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Impact of Agrochemicals on Soil Fertility and Biodiversity of Soil Arthropods

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ABSTRACT:

The widely applied agrochemicals--fertilizers, pesticides, herbicides, and fungicides--have drastically increased crop production, at the same time alarming scientists and farmers about the adverse effects on soil and ecosystems. The current study investigates how agrochemicals change the soil's fertility and influence the biodiversity of soil-dwelling arthropods. The presence of soil arthropods (such as mites, springtails, and beetles) is crucial for the processes of nutrient cycling, organic matter decomposition, and soil aeration. The findings indicate that short-term fertility may be improved, but long-term application of agrochemicals will lead to lower fertility, soil organic matter loss, disruption of nutrient cycles, and eventually extinction of certain species. Use of environmentally friendly practices and integrated pest management are proposed to maintain soil health.

Keywords: *Soil, Environment, Protection, Animal.*

1. INTRODUCTION:

In the past decades, agrochemicals have been an important part of agricultural intensification used to raise the yield, one of the reasons being (Tilman et al., 2002). Pesticides are responsible for controlling diseases and pests in crops, while fertilizers are supplying the essential nutrients which are potassium, phosphorus, and nitrogen (Matson et al., 1997). However, there exist the complex biological communities in soils that are necessary for the sfongs of ecosystem and the quality of soil to be preserved (Lavelle et al., 2006). The role of arthropods is very significant in decomposition, nutrient cycling, the control of pathogens, and more that they even get classified into microarthropods, such as Acari (mites), Collembola (springtails), and various insects (Seastedt, 1984; Hopkin, 1997). Their feeding activities and mobility through soil pores are the environmental factors that these organisms contribute to the formation and maintenance of soil structure (Bardgett & van der Putten, 2014). The biological factors that contribute to soil health and the living nature of the soil have been recognized by scientists in the first place, so they are studying the former more thoroughly (Doran & Zeiss, 2000). Soil animals, particularly arthropods, are important mediators between the above and below ground ecosystems due to their roles in the flow of energy and nutrition (Wardle et al., 2004). Their responsiveness to changes in the environment makes them good indicators of the resilience and health of soil ecosystems (Paoletti, 1999).

1.1 Problem Statement

The use of agrochemicals that is either excessive or unsuitable has the effect of modifying the physical, chemical, and biological characteristics of the soil (Aktar et al., 2009). This process eventually leads to soil getting less and less fertile, and the destruction of beneficial soil microorganisms, with arthropods being the most affected group (Pimentel, 2005). Some of the adverse effects are, among others, the interrupted nutrient cycles, the presence of toxic residues, and the weakening of the soil ecosystem's ability to recover (Geiger et al., 2010). It is true that agrochemicals have played a major role in enabling the growing world population to have enough food, but at the same time, the over-reliance on these chemicals has made it hard to keep the soil healthy, biologically diverse, and thus continue the practice of agriculture (Foley et al., 2005). A paradox exists in modern farming systems: the use of chemicals aimed at increasing productivity in the short term might be gradually negating sustainability in the long run by slowly killing off the biological resources that are needed to keep soil fertile (Tilman, 1999). The soil degradation can be detected through a decrease in the content of organic matter, a falling off of beneficial organisms, and a rise in the susceptibility of plants to pests and diseases (Altieri, 1999). One of the most important steps for the creation of such agricultural practices, which can satisfy the present food needs without risking the future production, is the full understanding of such trade-offs.

1.2 Objectives

The primary objective are:

1. To measure how the most used agrochemicals affect soil fertility conditions such as nutrient availability and organic matter.
2. To monitor the changes in the number, diversity, and community structure of soil arthropods due to different agrochemical applications.
3. To propose eco-friendly farming practices that keep soil health and productivity and at the same time minimize harm to biodiversity.

2. Literature Review

2.1 Soil Fertility and Agrochemicals

Brady and Weil (2008) explain that soil fertility is a complicated feature that incorporates biological factors such as microorganisms and soil fauna, physical aspects such as texture, structure and porosity, and chemical factors such as nutrient availability and pH. Among the many aspects of the Green Revolution, the synthetic fertilizer usage, which has been proved by Smil (2001) to be a major factor to significantly increase crop yield, has been the most prominent one. Fertilizers that supply the basic macronutrient lacks of nitrogen, phosphorus, and potassium in most agricultural soils make it possible to practice multiple cropping cycles and develop intensive production systems (Vitousek et al., 2009).

In the long run, synthetic fertilizers have negative impacts which are very pronounced through the studies done on them. Two researchers, Goulding (2000) and Schroder et al. (2011), proved that when inorganic fertilizers are used continuously without adding organic matter, the soil organic matter content which is the foundation of soil fertility and structure declines. As per Lal (2006), soil organic matter is a life-line to the microbes, it increases the water retention capacity, it acts as a reserve for the nutrients, and it helps in the process of soil aggregation. The only solution to partially compensate for the essential decline of soil quality due to its exhaustion is through increased fertilizer inputs.

Moreover, there is evidence that the application of specific herbicides and fungicides can lead to the death of beneficial soil microorganisms that are very crucial in the transformation of nutrients necessary for plant uptake (Imfeld & Vuilleumier, 2012). Fungicides, while they are directed against pathogenic fungi, can also act against mycorrhizal associations that are pivotal for phosphorus uptake and, consequently, making plants more tolerant to stress (Giovannetti & Mosse, 1980; Kahiluoto et al., 2001). Besides, it was revealed that herbicides like glyphosate have an impact on the composition of soil microbial community and also reduce the activity of the enzymes involved in nutrient cycling (Zobiole et al., 2011; Nguyen et al., 2016). Such microbial process disruptions can lead to reliance on chemical inputs from outside sources, whereas at the same time, the soil's innate capacity for nutrient provision is being diminished.

The nitrogen cycle, especially, has been significantly transformed by the application of fertilizers. The application of too much nitrogen leads to soil acidification, the leaching of nitrates into groundwater, and the release of nitrous oxide, a greenhouse gas (Robertson & Vitousek, 2009). When phosphorus is accumulated in the soil, it can cause eutrophication of water bodies in case it gets mobilized through erosion or runoff (Sharpley et al., 1994). The above-mentioned environmental problems highlight the necessity not only to optimize the use of fertilizers but also to look for new soil fertility management techniques.

2.2 Soil Arthropods as Bioindicators

The ecological niches of soil arthropods are very diverse, and their stress sensitivity varies, which is why they are one of the best indicators of soil health and ecosystem robustness (Paoletti & Bressan, 1996). Such organisms, which can be as small as mites or as big as beetles and ants, take part in very important processes of nature such as the breaking down of dead matter, nutrients' becoming available again, the development of soil structure, and balancing of microbes (Coleman et al., 2004).

Collembola (springtails) belong to the group of the most plentiful microarthropods residing in the soil, with the number of individuals in a particular area often going beyond 100,000 per square meter (Hopkin, 1997). Their primary diet consists of fungi, bacteria, and decaying organic matter, which they do by speeding up the process of decomposition and releasing the nutrients (Petersen & Luxton, 1982). Pesticide treatment impact on them has been duly recognized, for example, by George Fountain and M. Hopkin

(2005) and D. Menta and P. Remelli (2020) documenting the adverse effects on springtail population sizes and their prevailing loss in diversity measures after insecticide and fungicide applications respectively.

Soil mites (Acari) are yet another group of arthropods that are very diverse and functionally important. The predatory group of mites is responsible for keeping pest and microarthropod numbers down while the saprophagous ones help in decomposition (Walter & Proctor, 1999). The studies of Siepel (1996) and Behan-Pelletier (1999) have shown that the type of soil management practice can affect mite community composition, with very intensive agriculture systems being characterized by lower diversity compared to habitats that are less disturbed.

The negative impacts of pesticides on soil arthropods that are not the intended targets have been indicated by a variety of research. Insecticides, especially the organophosphates and pyrethroids, have a broad-spectrum toxicity and this affects even the useful predators and decomposers (Desneux et al., 2007). Even the selective pesticides would be able to have indirect effects through the change in food web dynamics and habitat structure (Thorbek & Bilde, 2004). Neonicotinoids insecticides which were found by House et al. (2016) to persist in soil and accumulate during several growing seasons, were responsible for the chronic exposure effects on soil invertebrate communities.

The loss of arthropod biodiversity has functional consequences that are not the only impacts on the particular species but also their whole environment. All the different species of arthropods dying out would mean slower breaking down of organic matter, less efficient cycling of nutrients and a decrease in the stability of soil structures (Hättenschwiler et al., 2005). Such effects might take time and not be manifested immediately, but finally the soil quality and ecosystem resilience would be affected. In contrast, the presence of diverse arthropod communities would render those environmental disturbances as non-issues and they also would still be a source of many ecosystem services at the same time (Bengtsson et al., 2005).

A number of studies comparing organic and conventional farming systems have shown repeatedly that the soils of organic farms had more arthropods and different species than conventional farms (Mäder et al., 2002; Bengtsson et al., 2005). Pesticides have a direct toxic effect which is the main reason for this difference, while the indirect effect is attributed to management practices that lead to better habitat and food availability. Thus, to preserve arthropods' diversity is synonymous to achieving a conservation target and at the same time having an access to a soil fertility and agricultural sustainability support.

3. Methodology

3.1 Study Area

The experiment was carried out in test areas of a farm dedicated to agricultural research that used a wheat-rice rotation system. To guarantee uniformity in the environmental variables, all the plots were created on the same soil types (loamy texture) and under the same climatic conditions. The location of the research had an average yearly rainfall of around 900 mm and winter temperatures varying between 12°C and summer temperatures of 28°C.

3.2 Treatments

A randomized complete block design with four replicates per treatment was the method used to carry out four experimental treatments:

- T1 (Control): Application of no agrochemicals; the least manual weed control
- T2 (Standard Inorganic Fertilizers): Pesticide-free application of NPK fertilizers at the recommended rates (120 kg N/ha, 60 kg P_2O_5/ha, 40 kg K_2O/ha)
- T3 (Intensive Chemical Management): Complete application of inorganic fertilizers at the standard rates plus the use of pesticides (broad-spectrum insecticides) and herbicides according to conventional agricultural practices.
- T4 (Integrated Organic Management): Organic amendments (10 tons/ha compost and green manure) together with limited pesticide use (only selective and targeted applications when pest threshold levels were exceeded)

The area of each treatment plot was 10 m × 10 m, while 2 m buffer zones were established between plots to prevent cross-contamination. The treatments were kept the same for three consecutive cropping seasons to allow the cumulative effects to be detected.

3.3 Soil Sampling and Analysis

3.3.1 Soil Collection

Soil samples at two different depth intervals (0–15 cm and 15–30 cm) were collected during three times: before the treatment start (baseline), mid-season (60 days after planting), and post harvest (after the removal of the crop). In every plot of each depth, five random subsamples were taken and merged to create one single representative sample per layer per plot.

3.3.2 Chemical Analysis

- Standard analytical methods were applied to determine soil chemical properties:
- The pH of the soil was measured in a 1:2.5 soil-water suspension with a pH meter
- Total nitrogen was determined through the Kjeldahl digestion method
- Available phosphorus was measured by the Olsen extraction method
- Exchangeable potassium was estimated using ammonium acetate extraction and flame photometry
- Soil organic carbon was assessed by the Walkley-Black method of chromic acid wet oxidation

3.3.3 Biological Analysis

The extraction of arthropods from soil samples was done through a modified Tullgren funnel apparatus which applied heat gradients over a period of 72 hours. The specimens obtained were then preserved in 70% ethanol and afterwards were classified to order level, with the predominant groups (Collembola, Acari) being classified to family or genus level whenever possible by the use of taxonomic keys. The arthropod population was indicated as the number of individuals per square meter.

3.3.4 Statistical Analysis

Data assessment involved the use of analysis of variance (ANOVA) with the main factor being treatment. Tukey's HSD test was used for post-hoc comparisons at the level of significance $\alpha = 0.05$. The following biodiversity metrics were determined:

- Shannon-Wiener diversity index (H')
- Simpson's diversity index (D) [6]
- Species richness (the total number of taxa counted)
- Evenness (J')

Also, correlation analyses were executed to analyze the relationships of soil chemical properties with arthropod community metrics.

4. Results and Discussion

4.1 Soil Fertility Indicators

Over the first two growing seasons, the application of inorganic fertilizers (T2) significantly raised the levels of nitrogen, phosphorus, and potassium in the soil compared to the control. Nevertheless, the T2 plots lost 18% of their soil organic carbon by the third year, while the control plots were almost unchanged. The trend was even more pronounced in T3 plots (fertilizers plus pesticides) which experienced a 25% drop in organic carbon but still had high levels of inorganic nutrients. In contrast, the integrated organic management treatment (T4) maintained nutrient concentrations and soil organic carbon. Additionally, the T4 plots experienced a slight increase of 7% in organic carbon during the whole study. Soil microbial respiration measurements, generally accepted as an indicator of biological activity, were extremely low in T3 plots when compared with all other treatments, thus inferring the microbial biomass and activity had been decreased.

In the short term the use of chemical fertilizers has been confirmed to be in line with the previously established understanding that increased plant-available nutrients are there but chemical fertilizers are incapable of maintaining the biological processes underlying the soil fertility. Organic matter comes into play by performing multiple functions which include the supply of nutrients, water retention, cation exchange capacity, and the support of microorganisms which are beneficial. Its depletion under intensive chemical management is a characteristic of degradation of the whole soil quality that finally leads to a decline in agricultural sustainability.

The diminished microbial activity noted in the plots that were treated with both fertilizers and pesticides (T3) presumably indicates both direct toxicity impacts and indirect effects through lowering organic matter inputs and changing soil conditions. This observation is worrisome especially since soil microorganisms are the ones that carry out the nutrient transformations which are then made available for plant uptake and at the same time they are contributing to disease suppression and soil structure formation.

4.2 Arthropod Biodiversity

The analyses of the arthropod community pointed out very different characteristics among the three treatments. The control and the integrated organic management plots exhibited a remarkable increase in the number of arthropods and the variety of their taxa compared to chemicals. The average number of all arthropods T4 was 12,400 individuals/m^2 while in T2 only 8,900 and in T3 a mere 3,200 were present. The control treatment yielded intermediate values of around 10,600 individuals/m^2.

Diversity measures reflected the same trends with Shannon-Wiener values of 2.50 for T4 and 2.45 for T1 compared with 2.00 for T2 and just 1.30 for T3. The Simpson's diversity index also indicated the same trend since it gives more weight to the abundant species (Table 1). These differences were found to be statistically significant ($p < 0.001$) at both the sampling depths and were consistent, even though generally, the population of arthropods was higher in the 0 15 cm layer.

Table 1: Biodiversity Indices Across Treatments

Treatment	Shannon Index (H')	Simpson Index (D)	Arthropod Count (ind./m^2)
T1 (Control)	2.45	0.88	**10,600 (High)**
T2 (Fertilizers only)	2.00	0.80	**8,900 (Moderate)**
T3 (Fertilizers + pesticides)	1.30	0.65	**3,200 (Low)**
T4 (Organic integrated)	**2.50**	**0.89**	**12,400 (Highest)**

The analysis of the taxonomic composition showed that the sensitive taxa, like predatory mesostigmatid mites and some families of collembola (Isotomidae, Entomobryidae), were nearly gone in the high-chemical plots (T3) but very rich in the control and organic plots. These groups are very sensitive to pesticide exposure and are used to indicate the presence of fairly undisturbed soil conditions. However, the r-selected, disturbance-tolerant taxa like some oribatid mite species did not show much difference among the treatments.

The reduction of the diversity of arthropods in intensive chemical management has a significant impact on the functioning of the ecosystem. The presence of a diverse community of arthropods maintains the decomposition process through the different feeding strategies acting in parallel, processing the organic matter at different rates, and occupying the different microhabitats. Their absence causes nutrient cycling to happen slower, less organic matter to be incorporated into soil, and the biological contribution to soil structure formation to be reduced. As these consequences accumulate, they will compound the indirect negative effects of the reduction of organic carbon content.

In addition, the removal of predatory arthropods might result in the decline of natural pest suppression and thus lead to a greater reliance on chemical pesticides, a case that perfectly illustrates the "pesticide treadmill" phenomenon. A variety of soil communities create a resilient ecosystem as they are highly diverse functionally and can interact in such a way that the ecosystem processes remain stable even under environmental stress.

The moderate effects noted in T2 (fertilizers only) imply that although the application of synthetic fertilizers changes the soil conditions in such a manner that the diversity of arthropods is reduced, the pesticides have much stronger direct toxic effects. This discovery advocates the reduction of pesticides as the main tactic in the struggle to keep the soil microorganisms diverse.

5. Conclusion

The findings of this study indicate that agrochemicals, by boosting nutrient and pest management, give immediate benefits to agriculture but their subsequent effects on soil ecosystems are still considerable, and hence they are not sustainable in the long run. The use of synthetic fertilizers, pesticides, and other methods that are not environment-friendly, in their turn, lead to soil fertility downgrade, thus impacting the whole agricultural sector. The T4 system of integrated organic management has been very successful in this regard as it has not only maintained soil fertility but also made it possible for very active arthropod communities to thrive. Thus, the concept of sustainable intensification has been proved to be workable to a certain degree in this case. The treatment involved the constant supply of organic matter to the soil, the use of pesticides at specific times, and the liberal application of organic matter for the upkeep of soil health.

6. Recommendations

In the light of the above-mentioned discoveries, we suggest the following ways of agricultural sustainability promotion:

1. Install Integrated Pest Management (IPM): Carry out complete IPM approaches giving priority to cultural, biological, and mechanical pest control methods, restricting chemical pesticides for the cases where the other methods are not sufficient. This practice reduces the usage of pesticides while at the same time assuring efficient pest control.
2. Use of Organic Fertilizers: An ongoing supply of compost, green manure, farm manures, and crop residues keeps soil organic carbon content at a certain level, helps the microorganisms and gives them habitat and food resources, and thus benefits the good arthropods as well. Even a little displacement of conventional fertilizers with organic materials gives great advantages to soil biology.
3. Monitor Soil Biodiversity: Create the necessary monitoring programs that will regularly assess the soil arthropod communities which are used as bioindicators of soil health. Straightforward indices of arthropod abundance and diversity can give an early warning of soil degradation before more expensive analytical assessments reveal chemical or physical changes.
4. Develop Supportive Policies: Government departments and agricultural extension services should work together to support the gradual reduction of chemical dependency by means of incentive programs, provision of expert guidance, and implementation of research on alternative methods.

Current subsidies that support the use of agrochemicals could be changed into financial assistance for the practices that promote biological fertility of the soil.

5. Enhance Education and Awareness: A better grasp of soil biological processes and the long term effects of chemical use will do well to farmers, agro-ecological advisors, and government officials. The extension services should promote soil health management through economic and ecological perspectives only.
6. Crop Diversification Proposed: The benefits of soil diversity by way of a diverse crop rotation and intercropping are coupled with the pest-resistance and lower nutrient-demand conditions, which lead to reduced use of chemicals.

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