

Impact of humic acid on various properties of soil and crop productivity- A review

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Summary

To raise the amount and quality of agricultural produce, numerous studies have been conducted in recent years. The development of agriculture is not just influenced by mechanization and new hybrid seeds; soil quality also plays a significant role. Lack of organic matter in soil frequently renders it unsuitable for plant growth. To address this problem and increase agricultural yields, humic compounds have started to be applied to soil in many parts of the world. Humic acid (HA) can now be applied to crops or soil using a variety of methods, including soil application, foliar application, seed treatment, root dipping, and drip irrigation, as HA is available in various forms viz., granule, powder, flakes, liquid and also in conjunction with inorganic fertilizers. However, soil application is the most effective in numerous studies. Numerous experiments on crops were carried out to determine the ideal dosage of humic acid, and it was found that character, yield, and soil characteristics all had a favourable impact on crop production. This review clarifies the significance of humic acid for various crops and the health of the soil, as well as how it increases agricultural output.

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Introduction

Maintaining agroecosystem productivity sustainably is getting more difficult as the world's population continues to rise. The only way to accomplish this is to increase crop production per unit area while having little or no negative environmental effects (Vitousek et al. 1997). Instead of boosting productivity and yield, many developing nations have increased production by transforming natural ecosystems into agriculture. Such declining production patterns are attributed to a decline in factor productivity, which can be linked to the emergence of multi-nutrient deficiencies and an increase in soil pathogens, weed flora, and nutrient deficiencies in general (Singh & Sharma 2001). There is an immediate and rapid loss of carbon due to anthropogenic actions that occur before this change in land use, such as a continuous cropping system and overuse of pesticides (Tilman et al. 2002). Farm equipment, fertilizers, insecticides, and fossil fuels are now significantly used in agriculture. There is an increase in greenhouse gas (GHG) emissions to the atmosphere as a result of these farming methods (Bhatt et al. 2018). The process of delivering several sources of nutrients to soil and crops intelligently and proportionately to maintain soil and crop productivity is known as "integrated nutrient management" (INM) (Parmar et al. 2003; Joshi et al. 2018). The importance of soil organic carbon in determining the feasibility of agriculture and the quality of the soil is frequently mentioned. Periodically

replenishing the soil by increasing the quantity of organic matter is crucial (Liu et al. 2006; Deore et al. 2023).

An essential step in the process is the creation of humus from organic material. Fulvic acid, humic acid, and humin are the components of humus. Humic acid is a material that is resistant to further weathering and has a dark, black colour. It is made up of plant and animal wastes by microbial decomposition. It is a complex molecule that naturally exists in soil, peat, the ocean, and freshwater. A notable source of humic acid is leonardite (Dulaimy et al. 2020). Mining can be used to find leonardite, an oxidized lignified sediment layer found in the lower subsurface levels. Humic acid has a complex chemical structure that cannot be encapsulated by a single structural formula. The range of its molecular weight is 1000–30,000. Humic acid contains carbon between 51 to 57 per cent, 4 to 6 per cent nitrogen, and 1 to 2 per cent phosphorus, along with trace amounts of other micronutrients (Haworth 1971). Numerous studies have been done in India to determine the impact of humic acid on various crops, but there hasn't been a thorough comparison of the results. Also, the connections between humic acid, the soil, and plant growth are not properly recognized. Research comparing the impact of various humic acid concentrations on various crop kinds is lacking. The growth, development, and yield of plants are influenced by a variety of biotic and abiotic variables. The role of humic acid in reducing the effects of disease infestation, soil salinity, and soil nutritional status has been described in this review paper. Any production of a crop is influenced by the soil's physical state and nutrient availability. This review article also describes the effect of humic acid on numerous soil parameters by outlining the substance's chemical composition, characteristics, and role in improving soil

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fertility. Humic acid can be used in a number of ways, although soil application and seed treatment are by far the most popular.

Humic acid properties

The most significant chemical byproducts of humic substances' degradation include aromatic carboxylic, phenolic, and aliphatic carboxylic acids. Depending on the environment in which they are located, various compounds are present at different relative levels. Most likely, humic substances are made up of monomers that were polymerized to form their fundamental chemical structure. Numerous humic compound functional groups that interact with metal ions, metal oxides, and metal hydroxides facilitate the breakdown of soil minerals. This interaction may occur by adsorption, ion exchange, or chelation. One of the most significant chemical breakdown products of humic substances is aliphatic carboxylic acids, which are also present in phenolic and aromatic carboxylic acids. Plants can obtain zinc, copper, and other nutrients while avoiding leaching with the use of metal-humic combinations. Humic chemicals stop leaching by adsorbing ammonium from urea. Amino and amide-nitrogen compounds seem to be significant in some bonding with clay minerals and humus. Carboxyl and phenolic hydroxyl may also interact in this way. The amount of released -COOH and -OH groups affect the cation exchanger's capability because of the significant amount of negative charge generated by proton release. As a result, humic compounds' cation exchange capacity is not constant but rather varies (Biswas & Mukherjee 1987). It is composed of chemically intricate non-biochemical organic elements that balance plant nutrition and enhance soil health. Thus, it is crucial for the productivity of the soil and plants (Adani et al. 2006).

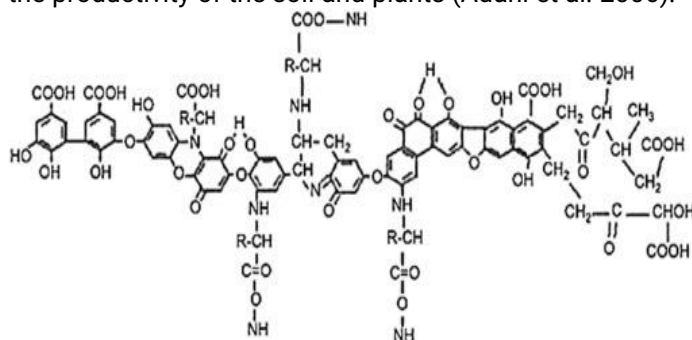


Figure 1. Humic acid structure

Humic acid extraction and fractionation from organic matter

Humic acid fraction, which is extracted from soil using alkali or neutral salts, precipitates as a result of acidity. Some samples of grassland soils included as much as 30% ash by mass, which is a considerable amount of ash. The amount of ash in the finished product can be greatly reduced by multiple mineral acid precipitations and passage through ion exchange resins. After the acid has been re-dissolved in alkali and the pH has been set to 7.0, clay removal is performed using a high-speed centrifuge. By utilizing acidic solutions, such as hydrofluoric acid, to treat humic acids, low-ash humic acids can be produced (HF). The initial step involves dissolving the raw humic acid material in a base solution,

setting the ionic strength to 0.1 M with KCl, and centrifuging the mixture to remove clay. The sample is then repeatedly treated with a dilute acid solution comprised of 0.3 N HF and 0.1 N HCl after the solution is acidified to precipitate humic acids (Rattan et al. 2015).

Humic acid use in agriculture

These days, a variety of problems, such as dryness, water logging, and acidic or alkaline conditions, prevent the majority of soils from absorbing plant nutrients. Humic acid utilization is the most important means of promoting sustainable agriculture to prevent this. If humic acid is absent from the soil to enable plants to get nutrients, fertilizers are a waste of money for farmers. Humic acid is therefore a crucial factor in the absorption of nutrients and crop output. Humic acid improves the physiochemical and biological characteristics of soil by acting as a soil conditioner.

Effect of humic acid on soil properties

Humic acid (HA) is essential for improving soil properties, plant growth, and other agronomic aspects. To assure the viability of agricultural output, humic acid-based products have been included in crop cultivation in recent years. The research indicates that HA may have a positive impact on the physical, chemical, and biological characteristics of the soil. The ability of the soil to store water, its cation exchange capacity (CEC), pH, its carbon content, the activity of the soil's enzymes, the cycling of macronutrients, and its availability are among these qualities (Ampong et al. 2022; Dular & Pratiba 2023). Numerous substances, including macromolecules, hydrophobic, hydrophilic, and functional groups, can be found in humic acid. Humic acid's hydrophilic properties absorb hydrogen ions, which increases the soil's ability to store water. Humic acid (HA), which is present in organic humus has the potential to have a substantial impact on plant growth and soil health. Additionally, it enhances the structure and water-holding capacity of the soil (Fahramand et al. 2014). Both the addition and adsorption of humic acid to the soil boost aggregate stability, but the adsorption strategy yields more notable results (Chaney & Swift 1986). By triggering the production of heat-tolerance enzymes and boosting the permeability of the plant membrane, the application of humic acid in arid areas gives plants protection against heat stress. By improving the ability of soil particles to aggregate, HA strengthens the soil structure and lowers soil erosion. Humic acid positively affects the cell division and development of roots (Khaled & Fawy 2011, Haldhar et al. 2023). Humic acid's high surface area as a component of humus results in a higher cation exchange capacity. As a result, HA exchanges the nutrients from organic fertilizer, stores them in its molecule, and then releases them gradually as needed by the plants. The result of the breakdown of plant matter is humic acid. It possesses several binding sites for micronutrient Zn as well as macronutrients Ca, P, and K. The yield contributing character, plant growth indices, and yield of chickpeas were greatly improved by foliar spraying humic acid at a rate of 400 ppm combined with NAA (Naphthalene Acetic Acid) and vermicompost waste (Kapase et al. 2014). The study was carried out at BHU in

Varanasi. The study assessed how INM affected the properties of the soil. They used RDF, PGPR, and HA at levels of 50, 75, and 100% respectively. *P. fluorescens* and humic acid both had an impact on soil physico-chemical parameters and cabbage yield. Higher levels of organic carbon (5.2 g/kg), available N (319 kg/ha), available P (37.9 kg/ha), and available K (332 kg/ha) were found in the 100% RDF + *P. fluorescens* and humic acid as compared to control (Verma et al. 2017). A field study revealed that humic acid increased soil pH, salt content, organic matter, phosphorous, magnesium, iron, and manganese levels. The best soil organic matter concentration was 40 kg/ha of HA treatment, which resulted in a pH reduction from 7.51 to 7.39. As humic acid applications of 0, 20, and 40 kg/ha were made, the HA group's P, Mg, Fe, and Mn levels were the highest. The humic acid group had the highest level of phosphorous, magnesium, iron and manganese as 0, 20 and 40 kg/ha of humic acid were applied (Dincsoy and Sonmez, 2019). In terms of yield and economics, a sufficient HA dose is required. The maximum value of mineral content was observed at 25 kg/ha among several dosages of HA in maize ranging from 5 to 30 kg/ha. Additionally, the results demonstrate a reduction in plant nutrient uptake at HA dosages of 30 kg/ha, showing the quadratic relationship between yield and HA doses (Daur & Bakhshwain 2013; Sarangthem et al. 2023a). The effect of HA depends on the level of doses; a higher amount of H5 (200 mg/kg of soil) gave maximum value in all parameters of soil nutrient status such as organic matter, total nitrogen, available phosphorus, and potassium. In comparison, H4 (150 mg/kg) was found non-significant with H5. The reaction of soil phosphorus

to HA was much greater than the responses of organic matter, nitrogen, and potassium among the several nutrients investigated (Arjumend et al. 2015). The presence of a microbial population in the soil is an indication of a good soil fertility index. Microorganisms facilitate the availability of nutrients in the soil by decomposing the organic residue and also prevent the residual effect of fertilizer in the soil. As HA improves the structure of the soil, it increases the porosity/aeration in the soil. Thus, HA stimulates plant enzymes and acts as an organic catalyst in various biological processes. The application of 100% NPK along with 20 or 30 kg HA/ha recorded sugarcane's maximum activity of catalase, dehydrogenase, and phosphatase. It might be due to the higher efficiency of nitrogen fertilizer in the presence of HA (Sellamuthu & Govindaswamy 2003). In another study, the application of HA changed the microbial population in the soil. It was found that HA increased the fungus population but decreased the bacterial numbers under the continuous cropping of peanuts. The acidic nature of HA reduces the pH of the soil, and generally, bacteria grow in the range of pH 6–7; thus, it might be the reason for the lower number of bacteria (Li et al. 2019; Sarangthem et al. 2023b). Treatment with HA has been demonstrated to be beneficial for plant growth, and researchers in China as observed that after applying HA to sweet potatoes, populations of Firmicutes bacteria, Basidiomycota fungi, and Mortierellomycota fungi all increased. Five treatments were employed in this analysis namely, control (C), humic acid urea, HA activator, nitrogen fertilizer weathered coal and urea (Chen et al. 2017).

Table 1. Effect of humic acid doses on properties of soil and growth of various crops

Soil properties/Crop	Dose of humic acid	Observation recorded
Soil water content (Piccolo et al. 1996)	0.05 g/kg	Significantly increased the field capacity (25.9%), permanent wilting point (21.7%), and available water content (29.9%) in Acireale soil than control.
Soil aggregates (Piccolo et al. 1996)	100–200 kg/ha	Increased the stable soil aggregates range from 40–120% than control.
Sugarcane (Sellamuthu & Govinda Swamy 2003)	20 kg/ha	Catalase and alkaline phosphate activity
	30 kg/ha	Dehydrogenase activity
Mustard (Rajpar et al. 2011)	6.35 kg/acre	Increased growth and yield
Fodder maize (Daur & Bakhshwain 2013)	25 kg/ha	Improved growth and quality of fodder maize
Wheat (Arjumend et al. 2015)	150 mg/kg	Increased shoot length 18%, root length 29%, and yield 19–55% as compared to control.
Chickpea (Kahraman 2017)	9 kg/ha	Increased the number of branches and pods per plant and seed yield.
Tobacco Rong et al. 2020	14.8 kg/ha	Decreased the concentration of Pb, Cd, Zn and Cu by 39, 37%, 29%, and 18%, respectively, as compared to control.
Almond (Abourayya et al. 2020)	30g/young tree	improving growth and nutritional status of Nonpareil almond young trees; stem length (112.6cm), diameter (13.00 mm), number of branches (44.55/young trees), and number of leaves (675.20/young trees)

Effect of humic acid on crop production

A form of organic material known as humic acid can be used to improve the quality of soil and enable plants to

take in more water and minerals. As a consequence of this, there is a possibility that the severity of the condition will decrease as a consequence of this

improvement. It's possible that the compounds could directly influence soil-borne plant diseases in humic substances. In vitro studies showed that the humic substance prevented the growth of *Fusarium oxysporum* species *melons* and *lycopersici*, in addition to *Alternaria alternata* and *Fusarium culmorum*. There is a possibility that the potential of humic acid to reduce the severity of diseases that affect strawberry plants is associated with the roots of the plant growing more quickly and, as a result, absorbing a greater quantity of nutrients and water (Khafagi et al. 2018). HA is a stable portion of carbon, which regulates and releases nutrients such as nitrogen and phosphorus, which could cause increased growth and yield metrics. This would lower the need for inorganic fertilizer for plant growth. HA stimulates the uptake of major and minor nutrients, the activation and inhibition of enzymes, enhances the activity of microorganisms in the rhizosphere, improves membrane permeability and protein synthesis, and increases biomass production. All of these processes are necessary for HA to be effective at promoting plant development (El-Ghamry et al. 2009). Black cumin (*Nigella sativa* L.) grain yield was significantly affected by humic acid at all levels, with the highest rate (531.24 kg/ha) being attained with humic acid treatment (3 kg/ha) and the lowest rate (398.72 kg/ha) being attained with control. When 3 kg/ha of humic acid was given to the soil, the grain yield increased by 33.24 per cent (Aiyafar et al. 2015). HA has altered germination in medicinal herbs such as *Borago officinalis* and *Cichorium intybus* favourably. Humic acid levels ranged from 0, 15 and 30 g/L. The findings showed that, except for germination percentage and mean germination time, humic acid (30 g/L) strongly altered the plant's germination attributes, including radical fresh weight, seedlings, and pedicle length (Ebrahimi and Miri, 2016). Humic acid and potassium treatments considerably increased grain yield and yield-related elements in chickpea. Humic acid and potassium were applied in dosages of 0, 30, and 60 kg/ha, respectively. The combination of 20 kg P₂O₅ and 60 kg humic acid produced the highest seed yield (286.9 kg/ha) in this study (Donder and Togay, 2021; Sarangthem et al. 2023c). The mung bean root's increased biomass after HA treatment may have an impact on how well the plant absorbs minerals, particularly potassium. The results of the study also showed that humic acid increases the plant's tolerance to salinity by lowering its sodium concentration, which helps to alleviate the negative effects of mild salt stress (50 mM NaCl) on the growth of mung bean plants. However, administration of HA during salt stress (100 mM NaCl) showed erratic outcomes in the consumption of the examined several nutrients. It didn't seem to play a significant part in enhancing the absorption of those nutrients or lessening the negative effects of salt. Additional research is necessary to completely understand the role that HA plays in regulating the permeability of membranes because HA did not significantly affect Ca, Mg, Mn, or Zn (Kalyoncu et al. 2017). A two-year study on mung bean evaluated the effect of humic acid in its solid and liquid forms. The

outcome showed that the maximum dose (60 kg/ha) boosted physiological indicators besides HA in both years, including photosynthesis, transpiration rate, total chlorophyll, stomatal conductance, and carotenoids enhanced the P and K content of mung bean by a significant amount (Alghabari 2020). In an experiment on mung beans, HA was treated using three different techniques: soil treatment (1, 2 and 3 kg/ha), foliar spray (0.01, 0.05, and 0.1%), and seed priming (0.5, 1, and 1.5%). The soil application method, out of the three HA application methods, provided the best value for all yield-attributing attributes and yield, according to the results (Waqas et al. 2014). By increasing the number of branches, which is a good indication of proper rectangularity in plants, humic acid incorporation enhances plant population. To make the best use of the limited growth resources available and, as a result, stabilize yields, the optimum planting geometry must be tailored to a certain genotype (Arya et al. 2020). Humic acid applied topically improves the soil's nutritional condition and growth factors. Parameters such as improvements in plant development and nutrient uptake by plants, also enhance the crop yield and quality. Humic acid improves nutrient status; as a result, it may cause farmers to use less nitrogen, phosphorous, and potassium fertilizer, which will reduce soil pollution and expenses (El Desuki 2004). Karimi et al. (2020) found increased chlorophyll content, leaf area, stem diameter, and dry shoot biomass of calendula (*Calendula officinalis* L.) with a combined application of biochar (40 g/kg) and humic acid (500 mg/L). Both were applied at the rate of 0, 250, and 500 mg/L and 0, 20, and 40 mg/kg, respectively. The most successful treatment combination was biochar (40 mg/kg) and humic acid (500 mg/L). Humic acid concentration (9 and 12 kg/ha) increased the number of pods per plant, plant height, and yield. The pod yield per plant ranged from 29.56 (12 kg/ha) to 41.44 (9 kg/ha). Fertile pods per plant ranged from 82.09% (control) to 89.66% (12 kg/ha) in chickpeas (Kahraman, 2017). The protein content of chickpea seeds ranged from roughly 17–20%, making them an essential component of a vegetarian diet (Upadhyay et al. 2019). It was observed that a new non-chemical fertilization approach for enhancing the growth and nutritional status of Nonpareil almond young trees in Nubaria circumstances is the foliar spray of natural bio-stimulant milagro at 30ml/l combined with soil application of humic acid at 30g/young plants. Additionally, its effects are inexpensive and safe for the environment Abourayya et al. (2020). Pulses are a great source of protein and are known as "little factories" for producing nitrogen due to their ability to incorporate nodules, which fix atmospheric nitrogen, into their root systems. Direct proportionality exists between the total number of nodules on a plant and the total nitrogen content of the soil. In comparison to the control, chickpeas grown with the required amount of fertilizer and humic acid added had a significantly higher nodule count and dry weight (Bhatt et al. 2022).

Conclusion

This review has demonstrated that the use of humic acid could have a considerable impact on the agronomic performance of many crops, including plant height, spread, dry matter accumulation, crop growth rate, relative growth rate, nodule count, nodule dry weight, nutritional content, yield components, yield, and quality. In this article, the impact of humic acid on soil quality indicators such as bulk density, water holding capacity, particle density, soil structure, porosity, soil pH, electrical conductivity, organic matter content, NPK content, microbial activity and cation exchange capacity is also reviewed. Humic acid is the main component of humus and the organic compound that it creates. It possesses a number of characteristics that enhance the soil's fertility. By enhancing the soil's physico-chemical and biological characteristics, soil fertility must be maintained. The use of humic acid has been shown to have positive effects on the production of fruits and vegetables in addition to cereals and pulses. Humic acid increases crop yield while also improving soil quality when it is administered to a variety of crops at various rates and dosages.

Its use in agricultural production is beneficial, whether it is applied to the soil or the plant itself, and through a range of application techniques, including soil application, seed treatment, and foliar application. Around the world, the majority of humic acid research is done in greenhouses or pots. To fully understand the potential of humic acid, field tests must be conducted. Humic acid treatment has produced a rapid response, in contrast to the several organic manures that are offered on the market, all of which behave slowly. Humic acid therefore has the potential to significantly contribute to the practice of sustainable agriculture by reducing the amount of fertilizer needed. To establish the most efficient method and the right amount of humic acid, additional research in the field is required.

Declaration of Interests

The authors have no conflict of interest to declare.

Data Sharing

All relevant data are within the manuscript.

References

- Adani F, Sepagnol M & Nierop KGJ. 2006. Biochemical origin and refractory properties of humic acid extracted from maize plants. *Biogeochemistry*, 82(1): 55–65.
- Aiyafar S, Poudineh HM & Forouzandeh M. 2015. Effect of humic acid on qualitative and quantitative characteristics and essential oil of black cumin under water deficit stress. *DAV. International Journal Science*, 4: 89-102.
- Alghabari F. 2020. Evaluating mung bean performance under different types and rates of humic acid application in arid conditions of Saudi Arabia. *International Journal of Agriculture and Biology*, 24 (5): 1273-1278.
- Ampong K, Thilakaranthna MS & Gorim LY. 2022. Understanding the role of humic acids on crop performance and soil health. Retrieved from <https://doi.org/10.3389/fagro.2022.848621>
- Arjumend T, Abbasi MK & Rafique E. 2015. Effects of lignite-derived humic acid on some selected soil properties, growth, and nutrient uptake of wheat (*Triticum aestivum* L.) grown under greenhouse conditions. *Pakistan Journal of Botany*, 47(6): 2231-2238.
- Arya A, Mahapatra SS & Singh VK. 2020. Growth and yield attributing characteristics of chickpea varieties as influenced by altering plant rectangularity by varying plant spacing. *International Journal of Chemical Studies*, 8(4): 3803-3810.
- Bhatt P, Kumar R & Chilwal A. 2018. Effect of different tillage practices and precision nutrient management on energy use efficiency, economics and wheat yield (*Triticum aestivum* L.). *International Journal of Chemical Studies*, 6(5): 373-376.
- Bhatt P, Kumar R & Reena. 2018. Effect of precision nutrient management and different tillage practices on growth, yield attributes and yield of wheat (*Triticum aestivum* L.) *International Journal on Agricultural Sciences*, 9(1): 1-4.
- Bhatt P, Singh VK, Singh R, Malik N & Chandra R. 2022. Effect of humic acid and PGPR on nodulation in chickpea (*Cicer arietinum* L.). Retrieved from IV International Conference on Innovative and Current Advances in Agriculture & Allied Sciences (ICAAAS-2022).
- Biswas TD & Mukherjee SK. 1987. *Textbook of soil science*. Tata McGraw Hill. pp: 106–109.
- Chaney K & Swift RS. 1986. Studies on aggregate stability: The effect of humic substances on the strength of re-formed soil aggregates. *Journal of Soil Science*, 37(2): 337–343.
- Chen X, Kou M, Tang Z, Zhang A, Li H & Wei M. 2017. Responses of root physiological characteristics and yield of sweet potato to humic acid urea fertilizer. *Plos One*, 12(12): 9-15.
- Daur I & Bakhshwain AA. 2013. Effect of humic acid on growth and quality of maize fodder production. *Pakistan Journal of Botany*, 45(1): 21–25.
- Deore SB, Satpute GU & Konde NM. 2023. Effect of harvested rainwater in farm ponds of a saline area on soil properties. *Journal of Agriculture and Ecology*, 15: 79–84. <https://doi.org/10.58628/JAE-2315-113>.
- Dinçsoy M & Sönmez F. 2019. The effect of potassium and humic acid applications on yield and nutrient contents of wheat (*Triticum aestivum* L. var. Delfii) with same soil properties. *Journal of Plant Nutrition*, 42(20): 2757–2772.
- Donder E & Togay Y. 2021. The effect of humic acid and potassium applications on the yield and yield components in chickpea (*Cicer arietinum* L.). *Journal of Agricultural Sciences*, 5(3): 568-574.
- Dulaimy MA & El-Fahdawi WA. 2020. Effect of humic acid on growth and yield of barley humic acid as interacted with row spacing. *Indian Journal of Ecology*, 47: 62-65.
- Dular AK & Pratibha. 2023. Comparative analysis of various soils concerning chemical parameters in command (canal irrigated) and uncommand (well irrigated and rainfed) areas of Raisinghnagar, District Sriganganagar (Rajasthan). *Journal of Agriculture and Ecology*, 15: 85–89. <https://doi.org/10.58628/JAE-2315-114>.
- Ebrahimi M & Miri E. 2016. Effect of humic acid on seed germination and seedling growth of *Borago officinalis* and *Cichorium intybus*. *Ecopersia*, 4(1): 1239-1249.
- El-Desuki M. 2004. Response of onion plants to humic acid and mineral fertilizers application. *Annals of Agriculture Science* 42(4): 1955-1964.
- El-Ghamry AM, Abd El-Hai KM & Ghoneem KM. 2009. Amino and humic acids promote growth, yield and disease resistance of faba bean cultivated in clayey soil. *Australian Journal of Basic Applied Science*, 3(2): 731-739.
- Fahramand M, Moradi H, Noori M, Sobhkhizi A, Adibian M, Abdollahi S & Rigi K. 2014. Influence of humic acid on increased yield of plants and soil properties. *International Journal of Farming and Allied Sciences*, 3(3):339–341.
- Haldhar SM, Hussain T, Thaochan N, Bana RS, Jat MK, Nidhi CN, Sarangthem I, Sivalingam PN, Samadia DK, Nagesh M, Singh B & Sunpapao A. 2023. Entrepreneurship opportunities for

- agriculture graduate and rural youth in India: a scoping review. *Journal of Agriculture and Ecology*, 15: 1-13.
24. Haworth RD. 1971. The chemical nature of humic acid. *Soil Science*, 111(1): 71-79.
 25. Joshi G, Chilwal A & Bhatt P. 2018. Soil nutrient studies under integrated nutrient management in baby corn (*Zea mays* L.). *The Pharma Innovation Journal* 7(9): 41-43.
 26. Kahraman A. 2017. Effect of humic acid applications on the yield components in chickpea. *Journal of Agricultural Faculty of Gaziosmanpasa University*, 34(1): 218-222.
 27. Kalyoncu O, Akinci S & Bozkurt E. 2017. The effects of humic acid on growth and ion uptake of mung bean (*Vigna radiata* (L.) grown under salt stress. *African Journal of Agricultural Research*, 12(49): 3447-3460.
 28. Kapase PV, Deotale RD, Sawant PP, Sahane AN & Banginwar AD. 2014. Effect of foliar sprays of humic acid through vermicompost wash and NAA on morpho-physiological parameters, yield, and yield contributing parameters of chickpea. *Journal of Soils and Crops*, 24(1): 107-114.
 29. Karimi E, Shirmardi M, Dehestani AM, Gholamnezhad J & Zarebanadkouki M. 2020. The effect of humic acid and biochar on growth and nutrients uptake of calendula (*Calendula officinalis* L.). *Communications in Soil Science and Plant Analysis*, 51(12): 1658-1669.
 30. Khafagi EY, El-Abeid SE, Soliman MS, El-Nahas SE & Ahmed Y. 2018. Role of Arbuscular Mycorrhizae Fungi and humic acid in controlling root and crown rot of strawberry *Plant Pathology Journal*, 17(2): 65-74.
 31. Khaled H & Fawy HA. 2011. Effect of different levels of humic acids on the nutrient content, plant growth, and soil properties under conditions of salinity. *Soil and Water Research*, 6(1): 21-29.
 32. Li Y, Fang F, Wei J, Wu X, Cui R, Li G & Tan D. 2019. Humic acid fertilizer improved soil properties and soil microbial diversity of continuous cropping peanut: a three-year experiment *Scientific reports*, 9(1):1-9.
 33. Liu X, Herbert SJ, Hashemi AM, Zhang X F & Ding G. 2006. Effects of agricultural management on soil organic matter and carbon transformation-a review. *Plant Soil and Environment*, 52(12): 531-542.
 34. Parmar DK, Parmar V & Katoch R. 2023. Effect of different agricultural practices on yield, profitability and soil properties under maize (*Zea mays*) – barley (*Hordeum vulgare*) cropping system. *Journal of Agriculture and Ecology*, 16: 32-36. <https://doi.org/10.58628/JAE-2316-207>.
 35. Rattan RK, Katyal JC, Dwivedi BS, Sarkar AK, Bhattacharya T, Tarafdar JC & Kukal SS. 2015. *Soil Science: An Introduction*, Indian Society of Soil Science, New Delhi. pp: 393-394.
 36. Saha R, Saieed MAU & Chowdhury MAK. 2013. Growth and yield of rice (*Oryza sativa*) as influenced by humic acid and poultry manure. *Universal Journal of Plant Science*, 1(3): 78-84.
 37. Sarangthem I, Haldhar SM & LK Mishra. 2023c. Embracing the 5A approach for soil-plant-microorganisms health connection. Souvenir of "International conference on one health-one world (Linking soil health with plant, animal and human health)" during 28-29 December 2023 at RVSKV, Gwalior. pp: 49-58.
 38. Sarangthem I, Mishra LK, Haldhar SM & Mishra AK. 2023b. Sustainable Agriculture Development of North East India through Nurturing BHUMI (Soil). Pub: College of Agriculture, Iroisemba, CAU, Imphal, pp. 159, ISBN: 978-81-947184-3-7.
 39. Saranthen I, Mishra LK & Haldhar SM. 2023a. Nature-based solutions for climate resilient agriculture: embracing the 5A approach. XVI Agricultural Science Congress 2023 during 10-13 October 2023 at ICAR-CMFRI, Kochi, pp: 52.
 40. Sellamuthu KM & Govindaswamy M. 2003. Effect of fertilizer and humic acid on rhizosphere microorganisms and soil enzymes at an early stage of sugarcane growth. *Sugar Technology*, 5(4): 273-277.
 41. Shaaban SA, Manal FM & Afifi MH. 2009. Humic acid foliar application to minimize soil applied fertilization of surface irrigated wheat. *World Journal of Agricultural Sciences*, 5: 207-210.
 42. Singh VK & Sharma BB. 2001. Productivity of rice as influenced by crop diversification in wheat-rice cropping system on Mollisols of foothills of Himalayas. *Indian Journal of Agricultural Science*, 71(1): 5-8.
 43. Tilman D, Fargione J, Wolff B, Dantonio C, Dobson A, Howarth R & Swackhamer D. 2001. Forecasting agriculturally driven global environmental change. *Science*, 292(5): 281-284.
 44. Upadhyay SP, Pareek N, Raverkar KP, Chandra R & Singh VK. 2019. Effect of different cropping pattern ratio on yield and yield attributes of chickpea under chickpea+coriander intercropping system. *International Research Journal of Natural and Applied Sciences*, 6(2): 1-7.
 45. Verma R, Maurya BR, Meena VS, Dotaniya ML, Deewan P & Jajoria M. 2017. Enhancing production potential of cabbage and improves soil fertility status of Indo-Gangetic Plain through application of bio-organics and mineral fertilizer. *International Journal of Current Microbiology and Applied Sciences*, 6(3): 301-309.
 46. Vitousek PM, Mooney HA, Lubchenco J & Melillo JM. 1997. Human domination of Earth's ecosystems. *Science*, 277(5): 494-499.
 - Waqas M, Ahmad B, Arif M, Munsif F, Khan AL, Amin M & Lee IJ. 2014. Evaluation of humic acid application methods for yield and yield components of mung-bean. *American Journal of Plant Sciences*, 5(15): 2269-2276.