Plant Archives Vol. 19, Supplement 1, 2019 pp. 496-507 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

SUSTENANCE OF SOIL MICROBIAL BIOMASS, THE BASIS OF SOIL FERTILITY IN THE AGRO-ECOSYSTEMS: INFLUENCE OF PESTICIDE AND SOIL AMENDMENTS

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Abstract

Intensive agriculture has raised global concerns and has stimulated scientists worldwide to devise suitable agricultural management practices in order to achieve sustained soil fertility which support productivity in long term. Pesticides effect on soil microbial biomass that plays a key role in driving many ecosystem processes in the soil ecosystem is often argued and no clear cut information is available till date. Maintenance of soil microbial biomass is essential to sustain soil fertility. We critically evaluate the current evidences for this argument. Soil fertility maintenance involves considerable intervention in the research agenda. Most of studies done with pesticides are from laboratories or green house experiments; however the field conditions are inconspicuously lacking. There are a few studies indicating towards the soil fertility sustenance when pesticides are applied in combination with the soil amendments. We give recommendations to test the many other soil amendments that may be applied with different pesticides to see the possible ecological implications leading to designing of new eco-technologies to maintain and sustain the soil fertility.

***Key Words*:** pesticides, soil amendments, soil microbial biomass, soil fertility, ecosystem processes.

Introduction

Pesticides application has now become the main method to control diseases, insects and weeds that infest crops (Jardim and Caldas 2012). The tropics with favorable environmental conditions for insect pests and weeds to proliferate lead to a greater reliance on pesticides than in temperate regions recently along agricultural expansion and changing agricultural practices (Sanchez-Beyo and Hyne 2011; Scopel *et al.*, 2013). The impact of pesticides varies from being hazardous to the ecosystem, health, persistence in the environment or even bioaccumulate (EPA 2017). Concerns have developed, however over the long term sustainability and negative environmental consequences of the intensification of agricultural system (Ladha *et al.*, 2003; Mandal *et al.*, 2003; Moreno *et al.*, 2007).

The extensive use of pesticides in the agricultural system since 1950's has played a pivotal role in the sustenance of crops (López *et al.*, 2002; Cycon *et al.*, 2006; Yang *et al.*, 2007) and lowering of agricultural costs in terms of input of labor and energy involved in agricultural production (Ayansina 2009). These are composed of active and inert ingredients in their formulations. The byproducts of pesticides being in inactive form which are present in the soil can still pose threat to non-target organisms leading to the environmental degradation (Candioti *et al.*, 2010; Vieira *et al.*, 2014), pollution of air, water and soil globally (Abhilash *et al.*, 2012; Volchko *et al.*, 2014) and their residues affects the humans in turn (Abhilash and Singh 2009). Only 1% of the pesticide is utilized by the plants in the protection against pests and rest of it leaches into the soil (Chang *et al.*, 2013). And the excess quantity of pesticides not reaching to the target organisms is absorbed by the plants (Ahemad and Khan 2011).

Most of the pesticides after application during soil management practices eventually reach the soil and thus cause changes in the growth and activity of soil microbial biomass as well (Floch *et al.*, 2011; Kumar *et al.*, 2012) that pertains to both the soil health and fertility levels (Fig. 1). The soil microbial biomass exhibits specific roles in the soil ecosystem. It constitutes the primary soil decomposers, a vital part of soil food web and the main drivers of key ecosystem processes such as organic matter decomposition, nutrient cycling and, thereby plant productivity (Pandey and Singh 2004) which comprise the basis of soil fertility (Singh *et al.*, 2011). Pesticides addition in general affects the soil microbial biomass not only quantitatively but also qualitatively resulting in changes in the soil biochemical process, the indicators of soil fertility and plant yield (Dutta *et al*., 2010; Xu *et al*., 2013).

Different soil management practices such as tillage, crop rotation, application of various agrochemicals, chemical fertilizers and organic resources have a profound influence on the size and activity of the soil microbial biomass (Kushwaha and Singh 2005; Singh and Ghoshal 2007; Singh *et al*., 2016). Microbial biomass responds much more rapidly to management changes than does the organic matter as a whole and hence its measurement has been mostly used as an early indicator of changes in soil chemical and physical properties resulting from management and environmental stress in agroecosystems (Doran and Zeiss 2000). Plenty reports are available related to the extensive and excessive use of pesticides in soil and possible side effects on the soil microbes (Getenga *et al*., 2000; Xie *et al*., 2004; Gundi *et al*., 2005; Moreno *et al*., 2007). In realistic agricultural conditions the pesticides are applied in combination with exogenous soil amendments like chemical fertilizer, animal manure, green manure and crop residues etc. which may interact with each other within the soil systems (Singh and Ghoshal 2010). The addition of exogenous soil amendments is required to maintain the soil fertility level in general. The effect of a pesticide may be changed when it interacts with other soil amendments coexisting in the soil, and such changes would have different side-effects on the biological function of the soil. There is, therefore, an increasing concern on the behaviors of combined application of pesticides and exogenous soil amendments and their potential effects on soil quality (Briceno and Palma 2007; Singh and Ghoshal 2016). Many reviewers have indicated the effects of pesticides even at recommended dosage application on soil microorganisms (Chowdhury *et al.* 2008; Lo 2010). In croplands, maintenance of soil fertility for sustained high crop production is a challenging task. This review compiles the rich data accumulated in literature since the beginning of twenty first century revealing the effect of pesticides both singly and in combination with exogenous soil amendments on soil microbial biomass. The purpose of this review is to assess briefly the effects of the use of pesticides and to make an initiative towards the study of its effect along soil amendments on soil fertility leading to replacement of agronomy from the centre of agriculture.

Effect of Pesticides on Soil Microbial Biomass

Soil microbial biomass is involved in the decomposition of organic matter and thus, the nutrient cycling in soils. Although soil microbial C constitutes 1-3% of the total soil organic C and soil microbial N up to 5% of the total organic N, they are the most labile C and N pools in soil (Jenkinsen and Ladd 1981). The turn-over time for C and N immobilized into the microbial biomass has been reported to be about ten times faster than that derived from plant materials (Smith and Paul 1990). Soil microbial biomass acts as the repository of major nutrients in soil via immobilization while release nutrients in soil through mineralization for the growth of plants and is therefore considered an indicator of soil fertility (Marumoto 1984; Hassink *et al*., 1991). Thus both the size and the activity of microbial biomass determine the nutrient availability and productivity of soils (Singh and Ghoshal 2010; Singh *et al*., 2011). Soil microbial biomass is considered to be the primary factor in the maintenance of not only the soil health and yield but also the sustainability (Zhao *et al*., 2014a). Therefore, the analysis of the impacts on soil microbial biomass as a result of adopted various soil management practices will help us in selecting the suitable management strategy for the establishment of more stable and sustainable agro-ecosystems (Li *et al*., 2012; Zhao *et al*., 2014b). The effect of pesticides on soil microbial biomass has been reported from negative (Busse *et al*., 2001; Sofo *et al*., 2012), positive (Moreno *et al*., 2007; Das *et al*., 2013) to no effect (Lupwayi *et al*., 2004; Lupwayi *et al*., 2007) but there is no clear cut information (Table 1).

Gomez *et al*. (2009) while studying the influence of prolonged use of glyphosate on soil microbial biomass C in a field trial at Zavala, Argentina being in use since 1997 with soybean cropping found that the soil microbial biomass C was significantly lower with dosage of 1.92 and 3.84 L a.i. ha^{-1} while it was lower but comparable to that of control with dosage of 0.48 and 0.96 L a.i. ha^{-1} after four days of application. Contradictory results were found after 45 days of application when the soil microbial biomass C was found higher in dosage of 0.48 L a.i. ha^{-1} while comparable in 3.84 L a.i. ha^{-1} as compared to control. This was explained on the basis that glyphosate can not only stimulate but also inhibit soil microorganisms, depending on the soil type and concentration of the herbicide use (Carlisle and Trevors 1986). Several researches had reported for glyphosate to act as the source of major nutrients like C, N and P in soil which is readily utilized by soil microbes (Dick and Quinn 1995; Busse *et al*., 2001). Glyphosate, an organophosphate is readily used by various soil microbes like gram-positive or gram-negative bacteria (Van Eerd *et al*., 2003), fungal population (Araujo *et al*., 2003; Ratcliff *et al*., 2006) and the actinomycetes (Araujo *et al*., 2003) as it acts as a rich source of energy and nutrients leading to an increase in bacterial biomass

(Zabaloy *et al*., 2008) and also the fungal and actinomycetes (Araujo *et al*., 2003). However, no change in soil microbial biomass of forest soils was reported by Busse *et al*., 2001. Glyphosate when degraded by soil microbes into aminomethyl fosfo´nico acid (AMPA) soon turn into water, carbon dioxide, ammonia and phosphate (Dick and Quinn 1995). Though glyphosate is easily degraded yet its half life ranges from days to months due to its association with the organo-mineral complex (Jonge and Jonge 1999). The glyphosate mineralization rate is related to the accumulation and activity of soil microbes which indicates its persistence in soil.

Several reports are available indicating that chlorpyrifos inhibited soil microbial populations like bacteria, fungi, and actinomycetes initially after its application (Pandey and Singh 2004; Shan *et al*., 2006; Chu *et al*., 2008). Contradictory to this chloropyrifos had also been reported to stimulate the growth of soil bacteria and fungi (Pozo *et al*., 1995; Pandey and Singh 2004; Shan *et al*., 2006). Such variations in the effect of a pesticide on soil microbes is attributed to concentration of pesticide applied, soil type, and microbial composition in tested soil. The deleterious effect of chlorpyrifos on soil microbes was enhanced when applied in combination with another pesticide chlorothalonil which depended on its concentration (Chu et al. 2008). Both herbicides together inhibit acetolactate synthase thus having low and indirect effects on soil microbial activities (Perucci *et al*., 1999).

Various studies are available depicting the negative effect of the herbicide bromoxynil, a sulfonyl urea on the soil microbial biomass (El-Ghamry *et al*., 2000, Pampulha and Oliveira 2006, Abbas *et al*., 2014). Allievi and Gigliotti (2001) explained reduction in soil microbial biomass on the basis of lowering in amino acid assimilation ability of bacteria which resulted in the death of bacteria and thereby the reduction in soil microbial biomass. Ratnayak and Audus (1987) found the decrease in nitrifying bacteria due to bromoxynil herbicide. Abbas *et al*., 2014 explained on the basis of restricted hydrolysis at high pH leading to a higher persistence of herbicide resulting in the death of microbes and thus a reduction in soil microbial biomass C.

Atrazine application is reported to exert significant changes in content of organic matter (Ayansina and Oso 2006). High organic matter content in soil is generally considered the prime factor among several factors like pesticides concentration, soil type etc. to be responsible for the persistence of any pesticide. Increase in duration of exposure of soil microbial biomass to pesticide resulted in decline in the content of soil microbial biomass. On contrary, Das *et al*. (2012) also found the increase in soil microbial biomass up to the 45 days of application of pendimethalin with fenoxaprop/ paraquat. Das and Debnath (2006) reported the stimulatory effect of herbicides on not only the quantity but also the function of non-symbiotic N_2-fixing bacteria and phosphate-solubilizing microorganisms respectively. The higher accumulation of soil microbial biomass in the herbicide treated soils in these studies revealed that the herbicides along their fractions and the autolyzed dead cells were used by the soil microbes to get the C, energy and other nutrients required for the growth and metabolism of soil microbes (Das *et al*., 2012; Perucci and Scarponi 1994). Similarly, Nongthombam *et al*. (2008) while studying the comparative residual effects of widely used aryl phenoxy propionic acid, dinitroaniline and bipyridilium herbicides on microbial biomass and availability of plant nutrients under a particular set of soil conditions found that the herbicides are degraded by the soil microbes when the catabolised/ co-metabolized fractions of herbicides remain in soil as oxidizable C. The negative effect of pesticides on soil microbial biomass decreased with time as the pesticide was degraded or the microbes became adapted to these agrochemicals. One another reason behind the increase in soil microbial biomass after a decrease for a short span of time was the multiplication of microbes due to increase in nutrients in soil or killing of microbes by the pesticides (Latha and Gopal 2010; Vandana *et al*., 2012). The decrease in soil microbial biomass depends upon the variability in the type, dosage, rate of application of pesticides (Ayansina and Oso 2006; Sebiomo *et al*., 2011), mode of application, group of microorganisms and the environmental conditions (Subhani *et al*., 2000; Zain *et al*., 2013). The deleterious effect of pesticides on soil microbial biomass may also be attributed to the lower input of organic residues (Wainwright 1978).

The decrease in soil microbial biomass caused by the application of butachlor at recommended rate (Singh and Ghoshal 2010) was attributed to the lowering in fungal biomass as compared to the other soil microbes (Min *et al*., 2007; Xia *et al.,* 2012). However, the higher soil microbial biomass due to butachlor application was on account of its degradation, while the higher concentration of butachlor resulted in the lowering in the soil microbial biomass (Xia *et al*., 2012).

No changes in soil microbial biomass have been found in studies done by Lupwayi *et al*. (2009) due to the effect of application of herbicides at the recommended rate although the functional structures of bacterial communities were altered. Lupwayi *et al*. (2010) in a field experiment with canola-barley crop rotation while studying the effect of 100% of the recommended herbicide rates viz., tralkoxydim at 200 g ai ha^{-1} and bromoxynil + MCPA at 560 g ai ha^{-1} on the soil microbial biomass found that it was significantly decreased when was applied at full rates while no effect was seen at 50 % rate of application. They suggested that the deleterious effect of herbicide on soil microbial biomass was reduced on reducing the application rate. This study also implied that herbicide when applied at recommended rate in single studies did not show any effect however the application of herbicides for a long duration could result in decreasing the soil microbial biomass.

Assessment of the effect of pesticides on soil microbial biomass is difficult to understand in soil due to different research findings as reported in the literature. A number of factors could be responsible for those controversial results such as soil properties, chemical nature and concentration of pesticides, biological function observed. Even if pesticides applied at recommended rates may cause slight and transient changes to populations or activities of soil microorganisms (Johnsen *et al*. 2001), it is obvious that long-term recurrent applications of pesticides are known to interfere with the biochemical balance, which can reduce soil fertility and productivity by affecting local metabolism. To preserve the environment, many of those molecules have been and will be withdrawn from the market such as clothianidine, imidaclopride, thiame´thoxame and endosulfan or methods be devised to overcome the side effects of pesticides.

The synthesis of the review is reported in Fig. 2. It highlights the effect of pesticides from 44 studies done in twentieth century as depicted in this review varies from positive to negative to no effect on soil microbial biomass which is generally represented as the early indicator of soil fertility. The variability in responses of soil microbial biomass depends on the concentration of pesticides applied, rate of application, soil type, environmental conditions etc. The general trends highlighted and reported in Fig. 2 have been compared with numerous results from other articles dealing with the impact of pesticides on soil microbial biomass. Moreover the response of soil microbial biomass varies with the pesticides dosage, number of times of application, agricultural condition etc. This review attempts to identify common determinants explaining variation in patterns of soil microbial biomass in relationship with application of different types of pesticides aiming at understanding the impact of pesticides on soil microbes. The deleterious effect on soil microbial biomass due to application of pesticides may further be changed when applied in combination with soil amendments of varying resource quality. The studies revealing deleterious effects of pesticides on soil fertility indices demands an urge to establish such agricultural practice which not only maintain the soil fertility level but also sustain it for long term. This perhaps led to the application of pesticides along soil amendments.

Effect of Pesticides in Combination with Soil Amendments on Soil Microbial Biomass:

Most of the researches have been done with a single application of pesticides (Lupwayi *et al*., 2007; Vischetti *et al*., 2007). The influence of pesticides on soil microbial biomass is attributed to its toxic behavior and their fate in soil to which many processes like adsorption, leaching, run-off, degradation, volatilization, plant uptake, etc. contribute (Jacobsen and Hjelmsø 2014). The pesticide content remaining after such processes is considered bioavailable to affect the soil microbial biomass which is further modified by the application of soil amendments (Herrero-Hernández *et al*., 2011).

Soil amendment is the process of adding manure, fertilizers, vermicompost, sewage sludge, wheat straw to the dry land covering upto 80% of global area which not only increases the organic matter, moisture content of the soil but also enhances the nutrient level necessary for the growth of the plant and crop yield. (Bastida *et al*., 2015; Singh *et al*., 2016; Singh and Ghoshal 2010; Pose-Juan *et al*., 2017). The nutrient limited condition favors growth and accumulation of k-strategists compared to r-strategists which accumulate in conditions of readily mineralizable C and N in soil. When pesticides are applied in combination with soil amendments, interaction may occur resulting in the changes in the efficacy of pesticide. The interaction between both amendments and pesticides may further result in the changes in levels of soil microbial biomass.

Pose-Juan *et al*. (2017) reported increased soil microbial biomass carbon while studying the combined effect of triasulfuron herbicide at the rate of 10 and 50 $mgkg^{-1}$ along green compost and at the rate of 2 mg kg^{-1} along sewage sludge. Similarly, Singh *et al*. (2016) while studying the effect of herbicide butachlor singly and in combination with soil amendments in a rice, wheat, summer fallow tropical dryland agroecosystem found significantly higher soil microbial biomass C, N and P throughout the annual cycle in combined treatments compared to control while the increase in the herbicide only treatment was comparable to that of control. The increase found was justified on the basis of the resource quality of soil amendments which masked the effect of herbicide when applied in combination. They found the higher levels of soil microbial biomass C, N and P in case of soil amended with butachlor and *Sesbania* in combination during early phase of annual cycle and explained this on the basis of high nutrient availability owing to its faster decomposition on account of lower C:N ratio. This same treatment showed lower soil microbial biomass during the later phase of annual cycle which was due to the lower availability of nutrients for either plant uptake or to be utilized by soil microbes.

Prolonged higher levels of soil microbial biomass were found in case of farmyard manure application along butachlor herbicide in the studies conducted by Singh and Ghoshal 2010 and Singh *et al*. 2016 and was explained by the fact that there are different fractions in farmyard manure which decompose at different rates and thus maintaining the sustained availability of nutrients (Sluijsmans and Kolenbrander 1977). Higher levels of soil microbial biomass C, N and P was also found by Das *et al*. (2015) while studying the effect of thiobencarb, pendimethalin and pretilachlor at the rate of 7.5, 10 and 2.5 kg a.i.ha^{-1} when applied in soil amended with farmyard manure. On contrary lower soil microbial biomass carbon was reported by Perucci *et al*. (2000) on application of herbicides rimsulfuron and imazethapyr at both the recommended rate of application and ten times the recommended rate of application when applied in combination with vermicompost.

Lower soil microbial biomass during early phase of annual cycle while higher during later phase of annual cycle was observed in case of herbicide applied along wheat straw and was explained on the basis of low resource quality of wheat straw i.e., the lower C:N ratio. Soil amendments with low resource quality is reported to immobilize nutrients during early phase which get remineralized during a later phase of the annual cycle leading to higher soil microbial biomass during the later phase of the annual cycle in a two year field study (Singh *et al*., 2016; Singh and Ghoshal 2010). These studies gave clear evidence that the variation in soil microbial biomass was mainly due to the application of organic amendments rather than the herbicide in all the combined applications.

Lupwayi *et al*. (2010) conducted a four year field experiment to compare the effect of chemical fertilizer (NPKS) at recommended rate along 100% of the recommended dose of herbicide viz., glufosinate-ammonium at 500 g a.i. ha^{-1} and clethodim at 30 g a.i. ha^{-1}, high yielding variety of crop, optimum seeding named as full package, full – 50% of the recommended rates of fertilizer and full – 50% of pesticides in canola and tralkoxydim and bromoxynil + MCPA in barley during canola - barley crop rotation on the response of soil microbial biomass. They found that the pesticides application had a negative effect on soil microbial biomass C which was limited in the treatment full – 50% pesticide.

Higher soil microbial biomass on account of application of pesticides in combination with soil amendments (Singh *et al*., 2016) can stabilize the soil ecosystem (Chauhan *et al*., 2006) due to their ability to contribute to several ecosystem processes and to enhance the plant productivity in turn.

Conclusion and Future Perspectives

The addition of pesticides in modern agriculture lead to the serious consequences on the environmental resources which further affects the health of soil in terms of soil microbial biomass. An overview of the data presented in this review article highlights the variations in the responses of soil microbial biomass due to application of different pesticides singly and in combination with soil amendments. Hence, it is the need of the hour to devise the suitable environmental friendly agricultural strategies aiming at reducing the negative effect of pesticides on the soil microbial biomass. A summary of findings in the present review indicated that diverse soil amendments when applied in combination might be involved in ameliorating the negative impact of pesticides. However, the diversity of contexts and approaches that constitute the basis of this analysis can strengthen our conclusions. Thus the application of pesticides in combination with soil amendments of varying resource quality could be useful for researchers and for policy decision markers in order to take the place of agronomy on which agriculture is generally focused.

Acknowledgements

We wish to thank the Head and the Program Coordinator, Department of Botany, University of Allahabad for providing laboratory facilities. Department of Science and Technology, New Delhi, India provided financial support in form of societal research fellowship (DST/Disha/SoRF-PM/062/2013/G) to 'Pratibha Singh'.

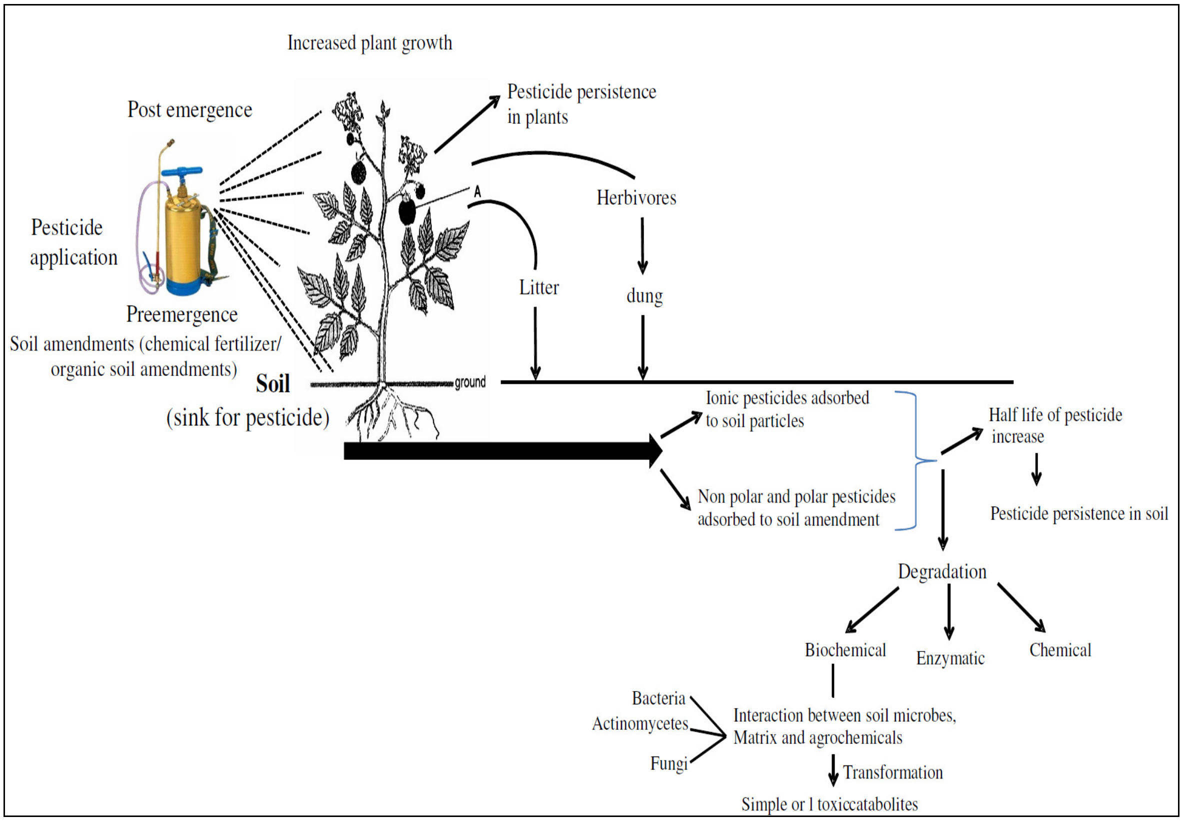

Fig. 1 : Schematic representation of pesticides accumulation in agroecosystems.

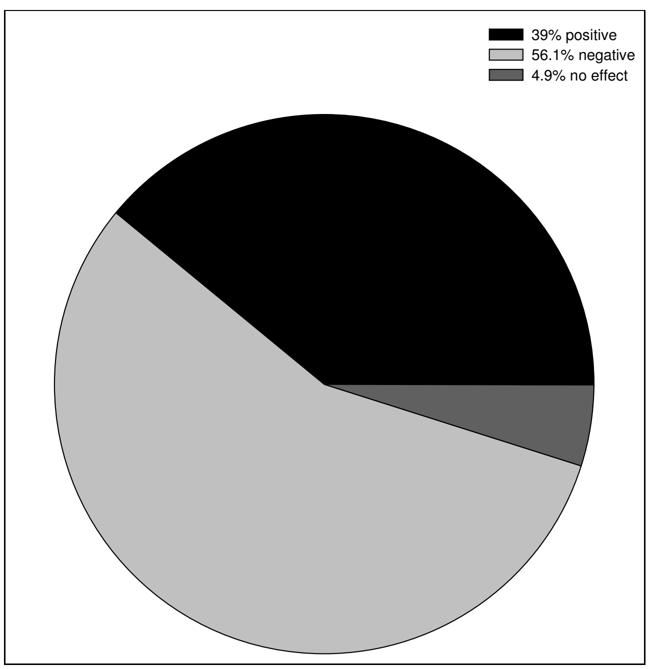

Fig. 2 : Response of soil microbial biomass to various pesticides from the total forty one studies reported in this review.

Table 1 Effect of application of pesticides on soil microbial biomass

S No.	Experimental conditions	Pesticide	Class	Dosage	Mode of application	Effect	References
1.	Ponderosa Plantations	Glyphosate	Miscellaneous	900ga.i.ha^{-1}	post emergence	no effect	Busse et al. 2000
2.	Laboratory cond.	Rimsulfuron	Sulfonylurea	fr,10fr, 100fr		transient decrease in SMBC	Vischetti et al. 2000
3.	Laboratory cond.	Imazamox	Imidazolinone	50% dose		20% decrease in SMBC	Vischetti et al. 2002
4.	Laboratory cond.	Chlorsulfuron	Triazene	fr,10fr, 100fr		decrease in SMBC	Ghamry et al. 2000
5.	Laboratory cond.	Rimsulfuron Imazethapyr	Sulfonylurea Imidazolinones	fr, 10fr		decrease in SMBC	Perucci et al. 2000
6.	Laboratory cond.	Glyphosate	Miscellaneous	900ga.i.ha^{-1}	all post emergence	no effect	Lupwayi et al. 2004
		Glufosinate-ammonium	Miscellaneous	500ga.i.ha^{-1}			
		Sethoxydim	Cyclohexane-diones	200ga.i.ha^{-1}			
		Bentazon azoles	Benzothiadi-	1100ga.i.ha^{-1}			
		Imazamet-habenz	Imidazolinones	400ga.i.ha^{-1}			
		Dicamba	Benzoic acids	110ga.i.ha^{-1}			
		Clopyralid acids	Carboxylic	200ga.i.ha^{-1}			
		2, 4-D amine	Phenoxys	560ga.i.ha^{-1}			
		Metribuzin	Triazinones	210ga.i.ha^{-1}			
		Imazamox/ Imazethapyr	Imidazolinones	30ga.i.ha^{-1}			
		Triasulfuron	Sulfonylureas	10ga.i.ha^{-1}			
		Metsulfuron-methyl	Sulfonylureas	4.5ga.i.ha^{-1}			
7.	Field condition	Glyphosate	Miscellaneous	900ga.i.ha^{-1}	post emergence	no effect	Lupwayi et al. 2007
8.	Italian bilobed	Chlorpyrifos	Organophosphate	10mg/kg 50mg/kg		decrease by 25% and 50%	Vischetti et al. 2007
9.	Laboratory cond.	2, 4-D	Phenoxys	10mg/kg		decrease in SMBC	Macur et al. 2007
10.	Laboratory cond.	atrazine	triazine	0.2 to 1000 mg/kg		increase in SMB	Moreno et al. 2007
11.	Laboratory cond.	Triasulfuron	Sulfonylureas	10 fr		decrease SMB	Sofo et al. 2012
12.	Field experiment	butachlor,	chloroacetanilide	1 kg/ha	post emergence	decrease in MBC	Baboo et al. 2013
			pyrozosulfuran,	25g/ha		„	
		paraquat	bipyridilium	200 g/l		„	
		glyphosate	organophosphate	360 g/l		„	
13.	Laboratory cond.	Fenoxaprop	arylphenoxy-propionic acid	50ga.i.ha^{-1}		39.8% inc. in MBC	Das et al. 2013
		pendimethalin	dinitroaniline	1kga.i.ha^{-1}		37.1% inc. in MBN,	
		paraquat	bipyridilium	1kga.i.ha^{-1}		28.2% inc. in MBC 15.2% inc. in MBP	
14.	Field conditions	Butachlor	Chloroacetanilide	2 kga.i. ha^{-1}	pre emergence	no effect on SMBC, SMBN and SMBP	Singh et al. 2016
15.	Laboratory cond.	Triasulfuron	Sulfonylureas	2, 10 and 50 mgkg^{-1}		decreased SMBC	Pose-Juan et al. 2017
16.	Field condition	Imidacloprid	Neonicotinoid	fr, 2fr, 5fr, 10fr	post emergence	Transient decrease in SMBC	Mahapatra et al., 2017

SMBC: Soil microbial biomass carbon, SMBN: Soil microbial biomass N, SMBP: Soil microbial biomass P, cond.: condition, fr: recommended rate

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