Allelopathic Modulation of Rhizosphere Soil Physicochemical Properties by Weed Aqueous Extracts in Legumes

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Research Article

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Abstract

The present study investigates the allelopathic effects of *Chloris barbata* sw. and *Phyllanthus niruri* L. on the physico-chemical properties of rhizosphere soil of *Vigna unguiculata* (L.) walp and *Lablab purpureus* (L.) sweet. Soil samples were treated with different concentrations of weed extracts and analyzed for parameters including pH, electrical conductivity (EC), organic carbon, available nitrogen, phosphorus, potassium, sulphur, moisture content, and water holding capacity. The results revealed significant variations in soil properties under allelopathic treatments. Soil pH shifted from alkaline towards neutral conditions, while EC showed moderate variation. Organic carbon and macronutrients (N, P, K) increased significantly in treated soils, indicating enhanced nutrient availability. Sulphur content, moisture, and water holding capacity also showed considerable improvement. Soil texture analysis indicated dominance of coarse and very coarse sand fractions. The findings suggest that allelopathic interactions of selected weeds can positively influence soil fertility and nutrient dynamics, thereby contributing to improved soil health and crop productivity.

INTRODUCTION

Allelochemicals can indirectly affect plants by reducing soil microorganisms such as nitrifying and nitrogen fixing (Walker et al., 1999) bacteria and ectomycorrhiza (Ahmed et al., 2007). Allelopathic interactions in the presence of bioactive compounds (Derouich et al., 2020) and plant proteomic responses to soil antibiotics (Margas et al., 2019), bio-fungicide (Bouhlali et al., 2021), biopesticide.

The allelochemical work should be capable of influencing soil chemical properties. The invasive evergreen asteraceae weed *Pluchea lanceolata* seems to affect several soil properties, electric conductivity, pH, K^+ and soluble chloride. Compared with uninfested soils, infested soils seriously inhibited the seedling growth of various crop species. Allelopathic effects of plants may be attributed to allelochemicals or changed soil nutrients (Inderjit, 1998). Inderjit and Duke, (2003) noted that phytochemicals are released into the soil by decaying plant tissue, so it makes their negative effects easier to observe in the field. The release of secondary metabolites into the soil is a major contributing factor to the detrimental effects of decaying weed residues. Microbial activity during residue breakdown may directly cause these chemicals to be leached out of the residues (Kumar et al., 2006). By releasing phenolic compounds into the soil, phenolic compounds also affect following crops' germination and seedling growth (Batish et al., 2005). According to Shaukat et al., (2003) and Singh et al., (2003), residues from a variety of allelopathic weed species release allelochemicals into the soil that affect the performance of related and next-season crop plants. It is the rhizosphere soil that allelochemicals are mainly produced, being synthesized directly or indirectly by the intermediary products and precursors exuded into the plant base or root zone (Tang et al., 1989). Allelopathic relationship is also a function of the quantum of allelochemicals cutting-edge the soil rhizosphere, texture and pH soil as well as the clay organic matter which influence its uptake and subsequently altering the natural habitat physiology and organic chemistry properties (Blum, 1995). Allelochemicals influence weed pests and soil micro-organisms, and the microbial ecology in soil (Einhellig, 1995).

According to Awodun and Ojeniyi, (1999) organic mulches enhance biotic activity and supply nutrients to the soil to increase soil fertility in addition to their impact on the physical characteristics of the soil. Mulch should be applied in a partially decomposed form rather than in a fully decomposed material, according to Bruce et al., (1995) since this approach encourages long-term biological production and aids in the creation of a physically stable soil surface. Hall et al., (1983) noted that allelopathic effects are influenced by soil nitrogen levels. Marschner, (1995) explained that most of them change the soil's pH or act as chelating agents for nutrients. These effects also influence other plants that have roots in this rhizosphere, besides the donor plant. Phenolic compounds and phenolic acids along with nutrients can form complexes that also influence the availability and cycling of the nutrients in soil (Appel, 1993; Kuiters, 1991). As noted by Kruse et al., (2000) *Pluchea lanceolata* affects the chemical assets of the dirt immediate its roots, involving pH, electrical conductivity, and the amount of potassium and chloride available. In terrestrial ecosystems, phenolic acids and several other allelochemicals are usually considered to have a significant impact on the cycling of nutrients in soil.

Research on allelopathy and its effects on soil provides valuable information for the agricultural sector, such as potential approaches for more sustainable and efficient crop management, weed control, and ecosystem preservation. For sustainable agriculture, a thorough understanding of the complex relationships between soil and allelopathy is necessary. Farmers are using this information to spread cut invention, reduce their employment of synthetic pesticides, and support a more ecologically balanced environment (Xu et al., 2023; Zhan et al., 2022; Choudhary et al., 2023).

MATERIALS AND METHODS

Soil collection

100 gm of soil samples were randomly collected from plots where plants that had been sprayed with various weed extract concentrations and control plants were taken at a depth of 10 to 20 cm. Larger pieces of soil were broken by hand, after that samples were transported to the lab and cleaned to get clear of stones, gravel, and other coarse residues. The air-dried soil samples were mashed before sieved through a 2 mm sieve. Additional physical and chemical analyses were performed on these materials.

Soil samples were collected and analyzed for physical and chemical properties. Soil texture was determined by the sieve method, while moisture content was estimated using the gravimetric method (Gardner, 1986). Water holding capacity (WHC) was measured by the saturation and drainage method.

Soil pH and electrical conductivity (EC) were determined using a pH meter and EC meter in a 1:2 soil–water extract (Jackson, 1973). Organic carbon was estimated by the Walkley and Black method (Walkley and Black, 1934). Available nitrogen, phosphorus, potassium, and sulphur were analyzed using standard methods such as Kjeldahl method (Subbiah and Asija, 1956), Bray method (Jackson, 1973), ammonium acetate method (Stanford and English, 1949), and turbidimetric method (Williams and Steinbergs, 1959), respectively. All analyses were performed following standard laboratory protocols.

RESULT AND DISCUSSION

The physicochemical parameters of the rhizosphere soil of *Vigna unguiculata* and *Lablab purpureus* varied significantly was treated with different amounts of *Chloris barbata* sw. and *Phyllanthus niruri* L. extracts. The parameters recorded were pH, electrical conductivity (EC), organic carbon, macronutrients (N, P, and K), sulphur, moisture and water-holding capacity in mention Table 1.

Soil pH values Before treated soil in 8.17 and *Vigna ungiculata* control in 8.12 with most treatments indicating slightly alkaline conditions compared to the baseline (*Vigna ungiculata* 100% *Phyllanthus niruri* extract treated: 7.43). Electrical conductivity (EC) ranged from 0.26 mmhos/cm (*Vigna ungiculata* 100% *Phyllanthus niruri* extract treated) to 0.69 (*Vigna ungiculata* control) mmhos/cm, as compare to before treated soil showing higher EC values than the baseline. The soil moisture content showed treatment-induced variations in moisture absorption, ranging from 84.42% (*Vigna ungiculata* control) to 96.07% (*Vigna ungiculata* 100% *Phyllanthus niruri* extract treated). Water holding capacity increased significantly in most treated soils, ranging from 19.67 ml (*Vigna ungiculata* control) to 20.61 ml (*Vigna ungiculata* 100% *Phyllanthus niruri* extract treated), compared to the baseline (18.50 ml).

Organic carbon content increased significantly across treatments, from 0.03% (Before treated soil, *Vigna ungiculata* control) to a maximum of 0.42% (*Vigna ungiculata* 100% *Phyllanthus niruri* extract treated), compared to the baseline of 0.06%. The available nitrogen 141.12 kg/ha (Before treated soil) showed low amount of nitrogen and maximum nitrogen amount showed in 254.02 kg/ha (*Vigna ungiculata* 100% *Phyllanthus niruri* extract treated). Available phosphorus increased significantly 9.66 kg/ha (Before treated soil, *Vigna ungiculata* control) to 63.48 kg/ha (*Vigna ungiculata* 100% *Phyllanthus niruri* extract treated). Potassium content ranged from 161.28 kg/ha (Before treated soil) to 336 kg/ha (*Vigna ungiculata* 100% *Phyllanthus niruri* extract treated). Sulphur levels ranged from 18.24 ppm (Before treated soil) to 535.03 ppm (*Vigna ungiculata* 100% *Phyllanthus niruri* extract treated), with the highest amount detected in the treated soil.

In Table 2 indicates the soil in all treatments maintained mostly coarse-textured, with gravel content ranging from 58.83% to 84.99%, based to the particle-size analysis. In most treatments, particularly in the controls and treatments T1, T2, T3, T5, T7, T9, T10, T11, T12, and T13, the major sand component was very coarse sand (1–2 mm). The major sand class increased as a result of treatments T4, T6, T8, T14, T15, and T16 showing significantly increased proportions of coarse sand (0.5–1 mm), with values ranging from 13.7% to 18.5%. T8 (40.03%) and T11 (40.44%) had the highest measured percentages of total sand and T10 (15.18%) had the lowest. Although the soil remained mostly coarse and gravel-rich. The soil analysis indicated that the presence of weeds was related to beneficial soil conditions, such as slightly acidic to neutral pH, moderate electrical conductivity and balanced water-holding capacity. Legume growth and microbial nitrogen fixation have been found to be influenced parameters (Fageria et al., 2011). The organic carbon content of soils under weed cover was significantly higher, possibly due to litter deposition and root turnover. Organic matter from weeds like *Phyllanthus niruri* can boost soil microbial activity, promote nutrient mineralization and improve soil structure (Brady and Weil, 2017).

Alsaadawi et al., (1986) observed that phenolic acid concentrations increased, the absorption of N, P, K, Fe and Mo decreased. Certain species have been direct allelopathic effects by influencing plant nutrition, or indirect effects by influencing interactions between plant microorganisms. Norby and Kozlowski, (1980) noticed that aqueous extracts of *Lonicera tatarica* leaf applied to red pine needles a decrease in the phosphorus content.

Conclusion

The study demonstrates that allelopathic extracts of *Chloris barbata* and *Phyllanthus niruri* significantly influence the physico-chemical properties of rhizosphere soil. The treatments improved soil fertility by increasing organic carbon, essential nutrients (N, P, K, S), moisture content, and water holding capacity, while slightly reducing soil pH towards neutral levels. These changes indicate enhanced soil quality and favorable conditions for legume growth. The results highlight the potential role of allelopathic weeds in sustainable soil management and nutrient enhancement. However, further studies are required to understand long-term effects and field-level applications.

Declarations

Data availability

The datasets analyzed during the current study are available from the corresponding author not available for publicly.

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Contributions

Bhoomi Shah was involved in conceptualisation, sample collection, laboratory analysis, literature review, data interpretation, manuscript formatting, methodology, data analysis, manuscript drafting, data curation, validation, and manuscript editing. Ruby Patel provided guidance and reviewed the final manuscript.

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Ethics declarations

The plant materials used in this study included locally available weed species collected from natural habitats and legume crops cultivated under field conditions. The collection of plant materials was conducted in accordance with local and national guidelines. No endangered or protected species were involved, and no specific permits or licenses were required. All experimental procedures were carried out following standard protocols and complied with relevant institutional and national regulations.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Additional information

Publisher's Note

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Tables

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