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Research Article

A Study on Positive Impact of Allelopathic Plant Leaf Ashes on Soil Fertility and its Characterization

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ABSTRACT

A method was developed to synthesize an eco-friendly alkaline solution from acidic leaves having an allelopathic effect.The mild alkaline solution prepared showed significant potential as a sustainable fertilizer for crops due to its rich nutrient composition. Ashes derived from allelopathic plants act as an excellent source of essential plant nutrients and contain elements that enhance soil conditions, thereby promoting better plant growth and development. Further, the study was carried out to analyze the presence of key elements, calcium, magnesium, potassium, boron, etc., by X-ray diffraction (XRD), field emission scanning electron microscopy (FESEM), and energy-dispersive X-ray spectroscopy (EDX). The study also examined how the application of allelopathic plant leaf ashes influenced soil pH from neutral (7.48) to highly alkaline (8.60) and salinity variations during the growth of various plant species. According to our findings, incorporating allelopathic plant leaf ashes greatly promotes plant growth because of the combined effects of elevated pH and nutrient levels, which are analyzed by soil sample analysis.

Keywords: Allelopathic plants, Soil fertility, Minerals, Alkalinity, Characterisations.

INTRODUCTION

In recent decades, deforestation has surged at an alarming rate, driven by demands for construction, furniture, and the paper industry. Therefore, to compensate, some fast-growing plants were introduced as early as the 1970s and 1980s for different purposes, such as in regions vulnerable to desertification and deforestation or for the beautification of cities.[1] Furthermore, it was also introduced as a source of fuelwood and fodder in rural areas. As the days passed served its purpose, but its negative impact on the environment is alarming, the native plants were having coexistence, eco-friendly and not invasive. However, the newly introduced fast-growing trees having allelopathic properties are invasive and not eco-friendly due to their allelopathic property. Allelopathic property is one of the significant phenomena that affects plant-plant interactions in the ecosystem. The deleterious effect of chemicals or exudates produced by one living plant species on the germination, growth, or development of other plant species or microorganisms sharing the same natural surroundings.[2] Exudation, leaching, and volatilization are the three different ways in which plants release chemical compounds into their near surrounding to elicit allelopathic activity.[3]

Allelochemicals found in allelopathic plants are known as secondary metabolites. Most of the time, it is organic acids like oxalic acid, phenols, etc., produced by higher plants that cause a phenomenon called allelopathy, which puts a break on the growth of neighbouring and other plants.[4] The allelopathic potential of many plant species has been documented.[5] Allelochemicals contribute to acidification; the immediate effect is negligible in comparison to other causes. At highly acidic pH values, there is less availability of plant nutrients such as calcium (Ca), magnesium (Mg), sulphur (S), potassium (K), phosphorus (P), nitrogen (N), and molybdenum (Mo). Right up until the soil becomes extremely acidic (pH less than 5), other nutrients like manganese (Mn), copper (Cu), and zinc (Zn) tend to be more available.[6] As soil acidity increases, so does the availability of iron (Fe) and aluminum (Al); Al turns hazardous to plants at pH values below 5[7] (Table 1), giving the details of essential plant nutrients and their role in plant growth.

The plants need alkaline cations like calcium to grow. An ideal soil pH range for plant growth and most soil functions, such as microbial activity and nutrient availability, is between 5.5 and 8.0. Aluminum becomes more soluble in soil when its pH decreases. A subtle decrease in pH can lead to a significant rise in aluminum solubility. This type of aluminum limits the availability of water and nutrients to roots by slowing down their growth Figure 1.[8] Inadequate nutrition and water cause poor pasture and crop development, decreased yields, and smaller grain sizes. Because plants have less access to stored subsurface water for grain filling during dry seasons.[9]

Soil pH

A pH range between 5 and 6 is considered ideal for most plants. Acid soils have a major effect on plant productivity once the soil pH falls below 5:

Table 1: Indispensable nutrients and beneficial elements: ionic forms and their vital roles in plant growth

	Elements	Forms uptaken by plants	Role
Non-mineral macronutrients	Carbon	CO_2	Crucial for driving photosynthesis
	Hydrogen	H^+, OH^- and H_2O	
	Oxygen	O_2	
Mineral primary macronutrients	Nitrogen	NH_4^+ and NO_3^-	Present in chlorophyll, nucleic acids, and amino acids; a key component of proteins and enzymes regulating biological processes.
	Phosphorus	HPO_4^{2-} and $H_2PO_4^-$	ADP and ATP essential for energy storage and transfer. A vital component of DNA and RNA, crucial for plant development and highly concentrated in seeds.
	Potassium	K^+	Regulates water use, enhances disease resistance and stem strength, and supports photosynthesis, drought tolerance, winter hardiness, and protein synthesis.
Mineral secondary macronutrients	Calcium	Ca^{2+}	Essential for cell elongation, division, root and leaf development, and the formation of cell membranes and walls.
	Magnesium	Mg^{2+}	Component of chlorophyll and important for photosynthesis.
	Sulfur	SO_4^{2-}	Essential for amino acid synthesis, protein formation, enzyme development, seed production, chlorophyll formation, and nodulation in legumes.
Mineral micronutrients	Copper	Cu^{2+}	An enzyme catalyst is required for chlorophyll formation.
			Acts as a catalyst in enzyme systems and is essential for chlorophyll synthesis.
	Iron	Mn^{2+} and Mn^{4+}	Essential for pollen tube growth, germination, and cell wall blooming.
	Boron	H_3BO_3, BO_3^-, and $B_4O_7^{2-}$	Obligatory for the building of growth hormones, chlorophyll and carbohydrates.
	Zinc	Zn_2^+	Vital for enzyme activity in converting NO_3^- and NH_4^+ in plants. Requisite for N fixation by rhizobia.
	Molybdenum	Mo_4^{2-}	

Figure 1: Aluminum toxicity on crops

- pH 5.0 — moderately acid — Depending on the soil type, pH below 4.8, aluminum becomes toxic to plants. Phosphorous may combine with aluminum and may be barely available to plants.
- pH 4.5 — strongly acid —Aluminum becomes soluble in dangerous amounts. Manganese (Mn) becomes soluble and harmful to plants in some soils, depending on temperature and moisture levels. Molybdenum (Mo) is becoming increasingly scarce. Soil bacterial activity is slowed down.
- pH 4.0 — extremely acid — Irreparable soil structural breakdown can occur.

pH of soil will influence both the availability of soil nutrients to plants and how the nutrients react with each other.[10]

For a number of reasons, soil pH is regarded as the "supreme component" in soil fertility. Soil pH frequently has a significant effect on (1) primary mineral precipitation and dissolution, (2) the degree of CEC and AEC covariable-charge minerals, and (3) the degree of ion-, ligand- -exchange and chemisorption processes, (4) microbial activity that affects the cycling of nutrients; and (5) the solubility of Al.[11] The overall shift in nutritional availability brought about by modifications in soil pH is shown in (Figure 2). Al^{3+} and H^+ predominate in low base saturation soils, which causes acidity and Al^{3+} toxicity in plants. Certainly, it has surged the concentrations of Al^{3+} and Mn^{4+} in solutions that are frequently the most harmful to plant growth in acidic environments.

By looking in to nuisance of allelopathic plants in decreasing soil fertility, the following selected allelopathic plant species, which are most widespread in an ecosystem, is considered in our research to combat their negative impact on the environment by increasing soil fertility from its own acidic leaves.

Peltophorum pterocarpum (PP), a copper pod tree planted for the beautification of the city, emanate various allelochemicals that affect the growth and development of surrounding plants. Among the various allelochemicals, chlorogenic acid and 4-hydroxybenzoic acid, with a pKa value of 4.4, have been identified as the main allelopathic agents.[12] These chemicals interfere with the normal physiological processes of other plants, thereby restricting their growth.[13]

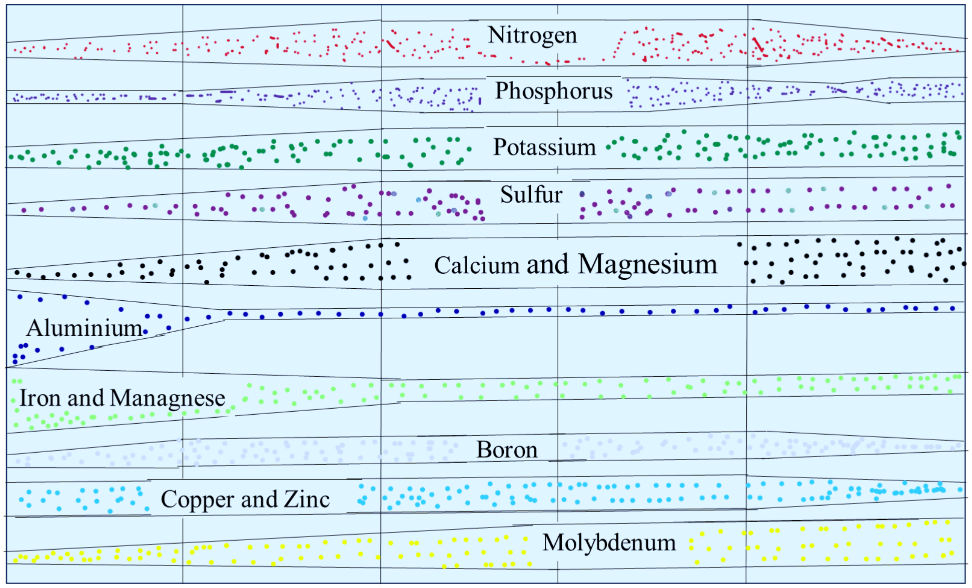


Figure 2: The width of the bar reflects relative nutrient availability; as the bar width grows, it consequently increases the nutrient availability. The relative availability of important plant nutrients fluctuates with pH[11]

Prosopios juliflora (PJ) was introduced as a source of fuelwood and fodder in rural areas. *P. juliflora* is being investigated in great detail for its allelopathy on many plant species, and it is one of the 100 most invasive plants worldwide.[1] The chemicals, including tannins, flavonoids, steroids, hydrocarbons, waxes and alkaloids, are present in the leaves of *P. juliflora*.[14] These are known to affect the growth and germination of other nearby plant species. Due to this, the plant diversity, i.e., both the number of individual plants of species and the species surrounded by *P. juliflora* will be affected by the allele chemicals. The low light under the canopy of *P. juliflora* likewise hampers the survival of other plant species.[15]

The evergreen fruit tree species *Tamarindus indica L. (TI).* (Family: Leguminosae), often known as tamarind, is grown around the world. Although *T. indica* L. is well known for its acidic characteristics and allelopathic potential. It was evident that almost no or very few weeds and plants grow or survive under the tamarind tree,[16] suggesting an allelopathic function for fallen leaves and root exudates of the tree.[17] Allelopathic competence of *T. indica* L. root involved in plant growth regulation. Using the bioassay-guided process concept, the organic acids found in its leaf extract were identified and quantified, and their contributions were examined. In its leaf aqueous extract, high-pressure liquid chromatography detected four organic acids: citric, malic, oxalic, and tartaric acids, which are shown in Figure 3.[18]

The widespread establishment of eucalyptus plantations for commercial timber and fiber production has sparked global controversy. Despite criticism, eucalyptus plantations have gained popularity, even in regions with historically low timber yields, due to their rapid growth and ease of cultivation, making them highly profitable.[19,20]

However, the expansion of eucalyptus plantations comes at a significant environmental cost. These plantations have been linked to severe ecological issues, including a decline in biodiversity within the understory and progressive soil degradation.[21-24] These adverse impacts underscore the need for sustainable management practices to balance economic benefits with environmental preservation.

The continuous monoculture of eucalyptus plantations leads to the accumulation of phytotoxins in the soil, resulting in soil degradation and a significant decline in productivity.[25,26] These plantations are known to adversely affect the germination and growth of native plant species.[27-29] Compounds such as phenolic acids and volatile oils, released from the leaves, bark, and roots of certain *Eucalyptus globulus(EG)* trees, exhibit harmful effects on surrounding vegetation. This allelopathic activity not only disrupts the natural growth of neighboring plant species but also contributes to long-term ecological imbalance and soil health deterioration.[30,31]

In the above plants, the major allelopathic chemicals are organic acids or phenol derivatives, so we planned to eliminate these organic acids by preparing ash from leaves of allelopathic

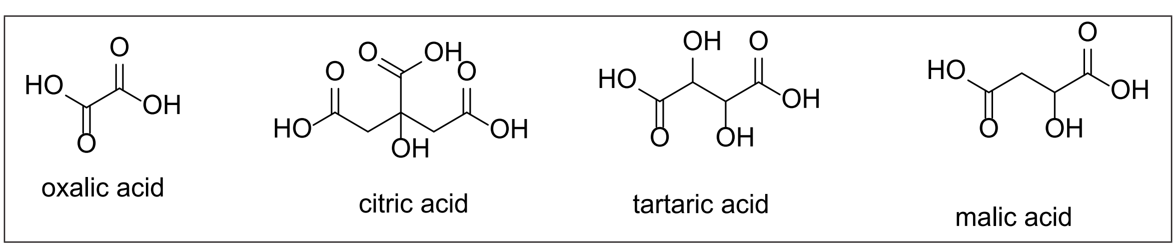


Figure 3: Major organic acids identified in *T. indica* L. leaf aqueous extract

plants. The understanding of alkalies and acids was well-known by ancient Indians. Concerning the preparation of caustic alkali. This is obvious from the subsequent elucidation of the manufacture of alkaline carbonates and caustic alkalies documented in the Ayurvedic literature written by Susruta (circa 5th century b.c.). Different types of alkalies are listed in both the alchemical book Rasarnava sodium carbonate trona or natron (sarjika-kshara), and potassium carbonate (yava-kshara).[32]

We aimed to prepare an alkaline solution with a pH range 7 to 8 derived from the acidic leaves of allelopathic plants. The goal was to create a solution that falls within the ideal soil pH range of 5.5 to 8.0, which is optimal for plant growth and crucial for maintaining key soil functions, such as microbial activity and nutrient availability.

MATERIALS AND METHODS

The leaves of selected allelopathic plants, represents *P. pterocarpum, P. juliflora*, *T. indica* L, and *E. globulus* are collected from Karnatak University, Dharwad shown in Figure 4.

The leaves were cleaned with water. The half of the quantities of leaves are ground and aqueous solutions pH is checked using pH meter. The leaf extract was found to be acidic, as shown in Table 1. The remaining quantity of the leaves are dried at 60°C in open air oven until constant weight is obtained. The dried leaves were cut into small pieces and burnt in the open air. Once the combustion is over, the ash left over is collected.

Similar to the method mentioned in Ayurvedic literature written by Susruta, an alkaline solution is prepared by dissolving ash in distilled water, then it is observed that the ash is not completely soluble in water. Therefore, it is filtered and filtrate pH is checked, details given in (Table 2). Since the filtrate of ash aqueous solution showed a basic nature compared to raw leaf extract in water. The ash is further analyzed using XRD, SEM and EDS.

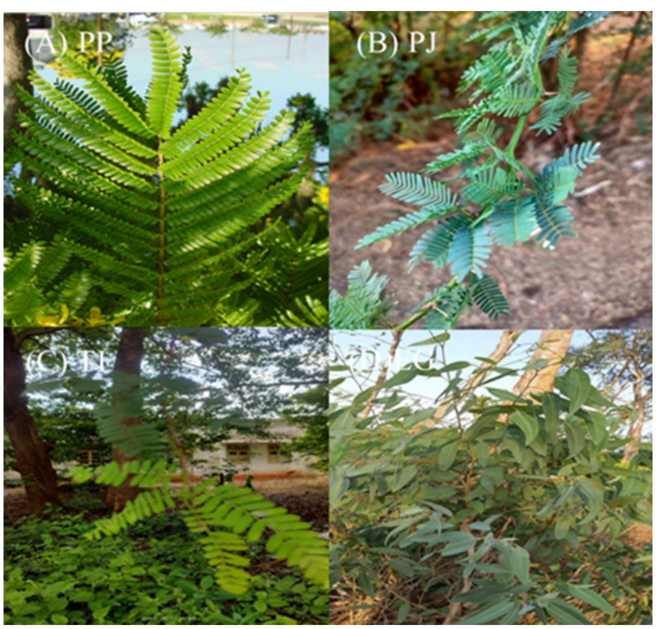


Figure 4: (A) PP (*P. pterocarpum*) (B) PJ (*P. Juliflora*) (C) TI (*T. indica* L) (D) EG (*E. globulus*)

Table 2: pH studies for plant leaf extract and plant leaf ash extract in aqueous medium

Allelopathic plant name	*Leaf extract pH*	*Aqueous ash pH*
P. pterocarpum	4.26	7.05
P. Juliflora	5.93	7.16
T. indica L	2.66	7.90
E. globulus	3.05	7.62

The pH data above clearly shows that the leaf extract of allelopathic plants is inherently acidic. However, when these leaves are dried, burned, and converted to ash, their pH shifts to a more basic nature.

MATERIALS AND METHODS

Preparation of Aqueous Leaf Extract

The fresh leaves were collected from Karnatak University Dharwad. Fresh leaves were weighed and washed with double distilled water. Washed leaves were mixed with distilled water and kept for stirring overnight. The sample was filtered to obtain aqueous extract of leaves, which is acidic in nature.

Ash Preparation

The leaves samples were collected from Karnatak University, Dharwad. They are dried in an oven at 60°C until the weight was constant (up to 7 days) and to make the sample homogeneous it is cut to 1 to 2 cm. Approximately 50 g of subsample placed in a crucible and burned in open air for about 15 minutes with agitation to maximize burning. Temperature was not recorded during the combustion process. Combustion was almost complete for each material with only small amounts of charcoal remaining in the ash.

Preparation of Mridukshara from Ash

The above mentioned allelopathic plants leaf ashes were collected, roughly 10 g of the ash powder is taken. The ash powder is combined with 2 to 3 times as much water and then sieved through cloth. Then the filtrate is taken in the beaker and slowly brought to boil while being stirred on magnetic stirrer. The hot solution is filtered, once it turns clear, smells strongly, and feels soapy. After discarding the residue, the strained liquid needs to be brought to boil. The solution is neither thick nor thin. When reduced to the desired consistency, the solution is taken from the heat and kept aside. Covered the mouth of beaker and kept it in an isolated place. This preparation is called madkyamakshara or alkaline caustic of middling strength.

RESULTS AND DISCUSSION

The ash prepared from different allelopathic plant leaves is taken for SEM, EDX and XRD analysis.

SEM and EDX Analysis of Ash

The surface morphology of plant ash was examined using a scanning electron microscope (SEM), and the elemental composition was analyzed with energy-dispersive X-ray spectroscopy (EDX) using a ZEISS instrument. To enhance the conductivity of the sample and improve imaging quality, the mounted sample was sputter-coated with a thin layer of gold. The thickness of the gold coating was approximately 10 μm. This coating minimizes charging effects

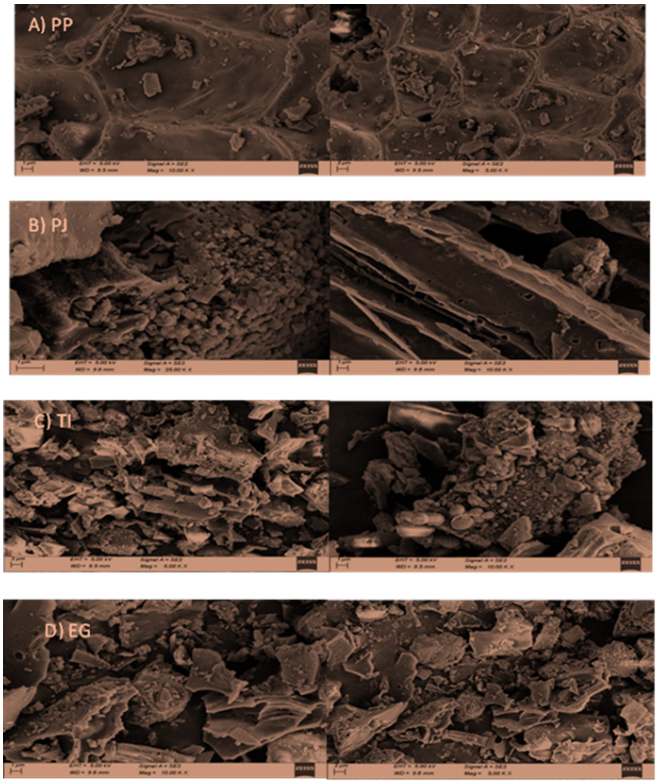
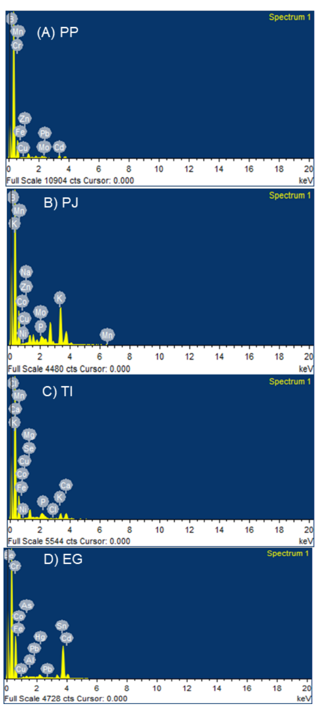


Figure 5: SEM images of indicated ash particles (A, B, C, D) for PP, PJ, TI, and EG.



Elements	Line	Mass%	Atomic %
B	K	76.22	99.63
Mo	K	1.62	0.19
Cd	K	1.23	0.12
Pb	K	1.09	0.06

Elements	Line	Mass%	Atomic %
B	K	77.65	93.17
P	K	1.45	0.61
K	K	17.26	5.73
Mo	K	3.64	0.49

Elements	Line	Mass%	Atomic %
Mg	K	27.48	37.07
P	K	12.72	13.46
K	K	25.84	21.67
Ca	K	33.96	27.79

Elements	Line	Mass%	Atomic %
Cd	K	27.77	28.87
Sm	K	72.23	71.13

Figure 6: EDX spectra of ash particles for PP, PJ, TI, EG

under the electron beam, ensuring accurate imaging and analysis. The sputter-coated sample was then subjected to SEM-EDX analysis. The SEM was operated at an accelerating voltage of 5 kV, which is suitable for achieving high-resolution surface imaging while preventing sample damage. Furthermore, the EDX analysis integrated with the SEM enabled the identification and quantification of the elements present in the sample. The combined SEM-EDX approach offers a comprehensive understanding of both the morphological and elemental characteristics of the plant ash, making it a valuable technique for material characterization.

SEM analysis shows that ash contains particles with sizes ranging from 1 to 100 μm. Microscope images show surface structural modifications and particle morphology. The surface of the plant's ash is uneven and rough: additionally, the particle size and shapes are also different. The particles vary in shape from spherical to long flakes. Some of the particles have a rough texture, while others seem smoother and more spherical. The particles range in size and shape, with some being angular and others more rounded. The spherical particles are likely smaller than the angular fragments.

The EDS spectra of plant leaf ashes are shown in (Figure 5) EDX analysis has provided evidence for the presence of chemical constituents present in the ash. The EDX spectrum is a plot of how frequently an X-ray is received for each energy level. An EDX spectrum normally displays peaks corresponding to the energy levels.

The EDX analysis of the plant leaf ash, as depicted in Figure 6, reveals the presence of several key elements. Among these are boron (B), potassium (K), magnesium (Mg), calcium (Ca), and phosphorus (P), which are well-known for their role in enhancing soil fertility and promoting the growth of neighboring plants. These elements act as essential nutrients, enriching the soil and supporting plant health. In addition to these beneficial elements, the analysis also detected trace amounts of elements such as lead (Pb), cobalt (Co), and others. While some of these trace elements may have environmental implications, their presence reflects the complex composition of plant ash.

XRD Analysis

The X-ray diffraction (XRD) analysis of plant leaf ash provides valuable insights into its crystalline structure and phase composition. The diffraction pattern reveals the presence of various crystalline phases, which correspond to the mineralogical components present in the ash. The Debye Scherrer equation, $D = K\lambda / \beta \cos\theta$, is employed to determine the crystalline size of the nanoparticles, where D denotes the nanoparticle's crystalline size, K represents the Scherrer constant (0.98), λ denotes the wavelength (1.54), β denotes the full width at half maximum (FWHM).

The analysis of plant leaf ash through X-ray diffraction (XRD) **(**Figure 7) reveals significant insights into the mineral composition and crystallinity of the ashes, common phases identified include oxides and carbonates of elements such as calcium, potassium, magnesium, and phosphorus. These compounds are often in the form of calcite ($CaCO_3$), potassium oxide (K_2O), magnesium oxide (MgO), and phosphate salts, which contribute to the ash's nutrient-rich properties.

Soil Analysis

Soil analysis plays a vital role in enhancing plant growth by examining the availability of essential nutrients and the overall characteristics of the soil. This process involves assessing key nutrients like nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O), which are crucial for plant health. It also evaluates important factors such as soil pH,

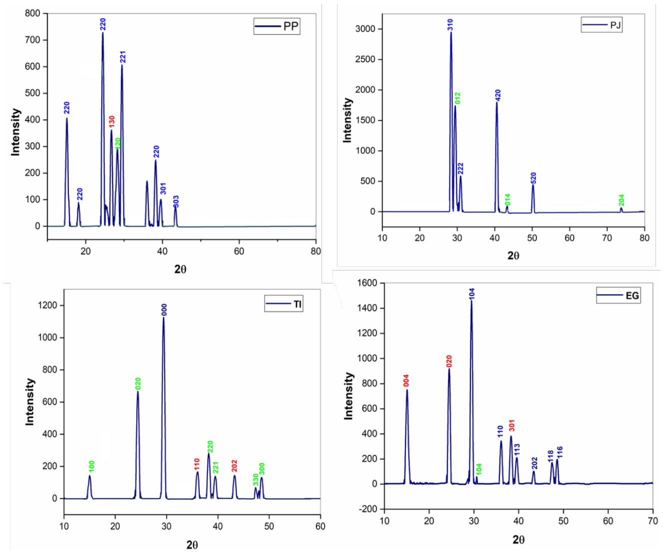


Figure 7: XRD graphs for PP, PJ, TI, EG.

Table 3: Comparative studies of soil before and after addition of allelopathic plant leaf ash

S. N	*Parameters/nutrients*	*Normal range*	*Soil*	*Soil + ash*
1.	Potential hydrogen (pH)	<6.3–8>	7.48	8.60
2.	Electrical conductivity (EC)	<1.0	0.34 ds/m	2.14 ds/m
3.	Organic carbon (OC)	0.5–0.75	3.8%	7.1%
4.	Available phosphorous (P_2O_5)	<12–25>	18.4 Kg/ha	39.4 Kg/ha
5.	Available potash (K_2O)	<180–280>	941 Kg/ha	841 Kg/ha
6.	Sulphur (S)	>10	12.4 PPM	12.4 PPM
7.	Boron (B)	>0.5	0.59 PPM	0.94 PPM
8.	Copper (Cu)	>0.2	1.84 PPM	2.41 PPM
9.	Magnesium (Mg)	>2.0	12.4 PPM	30.4 PPM
10.	Zinc (Zn)	>0.6	0.87 PPM	3.4 PPM
11.	Iron (Fe)	>4.5	12.4 PPM	25.4 PPM

humus content, total calcium carbonate ($CaCO_3$), available lime, organic matter, and total sulfur (S). Furthermore, soil analysis provides insights into organic carbon levels, micronutrients, and critical physical properties like potential hydrogen (pH), electrical conductivity, etc. By understanding these elements, we can make informed decisions to improve soil quality and promote optimal plant growth.

The results revealed that incorporating ash into soil raises its pH, shifting it from neutral to highly alkaline (Table 3). This addition also increases the concentration of vital nutrients, surpassing the levels typically considered sufficient. These nutrients include iron, zinc, magnesium, copper, boron, sulfur, potash, phosphorus, and carbon. Potassium, which is present as K_2O, may also appear in the form of potassium carbonate. Compared to soil alone, the soil mixed with ash shows a notably higher concentration of these essential elements. Specifically, organic carbon, phosphorus, iron, zinc, magnesium, and copper are more abundant in the soil + ash mixture. Additionally, electrical conductivity increases with the addition of ash. Therefore, the presence of these nutrients not only raises soil pH but also improves soil fertility, supporting better plant growth.

CONCLUSION

Allelopathic plant leaves are acidic, as confirmed by pH studies of their aqueous extracts. This acidity is attributed to the presence of organic acids such as phenols, tartaric acid, and chlorogenic acid, etc. However, when these leaves are converted to ash, the opposite characteristic is observed. The pH of the aqueous solution of the ash is found to be basic. Further analysis using EDX, SEM, and XRD revealed that the basicity of the ash is primarily due to the presence of elements like potassium (K), calcium (Ca), magnesium (Mg), and phosphorus (P). Further, it was also confirmed by carrying out a soil sample analysis test before and after the addition of ash to the soil sample. This clearly shows that the nutrient concentration has been increased after the addition of ash to the soil. Interestingly, XRD analysis also identified the presence of plant nutrients in the ash, including compounds such as calcite ($CaCO_3$), boron oxide (B_2O_3), etc. Based on these findings, we propose that the ash derived from these allelopathic plants can serve as a valuable soil amendment. The basic nature of the ash makes it suitable for neutralizing acidic soils, thereby enhancing soil fertility and plant growth. This approach provides an effective solution for managing these plants when they become a nuisance while simultaneously improving agricultural productivity.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest.

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DATA AVAILABILITY

Data will be made available on request.

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