ever increasing amounts of residues of a wide variety of pesticides which then move into the bodies of invertebrates, pall into air or water, are absorbed by plants, or are broken down into other products. The presence of pesticides in the soil must therefore continue to be of major interest to environmental scientists (Edwards, 1973; Khan, 1980).

The fate of pesticides applied in agricultural ecosystems is governed by the transfer and degradation processes and their interactions. Transfer is a physical process in which the pesticide molecules remain intact; it includes sorption-desorption, runoff, percolation, volatilization and absorption by crop plants or animals. Degradation is a chemical process in which pesticide molecules are split; it includes photodecomposition, microbiological decomposition, chemical decomposition, and plant detoxication. Transfer and decomposition determine pesticide persistence or retention, its efficacy for pest control, as well as its potential for contamination of the soil and water resources.

Pesticide degradation in ricefields is accelerated by the reducing conditions caused by submersion and by the temperature and pH ranges that favor microbial activity (Ponnamperuma, 1972). As a result, pesticides often persist longer in nonflooded soils then they do in flooded soils.

Microbial degradation is one of the main factors that affect herbicide persistence in flooded soils. Its importance varies quite broadly, depending upon the herbicide formulation, the mode of application, and the environmental conditions.

Some pesticides, such as methyl bromide, may disappear within 2 to 4 days. Eptam disappears in 3 to 10 weeks, while others such as BHC (Benzene hexachloride) and chlordane may remain for a year or more. Many herbicides that persist from one season to the next can injure sensitive plants. The triazine herbicides (e.g., atrazine, simazine) applied as pre-emergent herbicides for selective weed control in corn, sometimes persist and injure sensitive seedling crops the next year (Sethunathan and Siddaramapa, 1978).

Toxic impacts also are not instantaneous. The more persistent a chemical (the longer its concentration remains high), the greater the risk of an adverse environmental impact. Conversely, no matter how persistent a chemical, eventually there will be a concentration so low that no effect can be observed. This means that detection of a herbicide in an environment does not necessarily infer that it will have a toxic effect on non-target organisms. Herbicide concentrations in rice-field floodwater normally are in a low parts-per-million range, declining rapidly to nontoxic levels.

Some persistent pesticides may accumulate in the soil from repeated application. Volatilization, leaching from the soil and degradation by soil microorganisms may account for loss of a major part of some pesticides that disappear rapidly. The longer a pesticide persists in the soil, the greater the probability that several processes will become involved in its inactivation a disappearance.

Microbial biomass: It is generally recognized that the microbial biomass is the eye of the needle through which all organic matters that enter the soil must pass (Jenkinson, 1988). Although the soil microbial biomass represents only a small fraction of the total amount of soil C, N, P and S, it has a relatively rapid turnover (Amato and Ladd, 1980). Thus the soil microbial biomass is considered an active nutrient pool to plants. In soil-microorganism-plant system, microbes like bacteria, fungi, algae, protozoa, and some nematodes play a vital role in maintaining the soil productivity. In soil, they fix atmospheric nitrogen, decompose organic matter, and perform other biochemical transformations like ammunification, nitrification etc., responsible for the release of plant nutrients during decay of plant and animal residues (Alexander, 1977; Apsimon *et al.*, 1990). They also improve physical properties such as structure, porosity, aeration, and water infiltration by forming and stabilizing soil aggregates (Tisdall and Oades, 1982; Gupta and Germida, 1988; Dalton, 1991; Lal, 1991). Thus anything that disrupts microbial activity in soils, could be expected to affect the long-term soil productivity and would have serious consequences.

Microorganisms affect the availability of nutrients in several ways (Alexander, 1977).

Through release of elements during decay of plant and animal residues. Through immobilization of elements into microbial tissue. Through synthesis of biochemical chelating agents that immobilize insoluble forms of the micro-nutrients. By oxidation of a trace element (Fe, Mn) into a less available form. By reduction of the oxidized form of an element (e.g., Fe^{3+} to Fe^{2+} in an O_2- deficient environment). Through indirect transformations resulting from pH or oxidation-reduction potential changes.

The effect of Pesticides (herbicides) on soil microbial biomass in different soils: Pesticide use has increased tremendously during the past 30 years; current estimates of the total quantity applied annually in the world exceed $4x10^9$lb. Approximately one –half of this amount is used in the quest for increased productivity of agricultural crops (Bradley, 1980).

Pesticides are widely used throughout the world to control fungi and insects that destroy crop plants and their products. However, these agrochemicals also destroy a wide variety of beneficial non-target microorganisms, which are known to contribute significantly to improve crop productivity (Venkataaman, 1972; Roger and Kulasooriya, 1980)

Herbicides and pesticides affect various soil microbial processes (Johnen and Drew, 1977; Ross, 1974; Wainwright, 1978), inhibit decomposition (Pugh and Williams, 1971; Grossbard and Wingfield, 1978) and, depending upon type and rate of application, can alter the biomass quantitatively and qualitatively in both the short and long-term (Anderson and Armstrong, 1981). Short-term effects connected with use of fertilizers or pesticides are generally related to disturbances of chemical and biological balance in soil. Pesticide use is known to selectively suppress activity of microorganisms responsible for N2-fixation and nitrification for 4 to 12 wk in soil (Bollen, 1961; Chandra, 1964). Use of chemical fertilizers and pesticides at recommended application rates, however, has few direct long-term effects on microbial populations and their activity (Wainwrigt, 1978; Biederbeck *et al.*, 1987). Pesticide decomposition is frequently faster in soils high in organic matter, presumably because of more vigorous microbial activity (Greaves *et al.*, 1976).

There are several reports on the toxicity of a variety of pesticides to nitrogen-fixing bacteria of rice fields (Singh, 1973; Kar and Singh, 1978; Adhikary, 1989; Das and Adhikary, 1996). The use of synthetic chemical fertilizers and pesticides is thought harmful to microorganisms and other life forms and is avoided (Wolf, 1977). Pesticide decomposition is frequently faster in soils high in organic matter, presumably because of more vigorous microbial activity. Use of pesticides can reduce total microbial populations in soil (Greaves *et al.*, 1976), which some researchers attribute to reduced input of organic residues resulting from weed control (Wainwright, 1978).

Fraser *et al.* (1988) conducted a field study to evaluate microbial populations and their activities under organic and conventional farm management and they observed that no significant differences were found in measured biological properties due to insecticide or herbicide at field application rates. They also noticed that application of insecticide or herbicide in conjunction with fertilizer had little direct measurable effect on soil microbial activity. Xu and Zhang (1997) studied the effects of methamidophos, a widely used cotton pest control insecticide, applied at doses of 0, 0.5, 2.5, 5 and 10 ug/g soil on soil microbial activity. They reported that growth of bacteria, actinomycetes and azotobacter was inhibited, whereas fungi growth was stimulated. They also stated that, in general, soil respiration was stimulated, but it showed a complex trend and the effects of methamidophos were stronger, and lasted longer, as the dose increased.

Das and Adhikary (1996) found that the application of Sevin, Rogor and Hildan, commercial grade pesticide, at the recommended levels (4 kg/ha for Sevin and 1.0 L/ha for Rogor and Hildan) might not affect significantly the growth of beneficial soil organisms. However, an increase in the concentration of the pesticides above the recommended levels may adversely affect microbial growth. Numerous studies on the effects of pesticides on microorganisms have not revealed any long-term harmful effects on numbers, composition and activities of microorganisms at least at normal field rates of application (Johnen and Frew, 1977).

Changes in microbial number and activities in two non-flooded soil, treated with bensulfuron-methyl at 16 and 160 μg/kg were studied after 1 and 4 weeks of incubation under laboratory conditions. The data suggests that concentrations greater than those present under normal agricultural practice can alter some aspects of the structure and activity of the soil microbial community (Gigliotti, *et al.*, 1998). Tu (1994) reported that the pesticide effects had no consistent pattern with length of incubation. No inhibition was observed after 3 weeks incubations. He suggested that the nitrifying organisms recover after 3 weeks and nitrification proceeds as normal.

Marked reduction in biomass was observed from BHC applied at 100 or 1000 times the usual rate. At high rates of 2,4-D or glyphosate (20 and 60g/kg soil, respectively) the microbial population declined immediately after application and showed signs of a brief proliferation at 5 days after application, followed by a slow increase from day 16 onwards for 2,4-D and a decreasing trend for glyphosate (Anan-Eva *et al.*, 1986).

Anderson *et al.* (1992) concluded that, when used as directed, none of the pesticide tested should have negative or ecological unacceptable effects on C or N mineralization in soils.

Much of the research carried out on the effect of Herbicides on microorganisms was focused on microbial biomass in soils. In a review, (Nowak, 1984) showed a negative correlation between herbicide dose and microbial biomass which became more marked as temp. and moisture conditions became unfavourable. (Tyuryukanova *et al.*, 1987) reported that herbicides decreased microbial biomass in soil. Also (Santruckova and Vrany, 1989) found that microbial activity showed seasonal variations. (Schonborn and Dumpert, 1990) experimented with pentachlorophenol and 2,4,5-trichlorophenoxyacetic acid and observe that microbial biomass, (mainly fungi), decreased with increasing pesticide dose, as did the respiration rate.

Also in tilled field plots Wardle and Parkinson (1991, 1992) applied two post-emergence herbicides (glyphosate and 2,4-D) at field application rate and found that these chemicals affect certain variables associated with microbial biomass. But, Glyphosate did

Table 1: Effect of Herbicides on microbial biomass in different soils.

Herbicides	Concentration	Soil type	Effect	Reference
2,4-D Glyphosate	20 g/kg soil 60 g/kg soil	Grey forest ,Alluvial,and Podzolic soil	Microbial population declined immediately after application and showed signs of a brief proliferation at 5 days after application.	Anan'eva *et al.*, 1986.
Burex + Nortron Burex + Ronit	4kg + 10 litres /ha 4kg + 5 litres /ha	Chernozem soil	Herbicides decreased microbial biomass	Tyuryukanova *et al.*, 1987
2,4-D Picloram Glyphosate	0, 2, 20, and 200 mug g-1	Alberta agri-cultural soil	All herbicides caused enhancement of basal respiration	Wardle and Parkinson 1990
Dinoseb	5.5 litres/ha and 10 times this amount	Loamy sand and sandy loam	This is related to microbial biomass	Malkomes 1992
Afalon, Gramoxone	(50% linuron) (20% paraquat)	Sandy loam soil	Increasing doses increased the inhibitory effects of the herbicides. The effects of herbicides on microbial activity were markedly influenced by temp. and moisture.	Nowak and Michalcewic,1992
Imazethapyr	50 g a.i./ha	Clay loam soil	No adverse effects on microbial biomass activity	Perucci and Scarponi. 1994
2,4,5-T	5 g/m^2	Forest and grassland	decrease of microbial biomass to about 40%	Forster *et al.*, 1992
Trifluralin	0.5 and 5 ppm		The decrease in biomass C content was a function of the incubation time and the herbicide rate	Perucci *et al.*,1992
BAS518H [quinmerac]	Recommended rates and 10-fold	sandy soil	Soil biomass declined from 10-fold herbicide decreased respiration	Hart *et al.*, 1992
Glyphosate	10 and 100 times higher than recommended field rates	Forest soil	no deleterious effects on microbial biomass and respiration in forest soils	Stratton and Stewart, 1992
Acifluorfen	1and10 times the recommended field rate	Clay loam soil	Biomass-C was significantly higher in the enriched soil during the first 35 days	Perucci and Scarponi, 1993
Simazine and dinoterb	2 mg/g soil	Arable Luvisol	Microbial biomass was not apparently altered by simazine and dinoterb at day 5	Harden *et al.*,1993
Rimsulfuron	0.005 p.p.m.; FR),10 and 100 times of field rate	Clay-loam soil	Decreases in microbial biomass-C	Perucci; and Scarponi, 1996
Metsulfuron-methyl	50-75 gm/ha.	Clay soil Sandy loam soil	The presence of metsulfuron-methyl in the soil increased the microbial biomass	Ismail *et al.*, 1996

Table 2: Mean ± SE of microbial biomass (mg microbial C/ kg soil)in soils treated with metsulfuron-methyl at two concentration.

Concentration (ppm)	Time after application (days)					
	1	3	9	19	27	35
Clay soil						
0	704 ± 13.4	736 ± 13.2	636 ± 10.0	683 ± 16.6	723 ± 6.9	770 ± 1.3
0.5	723 ± 2.0	743 ± 13.2	656 ± 6.6	696 ± 16.6	697 ± 1.8	637 ± 16.9
2.0	750 ± 7.0	770 ± 20.0	730 ± 1.4	650 ± 13.2	663 ± 2.0	630 ± 7.0
Sandy loam soil						
0	510 ± 4.0	535 ± 5.0	487 ± 3.0	485 ± 2.0	475 ± 2.0	404 ± 7.0
0.5	476 ± 3.3	516 ± 3.4	474 ± 2.0	489 ± 3.0	501 ± 11.6	522 ± 2.5
2.0	485 ± 1.8	535 ± 2.6	502 ± 1.0	508 ± 1.6	527 ± 1.7	527 ± 16.0

not influence any of the microbial variables tested, and addition of 2,4-D significantly influenced all microbial variables investigated but these effects were transient, being detectable only within the first 1-5 days of herbicide addition.

Microbial biomass can be highly responsive to herbicide application, although, is influenced by herbicide concncentration or weed levels. The effect of herbicides is usually short-term and minor when compared with natural spatial and temporal variation in the soil microbial biomass. Growth of the microbial biomass may be enhanced by some herbicides (e.g. glyphosate), due to the herbicide acting as a nutrient source(Wardle and Rahman, 1992).

The presence of metsulfuron-methyl in the soil was indicated to increase the microbial biomass, except in sandy loam soil at the 1st day of incubation (Ismail *et al.*, 1996). Addition of aldicarb caused a significant increase of 7-16% in soil microbial biomass carbon (biomass C), an effect which appeared to be persistent (Hart and Brookes., 1996). The continuous use of pesticides (benomyl, chlorfenvinphos, aldicarb, triadimefon and glyphosate), either singly or in combination in soil, have no measurable long-term harmful effects on the soil microbial biomass or its activity (Hart and Brookes, 1996).

The effect of herbicides on microbial biomass is summarized in

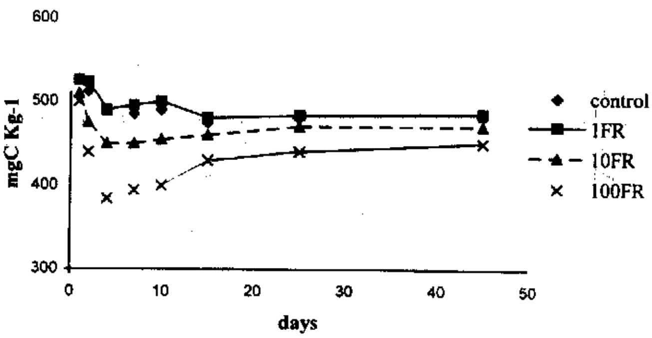

Fig.1: The behavior of biomass C content in control and in soil samples treated at 1FR, 10 FR, 100 FR in laboratory experiments carried out for 45 days.

Table 1. In the clay loam soil microbial biomass increased with the herbicide treatment during the first 9 days of incubation, but declined from day 19 onward (Table 2). However, in the sandy loam soil, the biomass decreased with an increase of herbicide (metsulfuron-methyl) concentration on day 1, but increased thereafter (Ismail *et al.*, 1996).

Data regarding the effects of rimsulfuron treatments in laboratory trials are shown in Fig. 1. The results confirmed that when applied at field rate (FR) the microbial biomass C content was not significantly modified. When applied at 10 FR and 100 FR the decreases in the microbial biomass C content became significant within the first 10 days (Perucci and Scarponi, 1996).

Conclusions

In laboratory experiments, herbicides affected soil microflora and its activities more often than did fungicides or insecticides. However, when applied on soil at recommended levels usually recovered within 1-3 wk. This seems to partially confirm the common belief that pesticides applied at recommended levels and intervals are seldom deleterious to the beneficial microorganisms and their activities (Wainright 1978).

Most modern herbicides used in rice (with the possible exceptions of bensulfuron-methyl and thiobencarb) are considered to have low environmental persistence. Pesticides, however, are industrial chemicals and are not entirely pure. Some byproducts can be unusually toxic and persistent.

Use of a slowly dissipating chemical, such as a copper compound, should be avoided.

The environmental impact of herbicides on non-target organisms Processes contributing to pesticide dissipation are volatilization, photolysis, chemical and biological degradation, plant uptake, and leaching from the soil surface by infiltrating water.

Pesticide dissipation rate also is a function of soil temperature, soil water content, and other soil environmental variables.

Current evidence, however, indicates that modern organic weed killers do not lasting harm and may even be ecologically beneficial, if the recommended rates and frequency of application are followed and modern herbicides are selected. This is not true of insecticides and other types of chemicals.

When herbicides are applied to soil, they may exert certain side effects on non-target organisms.

Herbicides in general are less toxic than insecticides or fungicides.

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