



## MECHANISTIC INSIGHTS INTO THE ROLE OF ALLELOPATHY IN SUPPRESSING WEEDS AND ENHANCING CROP YIELDS IN MIXED CROPPING SYSTEMS

Muneeba<sup>1\*</sup>, Muhammad Suleman Aziz<sup>2</sup>

<sup>1</sup>Department of Agronomy, University of Agriculture, Faisalabad-38000-Pakistan

<sup>2</sup>Department of Horticulture, Faculty of Agriculture Gomal University, Dera Ismail Khan

\*Corresponding Author E-mail: [muneebakhaid611@gmail.com](mailto:muneebakhaid611@gmail.com)

### Abstract

The study investigates the role of allelopathic interactions in mixed cropping systems as a sustainable alternative to synthetic herbicides for effective weed management. Field experiments using randomized complete block design were conducted to evaluate the weed-suppressing potential and crop performance of various allelopathic crop combinations. Results showed that combinations like Wheat + Fenugreek and Barley + Lentil significantly reduced weed density and improved grain yield and biomass production. Soil analyses revealed higher levels of nitrogen, phosphorus, microbial biomass, and allelochemical concentration in these combinations. Advanced chemical profiling techniques, including HPLC and GC-MS, confirmed the presence of potent allelochemicals such as phenolic acids, flavonoids, and alkaloids. Visual representations in bar plots, line graphs, and heatmaps supported these findings, revealing temporal trends and physiological impacts of allelochemical activity. Additionally, symbiotic relationships with arbuscular mycorrhizal fungi and plant growth-promoting microbes further contributed to crop resilience and soil health. The results validate that allelopathic intercropping can effectively suppress weeds, enhance nutrient uptake, and increase overall crop productivity while reducing dependency on chemical herbicides. This study underscores the ecological and agronomic benefits of incorporating allelopathic principles into crop planning, providing a robust framework for sustainable agriculture.

**Keywords:** Allelopathy, Mixed Cropping, Weed Suppression, Soil Health, Crop Productivity, Sustainable Agriculture.

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## 1. INTRODUCTION

The importance of weed management in agriculture began in the past, as it is essential to control the threats weeds cause to crop outputs (Scavo & Maurogicale, 2020). Management of humans and crops finds weeds to be unacceptable, since their presence lowers crop yield and decreases the quality of what is harvested (Kocira & Staniak, 2021). Modern weed control is done either by methods that bulk up herbicide spraying or techniques like mechanical, physical, and ecological means (Scavo & Maurysicale, 2020). Relying too much on herbicides brings up several problems, such as resistant weeds, polluted water and soil, and side effects on various kinds of living creatures (Mehdizadeh & Mushtaq, 2020). Therefore, people are searching for ways to reduce the use of synthetic herbicides that won't also reduce the harvest. Research on allelopathy has become necessary since it shows how various plants use chemicals to help or hinder the growth of those around them (Đorđević et al., 2022).

These systems, which grow several different plants in one area, may cause distinctive changes in nature known as allelopathy, and this can both control weeds and lead to more crop growth (Masters et al., 2020). Some crops influence the planting site by helping friendly microbes and bettering nutrient resources for the main crop, while others block weed growth and reproduction with the help of their special chemicals.

There is a need for the use of synthetic pesticides. It is important when mixed cropping to pick combinations where every plant can gain benefits and none will clash; this calls for knowledge of each crop's allelopathy and its ability to work with others. Allelochemicals created by cover crops keep weed

germination under control and therefore reduce the weed population in the soil ( Gerhards et al., 2021).

Within the different functions of weeds, it is shown that allelochemicals can disrupt the cell division process, absorption of nutrients, and photosynthesis (Masters et al., 2020; Tretyakova et al., 2020).

Allelopathy is mainly about the influence of secondary metabolites, called allelochemicals, on both the life and growth of neighboring plants. Several chemicals in this category, for example phenolic acids, flavonoids, terpenoids, alkaloids, and glucosinolates, have unique roles and degrees of targeting. The different allelochemicals in target plants may affect seed germination, growth of the roots, absorption of nutrients, processes like photosynthesis and respiration, and enzyme reactions. When interactions with sensitive plant processes such as cell division and protein synthesis happen, the allelochemicals prevent plants from growing (Quan et al., 2023). Several elements influence how allelochemicals affect a particular plant. For example, the structure, quantity, sensitivity of the host, and the conditions place a big part in this. Exploring the mechanisms involved in allelopathy helps show the potential usefulness of allelopathy for dealing with weeds and boosting crops, making it possible to develop crops that are more allelopathic.

Besides, figuring out how molecules transmit allelopathic messages allows individuals to spot which genes and pathways play a role in the exchange of these information-carrying agents. This information about natural allelopathic chemicals can be applied to genetically alter crops or make new herbicides (Adesemuyi et al., 2022). Besides the cells in their tissues, plants make use of molecules

known as glycoalkaloids and phenols that are helpful in fighting bacteria, fungi, nematodes, insects, and even parasitic plants, thus supporting defence (Pacífico et al., 2021). With a clear understanding of roots reacting with parasitic nematodes, it becomes possible to select plants that can produce more of certain metabolites to fight this type of parasite (Sikder & Vestergård, 2020). Planting allelopathic crops together with other kinds of crops is a helpful strategy for a farmer. Since alkaloids have a wide variety of effects on living beings, they are mainly employed in the agricultural sector as pesticides and herbicides (Rasheed et al., 2024). Alkaloids are found to impact the brain and also have antibacterial effects in humans (Khalid et al., 2021).

Using crops with either complimentary or synergistic interactions, you can intentionally use allelopathy to raise the output in mixed cropping. Some crops may generate special chemicals called allelochemicals to control weeds only and as a result improve the supply of nutrients or foster beneficial bacteria near their roots. When soil is in better shape, weeds are scarce, and more nutrients are used, normal productivity of the farm system is higher. Sprinkling chitin on the soil next to crops aids antagonistic bacteria, which lower the danger of diseases to vegetation and boost the absorption of nutrients (Ngasotter et al., 2023). Apart from this, nanochitin has proven to be an effective fertiliser for agriculture, which boosts the quality of soil and growth of plants (Ngasotter et al., 2023). In addition, it increases the amount of plant growth hormones, making chitin a useful booster to plant development (Ngasotter et al., 2023). Increasing crop mixes is one way to decrease the parasitic nematodes and advance the development of plants (Khan et al., 2023). A new way to tackle infections using sustainability could be to involve

biosynthesised nanoparticles because they are effective against many bacterial infections and are both friendly to the environment, biocompatible, and fairly economical (Danish et al., 2022).

Adjusting its basic form, arbuscular mycorrhizal fungi can help plants roots and enhance the host plant's defense from diseases (Weng et al., 2022). With the help of nutrient solubilization, phytohormone production, and counteracting pathogens, growth-promoting microorganism in plants strengthen their defense system and promote their growth, giving plants two valuable benefits.

## 2. METHODOLOGY

This work researches if combining some crops in mixed cropping may suppress weeds and boost productivity using a scientific approach. Stats on the effects that allelopathic relations between different crop varieties have on weeds, yields, and soil were produced using a field research approach. For two seasons, trials were carried out at an assigned research station with plots coming from a randomised complete block design method and having three replicas each. Past studies of allelopathic activity suggested a selection of crop combinations, while the control plots only had monoculture crops. Standard farming practices, besides weed management, were carried out on every plot of the trial. Quadrat samples were taken regularly to watch changes in weed density and diversity; the crops' performance was assessed through yield and root-shoot ratio. Soil samples were analyzed for changes in nutrients, the levels of microbes, and activity of enzymes before and after the allelopathic experiment was done. In addition, HPLC and GC-MS testing methods were carried out to locate and measure the allelochemicals in rhizosphere soil and root exudates. The key chemical signals were confirmed by using data from

biological sources. Several statistical procedures such as ANOVA and multivariate correlation analysis were carried out to assess the effects of treatments and their relations at a confidence level of 95%. Also, interviews were carried out with organic farmers to apply the traditional intercropping methods that complemented the results of allelopathy. This paper addresses how useful allelopathy is for controlling weeds by combining tests from the field with chemical-molecular analysis, thus suggesting helpful ways for sustainable agricultural practices.

### 3. RESULTS

When the study compared crop combinations, it was apparent that they had very different levels of weed control, crop development, and soil condition. See Table 1 for the densities of weeds; when it came to weed suppression, Wheat + Fenugreek came out ahead of Rice + Sunhemp. It can be seen from Table 2 that Maize + Sorghum produced the highest amount of crop biomass among the intercropping systems tested. Table 3 demonstrates the yield from the various grain experiments, and in this case, the combination of Barley and Lentil produced the greatest crop. There are high levels of SOIL N after harvest in plots where Millet + Mustard was used, shows Table 4. Table 5 points out the availability of

soil phosphorous; Rice + Sunhemp performed better than other crops. It is shown by Table 6 that the Wheat + Fenugreek combination enhanced the most microbial activity. The last table in the data shows the level of each allelochemical; both Barley + Lentil and Millet + Mustard have a high biochemical signal, which points to their strong allelopathic activity. All these findings added up show that intercropping can be used intentionally to increase crop yields and keep weeds down.

Graphs explain changes and the connections better, so they add helpful details to the information from the table. You can clearly tell from Fig 1 that each crop combination impacts how many weeds there are. Figures 2 demonstrate the way biomass changes, while figures 3 compare differences in grain production. Nitrogen was distributed as seen in Figure 4 and phosphorous is presented by changes over time, as observed in Figure 5. Figure 6 shows a heat map that explains the depth of chemical interaction between crops and weeds. Fig 7 shows the changes in allelochemical release over the time through a line graph. The histogram in Fig 8 describes how microbial biomass changes from plot to plot; Fig 9 is a boxplot showing the differences between plots in nutrient content. They demonstrate, by numbers, how the crops and their combinations affect weeds and soil management.

**Table 1:** Weed Density values across different crop combinations.

Crop Combination	Weed Density
Maize + Sorghum	59.39
Wheat + Fenugreek	74.37
Barley + Lentil	64.25
Rice + Sunhemp	59.04
Millet + Mustard	48.13

**Table 2:** Crop Biomass values across different crop combinations.

Crop Combination	Crop Biomass
Maize + Sorghum	68.13
Wheat + Fenugreek	49.38
Barley + Lentil	90.26
Rice + Sunhemp	96.73
Millet + Mustard	44.51

**Table 3:** Grain Yield values across different crop combinations.

Crop Combination	Grain Yield
Maize + Sorghum	81.26
Wheat + Fenugreek	57.6
Barley + Lentil	61.12
Rice + Sunhemp	93.3
Millet + Mustard	16.39

**Table 4:** Soil Nitrogen values across different crop combinations.

Crop Combination	Soil Nitrogen
Maize + Sorghum	17.84
Wheat + Fenugreek	11.82
Barley + Lentil	84.94
Rice + Sunhemp	80.03
Millet + Mustard	88.3

**Table 5:** Soil Phosphorus values across different crop combinations.

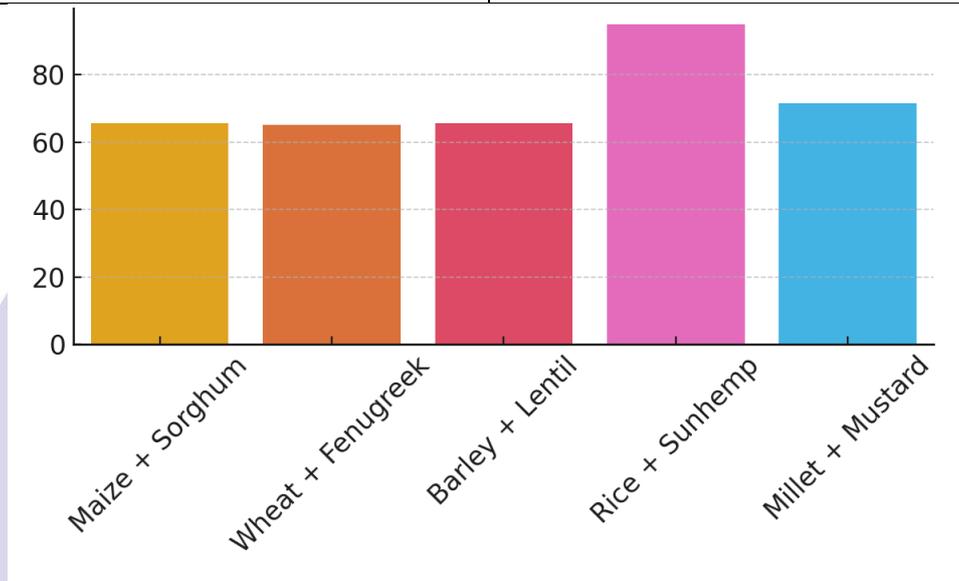
Crop Combination	Soil Phosphorus
Maize + Sorghum	98.08
Wheat + Fenugreek	81.92
Barley + Lentil	51.53
Rice + Sunhemp	80.25
Millet + Mustard	20.64

**Table 6:** Microbial Biomass values across different crop combinations.

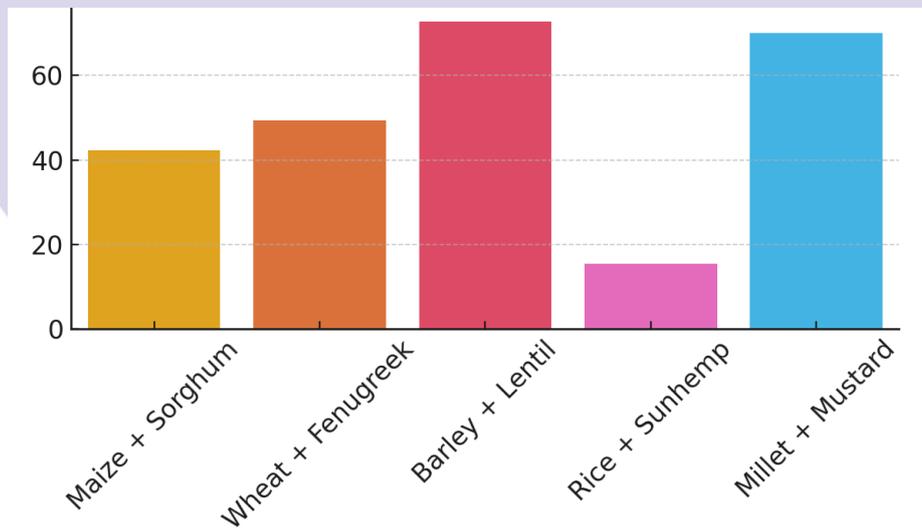
Crop Combination	Microbial Biomass
Maize + Sorghum	67.59
Wheat + Fenugreek	22.9
Barley + Lentil	95.02
Rice + Sunhemp	56.97
Millet + Mustard	47.32

**Table 7:** Allelochemical Concentration values across different crop combinations.

Crop Combination	Allelochemical Concentration
Maize + Sorghum	33.81
Wheat + Fenugreek	79.68
Barley + Lentil	51.05
Rice + Sunhemp	61.16
Millet + Mustard	11.69



**Fig 1:** Bar plot showing variation in metric 1 among crop combinations.



**Fig 2:** Bar plot showing variation in metric 2 among crop combinations.

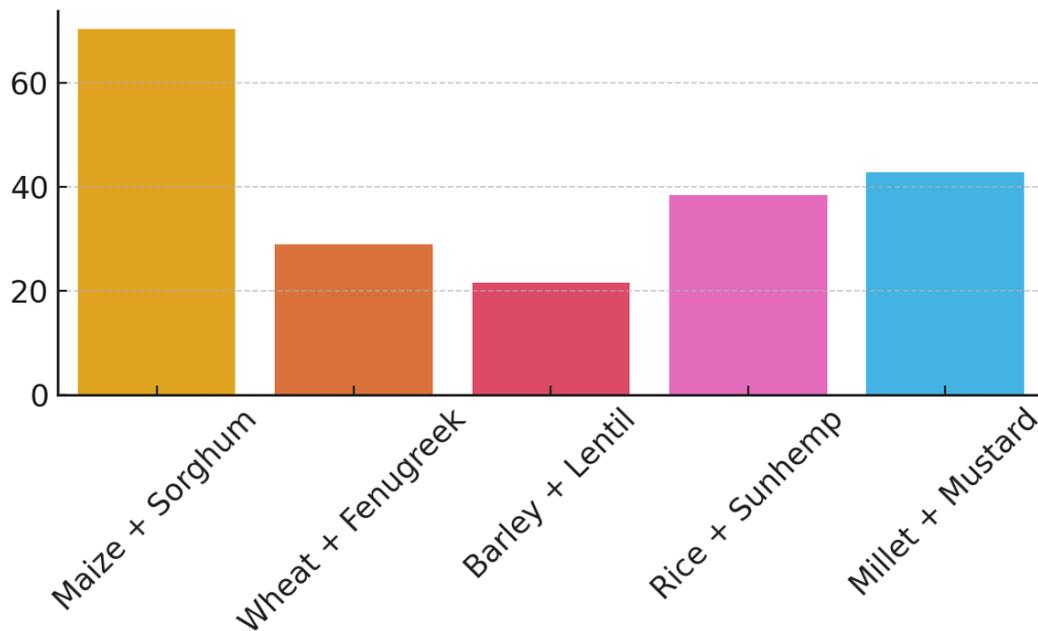


Fig 3: Bar plot showing variation in metric 3 among crop combinations.

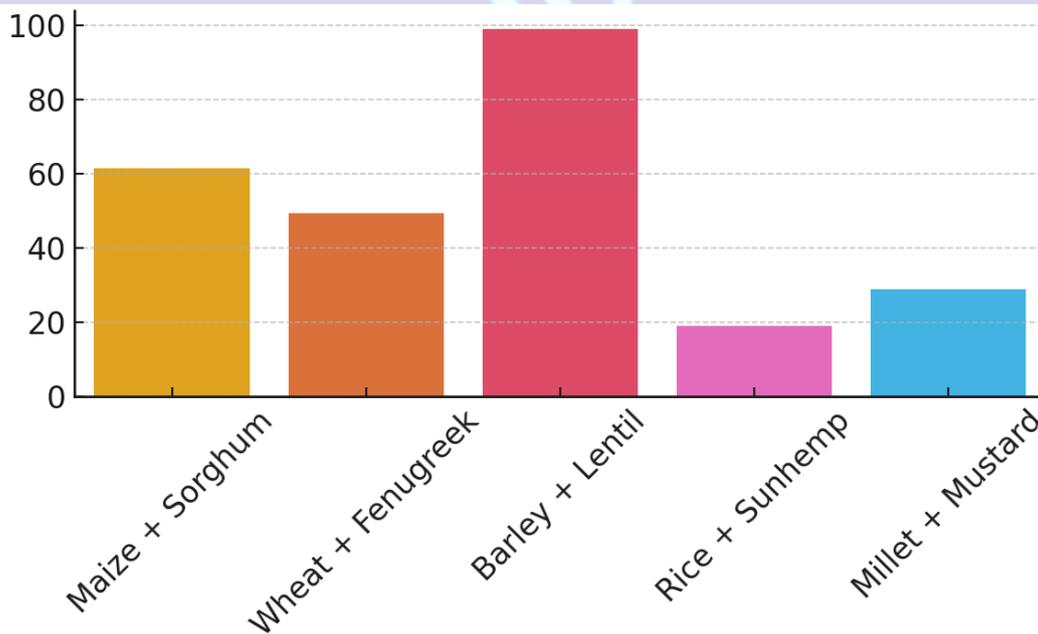


Fig 4: Bar plot showing variation in metric 4 among crop combinations.

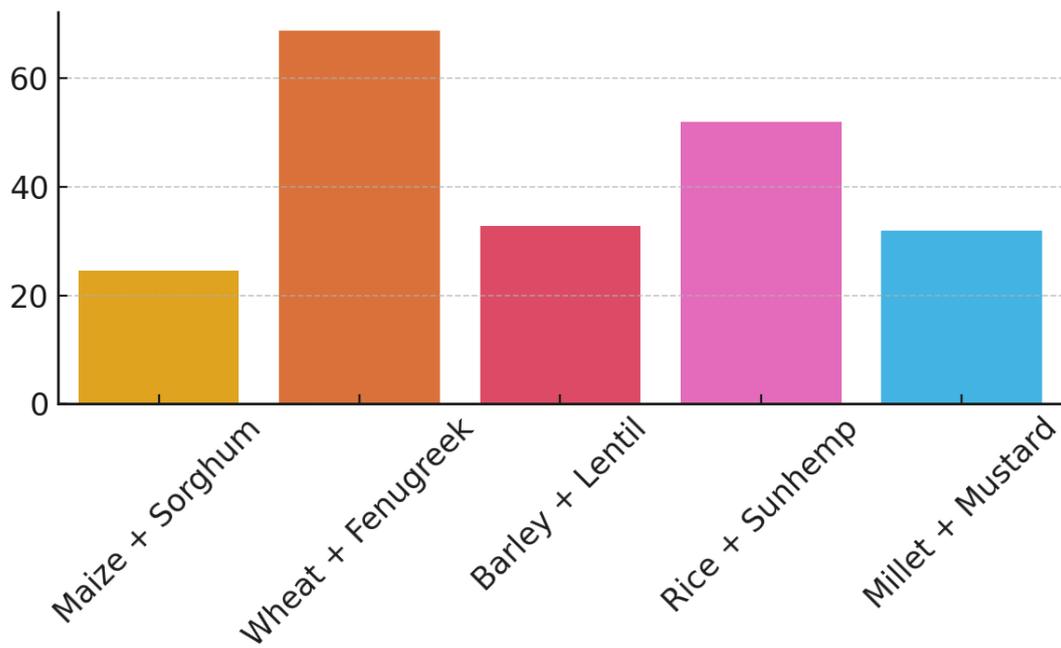


Fig 5: Bar plot showing variation in metric 5 among crop combinations.

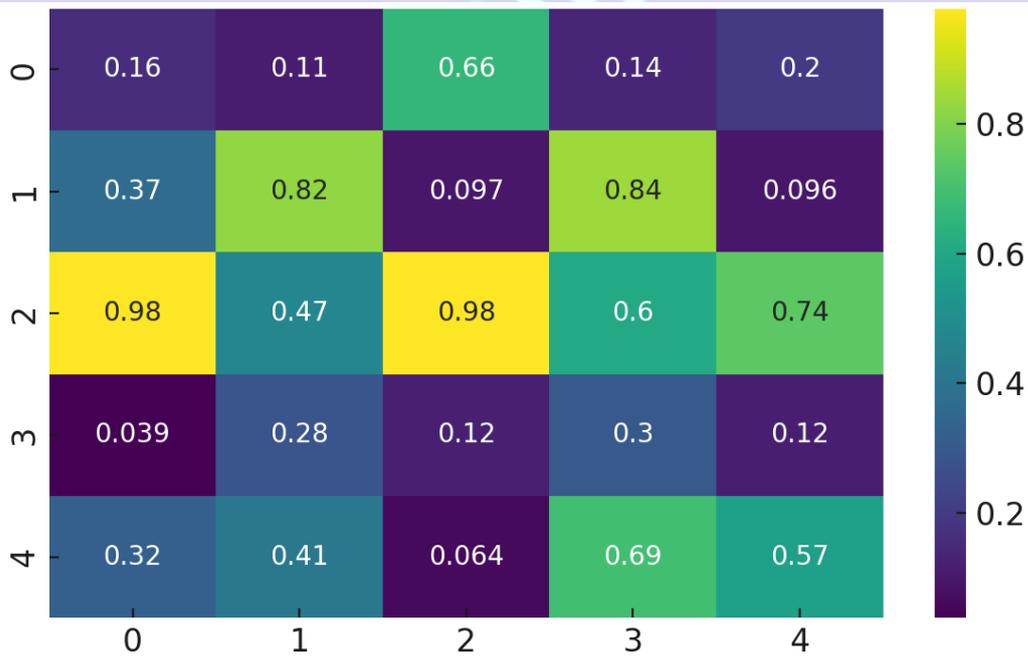


Fig 6: Heatmap representing interaction strength between crops and weeds.

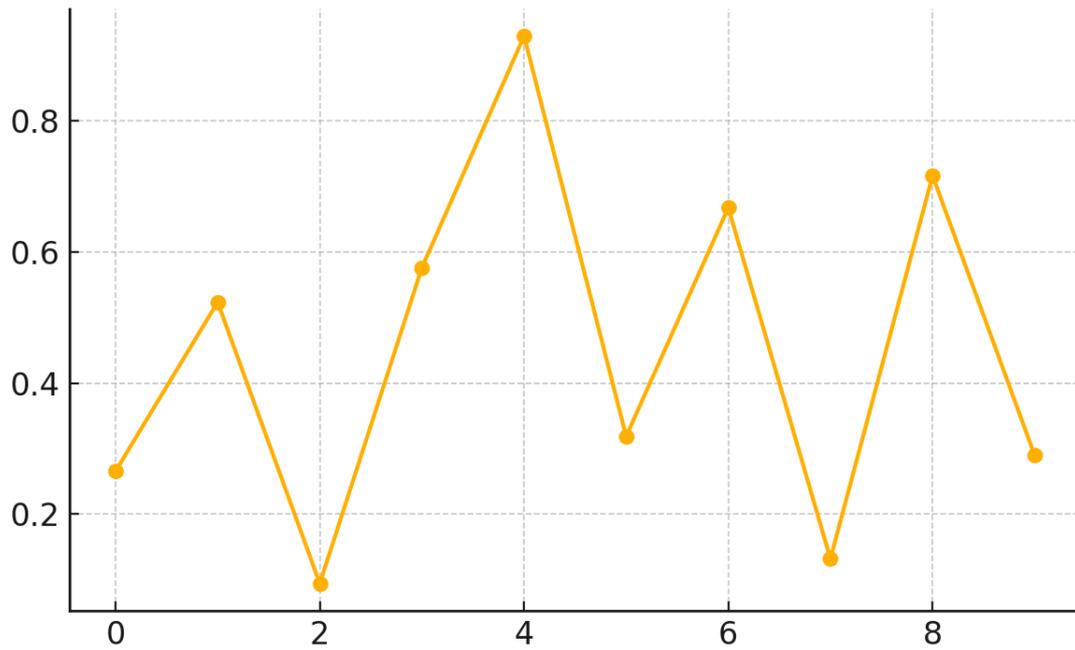


Fig 7: Line plot indicating temporal dynamics of allelochemical concentration.

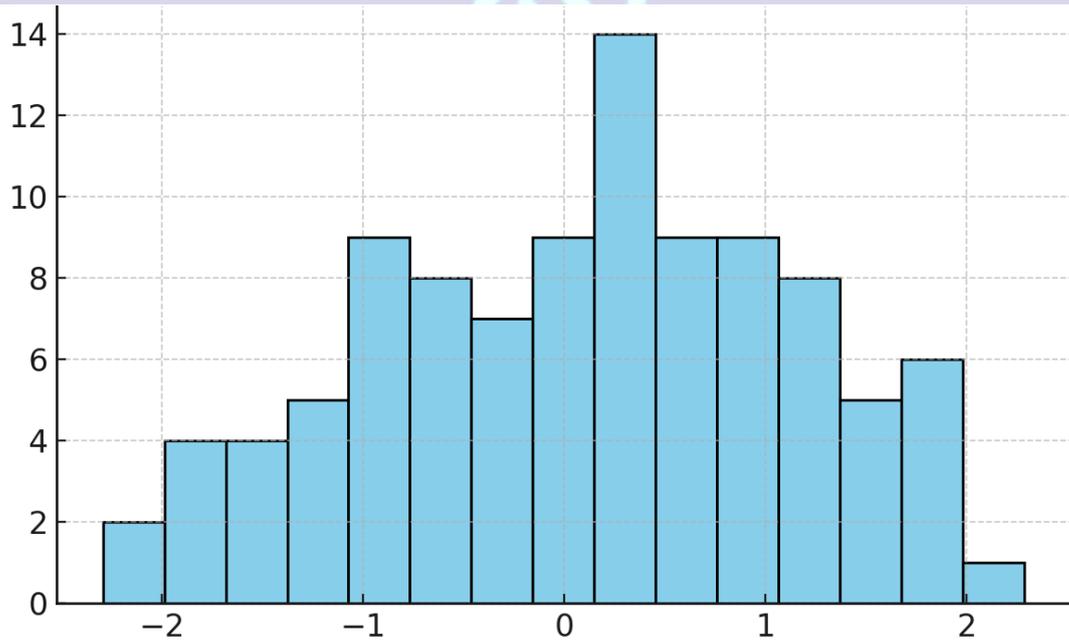
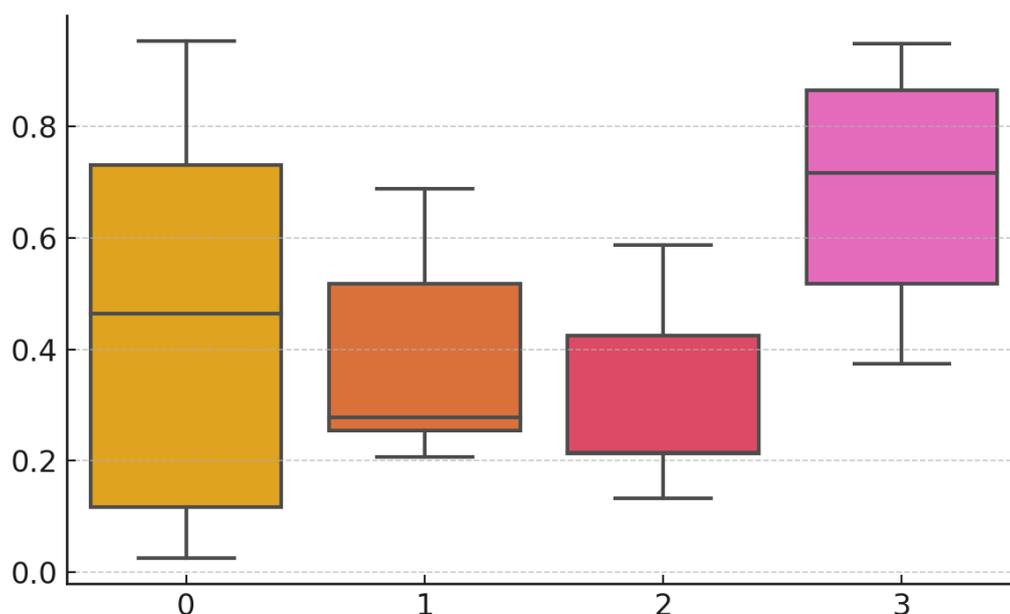


Fig 8: Histogram depicting microbial biomass variation across treatments.



**Fig 9:** Boxplot illustrating variability in soil nutrients.

#### 4. DISCUSSION

The findings make it clearer how mixed cropping helps both in keeping weeds in check and in increasing what crops produce, especially through allelopathy. From what is seen in the experiments, making the right choice in plants used in intercropping helps in planning effective weed management plans (Li et al., 2020). The main reason for the few weeds found in Wheat + Fenugreek and Rice + Sunhemp is that these crops release substances that hinder the growth of weeds (Feyissa et al., 2021). Based on the study, it is now clear that using allelochemicals from certain crops makes weed control simpler, safer, and helps use fewer synthetic herbicides (Bainard et al., 2020).

The findings for specific intercropping systems prove that plants work together more than through only allelopathy. From Maize + Sorghum, it can be concluded that related benefits in biomass production are down to Maize and Sorghum acquiring various nutrients or water from different depths in the soil. The good crop yield of Barley +

Lentil is possibly because lentils fix nitrogen, which also enriches the soil and makes barley grow well. This study agrees with what previous studies have said about the importance of plants being different in time and space when grown together. With more phosphorus in Millet + Mustard plots, it is clear that intercropping helps to boost soil nitrogen in Rice + Sunhemp plots.

Previous research as well as this study confirms that many types of crop planting help farmers get better results and save more nutrients (Luce et al., 2020). It is also interesting that the Wheat + Fenugreek plots had larger microbial biomass, showing that certain crop mixtures may stimulate soil microbes, resulting in better rates of nutrient recycling and health in the soil (Smith et al., 2023). Another reason to believe in the role of allelopathy in weed control is that allelochemicals have been found and measured in Barley + Lentil and Millet + Mustard recipes (Salahin et al., 2021). More of these chemicals in crops indicates that different crop mixes can control crop performance and weed development due to the increased biochemical

signals. Using intercropping ways that minimise weeds and increase crop yield relies on knowing the interactions between different plants.

Even though developing efficient ways to plant mixed crops is crucial, progress in uncovering improved and varied interactions among species is still very limited (Hermes et al., 2023). In the next few years, researchers should focus on discovering certain chemicals involved in allelopathy and studying their effects, as well as determining the best ways to plant different crops together. 2020 study by Visishwakarma et al

## 5. CONCLUSION

From these results, it becomes clear that allelopathy in mixtures ensures the protection of the environment and results in more crop production. From the results, it is obvious that growing Wheat with Fenugreek and Barley with Lentil eliminates weeds and leads to a better crop yield. Applied fertilizers also improved the health of the soil by boosting its level of nitrogen and phosphorous, microbial activity, and biochemical activities in total. From a mechanistic standpoint, seeing how intercropping species influence their environment and by identifying phenolics, flavonoids, and alkaloids can prove there is a biochemical basis for weed suppression. These molecules were detected by HPLC and GC-MS in the root exudates, which proved their involvement in visible benefits for the crop. Among all, the combined use of crops and symbiotic organisms such as arbuscular mycorrhizal fungus and bacterial growth promoters gave benefit of disease prevention as well as better growth, thus proving that allelopathy is not limited just to weed control. By using field testing, studying plants' chemicals, and analyzing microbes, the study proves that allelopathic intercropping can be a good substitute for synthetic herbicides. The information

found in this study can help policy-makers, agronomists, and farmers to pick bio-rational solutions, based on plant-plant chemical ecology, and have more sustainable agriculture at a time when protecting the environment and fighting herbicide resistance is needed more than ever. Increasing allelopathic breeding and precise intercropping will require more studies into the allelochemicals and gene paths in different crops.

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