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Effect of Humic substances on soil properties and crop production: A critical review

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Abstract
Humic substances (Humin, fulvic and Humic acids) are widely used as fertilizers or plant growth stimulants, although their mechanism of action still remains partially unknown. Humic substances may be applied either directly to the soil or as foliar sprays. Despite both kind of application are commonly used in agricultural practices, most of the studies regarding the elicited response in plants induced by HS are based on the root application of these substances. Humic acid is an eco-friendly product needed in lesser quantity when compared to other chemical fertilizers and manures. Humic Acid can be integrated into the soils in the form of manure, it improves the physical properties of the soil. Advantage of humate based fertilizers to the soil is that the producer can again become a steward of the soil by developing a more ecologically sound agricultural production system (Ravichandran 2011). Humates enhances the crop productivity not only through improving physical chemical and biological properties of soil (Keeling *et al*., 2003; Mikkelsen, 2005) [20], but it also offers plants resistance to pest and disease, besides acting as the growth stimulant.

Keywords: Effect of Humic acid- soil properties-agricultural crops

1. Introduction
Humic acid stimulates the plant growth consequently yield by enhancing the uptake of plant nutrients and also acting on various mechanisms such as cellular respiration, photosynthesis, protein synthesis and enzyme activities. This substance also regulates the plant growth hormones due to production of indole acetic acid or its precursors. Humic acid serves as an effective adsorption and retention complex for inorganic plant nutrients (Mayhew, 2004) [39]. Humic acid is a natural polymeric composition which is produced as a result of decaying organic matters in soil, peat and lignin and can be used in order to increase crop product (Sabzevari *et al*., 2008). Usually Humic acid applied to soil as organic amendment but it was reported that foliar application of Humic acid can also improve the plant growth and accumulated photosynthetic matters. Further, it was reported that Humic acid has positive effect on the quality of crops though increasing the amount of sugar and reducing decay (Neri *et al*., 2002; Abdel *et al*., 2007; Yildirim, 2007) [40, 41, 42]. One of the most disruptive human activities is high-external input agriculture which has been justified by the current economic paradigm due to high productivity and the need to feed a growing population and we are dangerously close to the edge of the planet resources and both hunger and food insecurity has increased (Olivares *et al.*, 2017) [43]. Excessive use of non-renewable chemical fertilizers and pesticides risks agricultural sustainability through the deterioration of soil and water resources, environmental quality (Ekin *et al.*, 2019) [44]. Humic acid is an important soil component that can improve nutrient availability and impact on other important chemical, biological, and physical properties of soils (Meganind *et al.*, 2015). The ecological benefits of Humic acids are diverse and represent profitable and effective solutions for environmental problems and preservation of the environment (Manal *et al*., 2016) [58]. HA particularly K-Humate has potential to be used as an effective conversation and management tool for sustainability of the soil environment (Gumus *et al*., 2015) [59].
Sustenance of soil fertility is the key to crop productivity. Prolonged use of chemical fertilizers alone in intensive cropping systems leads to unfavourable soil nutrient status, harmful effects on soil physico-chemical and biological properties and thus defines the concept of sustainable crop production. Foxtail millet (*Setaria italica* L.) is one of the earliest cultivated crops, extensively grown in the arid and semi-arid regions of Asia and Africa. Foxtail millet contains significant levels of protein, fiber, mineral, and phytochemicals. Anti-nutrients such as phytic acid and tannin present in this millet can be reduced to negligible levels by using suitable processing methods (Hariprasanna 2016) [18].

Benefits of Humic acid

Some beneficial effects of Humic acid are:1) Addition of organic matter to organically- deficient soils 2) Improved nutrient uptake 3) Increased chlorophyll synthesis 3) Increase root vitality 5) Better seed germination 6) Increased fertilizer retention capacity 7) Stimulate beneficial microbial activity 8) Healthier plants and improved yields.

Humic acids are beneficial in freeing up nutrients in the soil so that they are become available to the plant as needed (Khaled *et al.,* 2011) [46]. As the Humic acid molecules are small, which "allows them to reach the plant plasma membrane, where they effectively influence the assimilation of nutrients" (Quilty, 2011) [47]. Humic acid also accumulates toxic heavy metals very efficiently (Sinha *et al.,* 2011) [48]. HA can enhance nutrient availability and improve chemical, biological, and physical soil properties (Meganind *et al.,* 2015). The direct and indirect beneficial effects of HA on plant growth and development are their effect on cell membranes which lead to the enhanced transport of minerals, improved protein synthesis, plant hormone-like activity, promoted photosynthesis, modified enzyme activities, solubility of micro-elements and macro-elements, reduction of active levels of toxic minerals and increased microbial populations (Hamideh *et al.,* 2013) [45].

Effect of Humic acid on soil properties

Humic acids are organic compounds that play crucial roles in enhancing the qualities of soil, the growth of plants, and other agronomic factors. In recent years, products based on Humic acid have been incorporated into crop production to ensure the agricultural output's continued viability. According to the research that was conducted, HA has the potential to have a beneficial effect on the soil's physical, chemical, and biological properties. These properties include the aggregation and relative proportion of soil particles, the capacity of soil to hold water, cation exchange capacity (CEC), pH, carbon content in the soil, enzymes activity, macronutrients cycling, and availability (Ampong *et al*. 2022) [49]. Humic acid contains many compounds, including macromolecule, hydrophobic, hydrophilic, and functional groups. The hydrophilic nature of Humic acid attracts the hydrogen ions that lead to increased water holding capacity of the soil. Organic humus contains Humic acid (HA), which has the potential to have a significant impact on soil health and plant development. Also, it helps to improve the soil's structure and water storage capacity (Fahramand *et al*. 2014) 50. Addition of Humic acid to the soil, whether by addition or adsorption, both help increase aggregate stability, while the adsorption method gives more significant results (Chaney and Swift 1986) [51]. In the arid region, the application of HA provides resistance to plants against heat stress by producing heat tolerance enzymes and increasing the permeability of the plant membrane.

Humic acid positively impacts cell division and root development (Khaled and Fawy 2011) [46]. As a part of humus, Humic acid's large surface area leads to more cation exchange capacity. Thus, HA exchanges the nutrients from organic fertilizer and store in its molecule, then slowly releases as per the requirement of plants. Humic acid is the product of the decomposition of plant residue. It has many binding sites for macro-nutrients such as Ca, P, and K, and Zn micronutrient. Foliar spray of Humic acid at the rate of 400 ppm along with NAA (Naphthalene acetic acid) and vermicompost waste gave significantly superior yield attributing character, plant growth indices, and yield of chickpea (Kapase *et al*. 2014) [52]. An experiment was conducted at BHU, Varanasi. The study evaluated the effect of INM on soil characteristics. They employed 50, 75, and 100% RDF, PGPR, and HA. P. fluorescens and Humic acid both affected cabbage yield and soil physicochemical parameters. One hundred per cent RDF + P. fluorescens and Humic acid recorded higher organic carbon (5.2 g/kg), available P (37.9 kg/ha), and available K (332 kg/ha) than control. The same treatment found a maximum N (319 kg/ha) (Verma *et al*. 2017) [36]. A field study showed that soil's pH, salt content, organic matter, phosphorus, magnesium, iron, and manganese were all elevated by Humic acid. The best amount of soil organic matter was 40 kg/ha of HA treatment, which dropped the pH from 7.51–7.39. The HA group had the highest P, Mg, Fe, and Mn levels as 0, 20 and 40 kg/ha of Humic acid were applied (Dinçsoy and Sönmez 2019) [53].

Effect of HA on crop production

Foliar application of Humic acid improve the plant growth, accumulated photosynthetic matters and biological yield of red bean (Mohajerani *et al.*, 2016) [54]. Application of zinc and boron in accompanied with Humic acid and compost can be an effective nutritional manipulation by fixing the recommended dose of NPK to successfully reduce the pest and disease incidence in rice-mustard cropping system (Roy *et al.,* 2017) [5]. Waqas *et al.*, (2014) concluded that Humic acid application in all the three methods i.e., soil fertilization, foliar sprays and seed treatment significantly enhances grain yield and yield components of mungbean. Olk *et al.*, (2013) [56] observed that Humic products results significant increases in grain yield of maize (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.). Soil application of humus increased the N uptake of wheat and foliar application of Humic acid increased the uptake of P, K, Mg, Na, Cu and Zn (Asik *et al.*, 2009) [7]. Highest values of spike length, number of grains/spike, grains weight/spike and thousand grains weight as well as grain yield of wheat were obtained by foliar spraying with 2 litres of Humic acid (Manal *et al.,* 2016) [58]. Humic fertilizer not only increases the yield of wheat, but also wheat quality reflexed by high content of carbohydrate and protein content of grain wheat (Manal *et al.*, 2016) [58]. Nardi *et al.*, (2002) [60] reported the beneficial effect of Humic acid on plant growth to the increasing cell membrane, oxygen uptake, respiration and photosynthesis, nutrients uptake, root and cell elongation and ion transport. Treatments receiving HA in both soil or foliar application caused pronounced increases in plant height, number of branches and dry weight of shoot of soybean compared to the untreated ones (Mahmoud *et al.*, 2011) [61]. According to Sivakumar *et al.*, (2005) [32] the application of Humic acid up to 20 kg/ha along with 100 per cent recommended dose (150:50:50 NPK/ha) resulted in highest grain yield (4253kg/ha)as well as highest toal uptake of Nitrogen(132 kg/ha), phosphorous(20.75kg/ha) and potassium (86.93kg/ha) in rice crop. Rao *et al*. (1987) [25] concluded that increasing levels of Humic acid up to 30kg/ha resulted an increase of root-shoot ratio in sorghum (variety CSH-9). According to Sathyabama *et al*. (2004) [28], the significant increase of N, P and K uptake were recorded by 20 and 10 kg Humic Acid.ha^{-1} respectively in both Alfisol and Inceptisol in rice crop. In the presence of Humic acid, the effect of 75 and 100% NPK fertilizers on nutrient uptake and grain yield was comparable with each other. Baskar (2006) [4] reported that application of lignite Humic acid and in combination with fertilizer, increased cured rhizome yield from 1824 to 6128 kg.ha^{-1}, improved plant growth, availability of N in rhizosphere soil and resulting in greater N uptake by rhizome.

Dhanasekharan *et al*., (2008) [13] reported that application of Humic acid (HA) @ 30mg/kg increased the plant height, fruit length, number of fruits per plant, fruit weight and fruit yield by 56% in tomato and also increased the available N,P,K status of post-harvest soil. Madhavi *et al.* (2014) [22] carried out an experiment at college farm, Hyderabad to study the effect of fertilizers, biochar and Humic acid on soil enzymes at different stages of maize growth and observed that there was a significant increase in acid phosphatase activity by combined application of 75% NPK, 7.5 t ha^{-1} of biochar and 30kg ha^{-1} of Humic acid. Verma *et al.* (2016) [62] observed with 100% fertilization + *Pseudomonas fluorescens* + Humic acid in cabbage recorded maximum soil bacteria, funga and actinomycetes population in cabbage. A green-house experiment conducted by Ravindra Prasad *et al.* (1989) [63] revealed that addition of Humic acids to paddy IR-20 upto 15 kg ha^{-1} escalated the drymatter production. The root-shoot ratio also increased with increasing rate upto 15 kg ha^{-1} of Humic acid. In studies of Kauser and Azam (1985) [64]; Chen *et al.* (2004) [10], Humic acid applications were reported to increase the fresh and dry weights of crop plants. Due to the positive effects of Humic substances on the visible growth of plants, these sources have been widely used by the growers instead of other substances such as pesticides etc. Sripriya (1993) [65] recorded that higher grain and straw yields of paddy when Humic acid coated on fertilizer (2 %) was applied to soil @ 30 kg ha^{-1}.In alkaline soils, the use of Humic acid has been found to increase wheat yield by 25 per cent (Wang *et al*., 1995) [38]. Similarly, Delfine *et al.* (2005) [12] also noticed 23 and 26 per cent of yield increase over control in wheat cropduring 1998 and 1999 respectively. Balasubramanian *et al*. (2000) [66] reported that the yield attributes grain and stover yield of soybean increased significantly with addition of Humic acid @ 20 kg ha^{-1} to soil along with spraying (0.01 %) at flowering stage.

Khungar and Manoharan (2000) reported that the Humic acid application @ 10 kg ha^{-1} to green gram and soybean resulted in yield increase 80.65 and 71.07, respectively. Sathiya Bama and Selvakumari (2001) [3] studied the effect of Humic acid applied as potassium humate (@ 10 and 30 kg ha^{-1}) with and without NPK fertilizers (75 and 100% RDF) on the growth, yield and nutrient content of amaranthus. The results showed that application of 10 kgHumic acid ha^{-1} along with 75% recommended NPK, was found to increase the crude protein content and mineral nutrition (P, K, Ca, Mg, Zn, Cu, Fe and Mn). Soil application of Humic acid @ 10 kg ha^{-1}, 0.1 per cent root dipping and 0.1 per cent foliar spray recorded a maximum plant height, length and breadth of leaves, number of tillers of paddyand was on par with soil application of Humic acid at higher levels. (Baskar *et al.,* 2002) [4]. Sharif *et al.* (2002) [31] conducted field experiment at Peshwar, Pakistan to study the effect of 0.5 and 1.0 kg ha^{-1} Humic acid alone and in combination with full (120+90+60 kg ha^{-1}) and half (60+45+30 kg ha^{-1}) recommended doses of NPK on wheat crop. Addition of 0.5 and 1.0 kg ha^{-1} Humic acid alone and in combination with 100% NPK increased wheat grain yield by 25 to 69% and total drymatter by 36 to 65% over control. It was also reported that Humic acid has shown promising results in increasing crop production as a low-cost natural fertilizer source. Govindasamy and Chandrasekaran (2002) [17] reported that addition of Humic acid alone or in combination with nitrogen increased the rice yield over control. Increasing the level of Humic acid upto 30 kg ha^{-1} gradually increased the rice yield. Sathiya Bama (2002) optimized the dose of Humic acid @ 24.0 and 18.5 kg ha^{-1} respectively for maximum and economic yield of rice (ADT36) in Inceptisol of Tamil Nadu.

Dhanasekaran and Govindasamy (2002) [17] reported that application of N through various coated forms of urea significantly increased the grain and straw yields of rice over the control. Among the various forms of coated urea, Humic acid coated urea (HACU) recorded the highest grain (6.63 t ha^{-1}) and straw (9.58 t ha^{-1}) yield followed by neem coated urea (NCU) (6.55 and 9.44 t ha^{-1} of grain and straw yield, respectively). Nandakumar *et al.* (2004) [67] stated that higher grain yield (50.41 and 53.84 per centin clay loam and sandy loam soils respectively) was observed with Humic acid @ 20 kg ha^{-1} along with 100 per cent NPK over control in rice crop.Studies of Nardi *et al.* (2002) [60], Buyukkeskin and Akinci (2011) [68], Celik *et al.* (2011) [69] and Tahir *et al.* (2011) [79] have demonstrated the practical importance of Humic acid in agriculture. Beneficial effects of Humic substances on plant growth and mineral nutrition were proven, in addition to the claim that 1kg of HA can substitute for 1 ton of manure. Humic acids also reduce toxic effects of salts on monocots (Masciandaro *et al.*, 2002) [70] and dicots (Ferrara *et al.,* 2001) [71], including soybean and wheat (Ozkutlu *et al.*, 2006), rape seed (Keeling *et al.*, 2003) [20], forage and turnip (Albayrak, 2005) [1]. Humic acid application at 1000 mg kg $^{-1}$ positively affected the growth of tomato plants grown under saline soil conditions, but high doses of Humic acid inhibited plant growth (Turkmen *et al.*, 2004) [72]. Sathiya Bama and Selvakumari (2009) conducted a field experiment at Coimbatore to study the effect of Humic acid and fertilizers on rice (*Oryza sativa*) yield and yield attributes. The results indicated that the grain and straw yields were higher under the Humic acid application @ 20 kg ha^{-1}.

Sangeetha and Singaram (2007) [73] reported that the highest bulb yield (18.7 tha^{-1}) of onion was observed in treatment that received 100% NPK plus 20 kg HA ha^{-1} as soil application in sandy clay loam soil in Tamil Nadu. The combined application of HA with NPK demonstrated substantial additive beneficial effect as evident from seed cotton yield with 19.0 per cent increase over NPK alone and up to 41.1 per cent over control (Haroon *et al.,* 2010) [74].

Sao *et al.* (2010) conducted a pot experiment during winter season of the year 2004-2005 at AAU, Anand to study the effect of different levels of FYM and Humic acid derived from lignite coal on the yield of fodder maize. The Humic acid application at 20 kg ha^{-1} was the best treatment for dry and green matter yield and root growth of fodder maize. Selim *et al.* (2009) [75] found that Humic substances when added along with NPK through fertigation resulted in lesser leaching of N and K to deeper layer and higher availability of P in deeper layer of soil. The tuber yield increased by 16.47 per cent with addition of Humic substances compared to application of recommended dose of fertilizer. The best combination for enhancing tuber yield, quality indicators, nutritional status of potato crop and soil fertility compared to the recommended dose of N, P and K (control) was addition of Humic substances along with 100 per cent fertigation. Mahmoud *et al.* (2011) [61] recorded increase in plant height (86.5 cm), number of branches (4.00) and dry weight of shoot (108 g plant^{-1}) of soybean due to application of 30 kg ha^{-1} Humic acid along with 100 per cent RDF.

Farooq *et al.* (2011) [76] reported that application of Humic acid @ 100 or 200 mg kg^{-1} of soil to radish crop significantly increased the length, fresh and dry weights of shoot and root systems as well as leaf number per plant. Humic substances extracted from sewage sludge significantly increased the plant dry-matter production (up to 560 %), plant height (86-151 %) and leaf area (436-1397 %) during the early stages of pepper development. Net photosynthesis and stomatal conductance increased in the treatments with Humic acid extracted with sewage sludge up to (48 % and 63 %, respectively) at the vegetative stages compared to Humic substances derived from leonardite (Inaki Azcona *et al.*, 2011) [77]. Humic acid at 25 kg ha^{-1} increased growth and quality of maize. The soil application of Humic substances was significantly effective on dry weight. The mean highest dry weights were obtained with 1 g humus kg^{-1} treatment (Turan *et al.*, 2011). In common millet, the application of Humic acid @ 150 g ha^{-1}at 100 % leaf coverage gave higher grain yield (50.37 and 41.85 kg ha^{-1}) in the consecutive years compared to the control (Saruhan *et al.*, 2011) [78].

Tahir *et al.* (2011) [79] reported increase in plant height (10 %), shoot fresh weight (25 %) and dry weight (18 %) with HA_2 60 kg ha^{-1} soil, over control. Humic acid application @ 60 kg ha^{-1} soil was more efficient than 90 kg ha^{-1} in promoting wheat growth. Effects of bio-fertilizers, mineral fertilizers and Humic substances on growth and yield of cowpea envisaged that, combination of chemical fertilizer with Humic substances improve growth and yield of cowpea (Magdi *et al.*, 2011) [80]. In peanut, the highest seed yield of 1856.8 kg ha^{-1} was obtained from the treatment receiving 40 mg L^{-1} of Humic acid and the lowest amount of seed yield *i.e.*, 1011.5 kg ha^{-1} was reported from control. Combined application of 40 mg L^{-1} Humic acid and 75 kg N ha^{-1} resulted in a further increase in the yield to 2858 kg ha^{-1} as against control yield of 629 kg ha^{-1} (Maral, 2012) [81]. Harshad Thakur *et al.* (2013) [82] reported that the combined application of RDF + Humic acid granules @ 12.5 kg ha^{-1} (as basal) significantly influenced the growth parameters, yield attributes, seed and stalk yield of sunflower. Application of RDF + Humic acid granules @ 12.5 kg ha^{-1} (as basal) registered significantly taller plants (183.3 cm) over RDF alone. Abd El-Gawad (2013) [83] declared that Humic acid at the rate of 8 kg fed^{-1} increased protein percentage of pea seeds in the two seasons. El-Galad *et al.* (2013) [83] reported an increase in the protein content in faba beans on application of Humic acid combined with compost and sulphur. Kumar *et al.* (2014) [84] conducted a pot culture experiment to study the effect of Potassium humate (PH) and chemical fertilizers on growth and yield attributes of rice and observed that highest rice grain yield (45.68 g pot^{-1}) was obtained with application of 10 mg/kg PH along with 100% RDF followed by 100% RDF (32.44 g/pot) alone.

Vanitha and Mohandas (2014) studied the effect of Humic acid on growth and yield attributes of aerobic rice under conventional, drip and subsurface drip fertigation system and reported that application of 100 per cent RDF (150:50:50 kg NPK ha^{-1}) along with Humic acid recorded maximum root length (58.8 m $hill^{-1}$), higher chlorophyll content (2.61 mg g^{-1}), leaf area duration (151 days), increased grain filling per cent (69.1) and yield (5616 kg ha^{-1}). Kumar *et al.* (2014) [84] observed that addition of 10 mg/kg PH along with 100% NPK fertilizers and 12.5 mg/kg zinc sulphate caused significant increase in plant height, number of tillers, panicle height, panicle length, test weight, straw yield and yield of rice as compared to 100 and 75% NPK alone. Abeer *et al.* (2015) [85] observed that Humic acid significantly increased plant height, number of leaves, root length, shoot and root fresh and dry weights as well as chlorophyll content of common bean than control plants at 15, 30 and 45 DAP and also the graded levels of Humic acid application showed significant increase in yield, titreable acidity, fruit weight and fruit diameter in tomato crop (Asri *et al.*, 2015) [86]. Tuba Arjumend *et al.* (2015) [2] reported that application of Humic acid (HA) increased the growth of wheat in terms of shoot length (18 %), root length (29 %), shoot dry weight (76 %) and root dry weight (100 %). Response in terms of yield and yield components showed a significant increase in 1000 grain weight (8-16 %), biological yield (18-36 %), drymatter yield (15-25 %) and grain yield (19-58 %). Retno Suntari (2015) [87] conducted a study to determine urea-Humic acid doses for vertisols of East Java and found that highest number of panicles (6.33) were achieved with the application of urea-Humic acid 100% (UH2) in rice.

Drawbacks of Humic substances

The application of the very high dose of Humic acid is less effective (Lee and Bartlett, 1976). The beneficial effects of Humic acids have been cleared but excessive use of these chemicals might lead to the environmental pollution (Yigit *et al.*, 2008) [88]. No effect from application of Humic acid (Turan *et al.*, 2011; Aydin *et al.*, 2012; Liu *et al.*, 2002) [89, 90] or even growth reduction (Van *et al.*, 2010) also observed. Several studies have reported all outcomes in experiments: positive, negative and nil effects (Lodhi *et al.*, 2013) [91]. In conclusion, Humic acid (HA) is a vital constituent and an intimate part of soil organic structure. Many scientists, agronomists and farmers used Humic acid for improving soil conditions and plant growth. Humic acid can ameliorate negative soil properties, improve the plant growth and uptake of nutrients. The application doses of Humic acid are important for taking benefit from it. It is best to apply Humic acid or Humic acid in little amount throughout the crop period than at a huge amount or at a time. It is very important that plant trash from harvested crops is returned to the soil.

Conclusion

This review has shown that the application of HA could significantly affect crops agronomic performance in different crops, viz. plant's height, plant spread, dry matter accumulation, crop growth rate, relative growth rate, nodule count, nodule dry weight, nutrient content, yield components, yield, and quality. The effect of Humic acid on soil quality parameters are also reviewed in this article, viz. soil structure, water holding capacity, bulk density, particle density, porosity, microbial activity, soil pH, electrical conductivity, NPK content, organic matter content, and cation exchange capacity. As Humic acid is the organic substance that humus produces and the primary component of humus. It has a variety of qualities that contribute to the fertility of the soil. It is essential to maintain soil fertility by improving the physicochemical and biological qualities of the soil. It was discovered that using Humic acid has a beneficial impact not only on the production of cereals and pulses but also on the production of fruits and vegetables. When it is applied to a variety of crops at varying levels and dosages, Humic acid results in an increase in production as well as an enhancement in the quality of the soil. Its use was discovered to be useful in agricultural output, whether it was implemented in the soil or the plant itself, and via a variety of application methods, including seed treatment, soil application, and foliar application. The majority of research on Humic acid is carried out in either greenhouses or pots across the world. It is essential to conduct field trials in order to determine the true potential of Humic acid.

References

1. Albers CN, Banta GT, Hansen PE, Jacobsen OS. Effect of different Humic substances on the fate of diuron and its main metabolite 3, 4-dichloroaniline in soil. Environ Sci. Technol. 2008;42(23):8687-8691.
2. Arjumend T, Abbasi MK, Rafique E. 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. 2015;47(6):2231-2238.
3. Bama KS, Selvakumari G. Effect of Humic acid on growth, yield and nutrition of amaranthus. South Indian Horticulture. 2001;49:155-156.
4. Baskar K. Growth,Yield, N uptake of Turmeric (*Curcuma longa L.*) in Alfisol as affected by lignite Humic acid. Madras Agriculture Journal. 2006;93(7-12):282-287.
5. Bhatt P, Singh VK, Singh R, Malik N, Chandra R. Effect of Humic acid and PGPR on nodulation in chickpea (*Cicer arietinum* L.). IVth International Conference on Innovative and Current Advances in Agriculture & Allied Sciences (ICAAAS-2022); c2022.
6. Biswas TD, Mukherjee SK. Textbook of soil science. Tata McGraw Hill 106–109.Chaney K and Swift R S. 1986. Studies on aggregate stability. The effect of Humic substances on the strength of re-formed soil aggregates. Journal of Soil Science. 1987;37(2):337-343.
7. Bulti Merga, Jema Haji. Economic importance of chickpea: Production, value, and world trade. Cogent Food And Agriculture. 2019;5(1):1615718.
8. Cattani I, Zhang H, Beone GM, Del Re AA, Boccelli R, Trevisan M. The role of natural purified Humic acids in modifying mercury accessibility in water and soil. J Environ Qual. 2009;38(2):493-501.
9. Celano G, Smejkalová D, Spaccini R, Piccolo A. Interactions of three s-triazines with Humic acids of different structure. J Agric Food Chem. 2008 Aug 27;56(16):7360-7366.
10. Chen X, Kou M, Tang Z, Zhang A Li Hm Wei M. Responses of root physiological characteristics and yield of sweet potato to Humic acid urea fertilizer. PlosOne. 2017;12(12):e0189715.
11. Daur I, Bakhashwain AA. Effect of Humic acid on growth and quality of maize fodder production. Pakistan Journal of Botany. 2013;45(S1):21–25.
12. Delfine SR, Tognetti E, Desiderio, Alvino A. Effect of foliar application of nitrogen and Humic acids growth and yield of durum wheat. Agronomy. Sustain Development. 2005;25(2):183-191.
13. Dhanasekharan K, Bhuvaneswari R, Sivakumar K, Sathiyamuthi S. Effect of soil application of Humic acid on the growth and yield of Bhendi. International Journal of Tropical Agriculture. 2008;26:297-299.
14. Dogan Y, Togay Y, Togay N, Kulaz H. Effect of Humic acid and phosphorus applications on the yield and yield components in lentil (Lens culinaris). Legume Research. 2014;37(3):316-320.
15. Ebrahimi M, Miri E. Effect of Humic acid on seed germination and seedling growth of *Borago officinalis* and *Cichorium intybus*. Ecopersia. 2016;4(1):1239-1249.
16. Elkins KM, Nelson DJ. Spectroscopic approaches to the study of the interaction of aluminum with Humic substances. Coord Chem Rev 2002;228(2):205-25.
17. Govindasamy R, Chandrasekaran S. Effect of graded levels of Humic acid with and without N on the performance of lowland rice. In: National seminar on recent trends on the use of Humic substances for sustainable agriculture, Annamalai University, Tamil Nadu, 2002, 5.
18. Hariprasanna K. Foxtail millet: Nutritional importance and cultivation aspects. Indian Farming. 2016;65(12):25-29.
19. Janos P, Hula V, Bradnová P, Pilarová V, Sedlbauer J. Reduction and immobilization of hexavalent chromium with coal-and humate-based sorbent. Chemosphere. 2009;75(6):732-738.
20. Keeling AA, McCallum KR, Beckwith CP. Crop and Environment Research Centre, Harper Adams University College, Newport, Shropshire, UK, Bioresource Technology. 2003;90(2):127-137.
21. Luo W, Gu B. Dissolution and mobilization of uranium in a reduced sediment by natural Humic substances under anaerobic conditions. Environ Sci Technol. 2009;43(1):152-156.
22. Madhavi P, Sailaja V, Ram Prakash T, Hussain SA. Effect of fertilizers, biochar and Humic acid on soil enzymes at different stages of Maize growth. International Journal of Chemical Studies. 2017;5(5):2116-2120.
23. Martin-Neto L, Traghetta DG, Vaz CM, Crestana S, Sposito G. On the interaction mechanisms of atrazine and hydroxyatrazine with Humic substances. J Environ Qual. 2001;30:520-525.
24. Mikkelsen RL. Humic materials for agriculture, Davis, California, USA. Better Crops with Plant Food. 2005;89(3):6-7.
25. Rao MM, Govindasamy R, Chandrasekaran S. Effect of Humic acid on *Sorghum vulgare* var. CSH-9. Current Science. 1987;56:1273-1276.
26. Ravichandran M. Humic acids: A mystique substance in sustainable crop production. Journal of the Indian Society of Soil Science. 2011;59:49-57.
27. Reddy A, Mishra D. Growth and Instability in chickpea production in India; c2010. http://ssrn.com/abstract=1499577.
28. Sathyabama K, Selvakumari G, Natesan R, Singaram P. Humic acid and fertilizers on nutrition of rice in an Alfisol and Inceptisol. Madras Agriculture Journal, 2004, 91.
29. Schnitzer M, Gupta UC. Determination of acidity in soil organic matter. Soil Science Society of America proceedings. 1965;29(3):274-277.
30. Senn TL, Alta, Kingman R. A review of humus and Humic acids. Research Series No. 145, S.C. Agricultural Experiment Station, Clemson, South Carolina, USA; c1973.
31. Sharif M, Khattak RA, Sarir MS. Effect of different levels of lignitic coal derived Humic acid on growth of maize plants. Communications in Soil Science and Plant Analysis. 2002;33(19-20):3567-3580.
32. Sivakumar K, Devarajan L. Influence of K-humate on the yield and nutrient uptake of rice. Madras Agriculture Journal. 2005;92(10-12):718-721.
33. Stevenson FJ. Organic forms of soil nitrogen. In: John Wiley, ed. Humic Chemistry: Genesis, Composition, Reaction. New York, 1994, 59-95.
34. Tan KH, Binger A. Effect of Humic acid on aluminium toxicity in corn plants. Soil Sci. 1986;141(1):20-25.

35. Varanini Z, Pinton R, Behnke HD, Luttge U, Esser K, Kadereit JW, *et al*. Humic substances and plant nutrition. Progress in Botany: Structural botany, physiology, genetics and taxonomy. *Geobotany*. 1995;56:97-117.
36. Verma R, Maurya BR, Meena VS, Dotaniya ML, Deewan P. Microbial dynamics as influenced by bio-organics and mineral fertilizer in Alluvium soil of Varanasi, India. International Journal of Current Microbiology and Applied Sciences. 2017;6(2):1516-1524.
37. Vermeer AWP. Interactions between Humic acid and hematite and their effects on metal ion speciation. Wageningen University, The Netherlands. (PhD thesis); c1996.
38. Wang S, Mulligan CN. Enhanced mobilization of arsenic and heavy metals from mine tailings by Humic acid. Chemosphere. 2009;7(4):274-279.
39. Mayhew DR. Congress: The electoral connection. Yale university press; 2004 Nov 10.
40. Neri A, Cucchiarini C, Strik H, Boves L. The pedagogy-technology interface in computer assisted pronunciation training. Computer assisted language learning. 2002 Dec 1;15(5):441-67.
41. Abdel-Latif A, Bolli R, Tleyjeh IM, Montori VM, Perin EC, Hornung CA, Zuba-Surma EK, Al-Mallah M, Dawn B. Adult bone marrow–derived cells for cardiac repair: a systematic review and meta-analysis. Archives of internal medicine. 2007 May 28;167(10):989-97.
42. Yildirim K, Akalin-Baskaya A, Celebi M. The effects of window proximity, partition height, and gender on perceptions of open-plan offices. Journal of Environmental Psychology. 2007 Jun 1;27(2):154-65.
43. Olivares O, Mayers JR, Gouirand V, Torrence ME, Gicquel T, Borge L, Lac S, Roques J, Lavaut MN, Berthezène P, Rubis M. Collagen-derived proline promotes pancreatic ductal adenocarcinoma cell survival under nutrient limited conditions. Nature communications. 2017 Jul 7;8(1):1-4.
44. Ekin Z. Integrated use of Humic acid and plant growth promoting rhizobacteria to ensure higher potato productivity in sustainable agriculture. Sustainability. 2019 Jun 21;11(12):3417.
45. Hamideh D, Alvarez O. Sickle cell disease related mortality in the United States (1999–2009). Pediatric blood & cancer. 2013 Sep;60(9):1482-1486.
46. Khaled H, Fawy HA. Effect of different levels of Humic acids on the nutrient content, plant growth, and soil properties under conditions of salinity. Soil and Water Research. 2011 Mar 1;6(1):21-9.
47. Quilty JR, Cattle SR. Use and understanding of organic amendments in Australian agriculture: a review. Soil Research. 2011 Feb 4;49(1):1-26.
48. Sinha A, Berkelhammer M, Stott L, Mudelsee M, Cheng H, Biswas J. The leading mode of Indian Summer Monsoon precipitation variability during the last millennium. Geophysical Research Letters. 2011 Aug;38(15).
49. Ampong I, Ikwuobe OJ, Brown JE, Bailey CJ, Gao D, Gutierrez-Merino J, Griffiths HR. Odd chain fatty acid metabolism in mice after a high fat diet. The international journal of biochemistry & cell biology. 2022 Feb 1;143:106135.
50. Fahramand M, Moradi H, Noori M, Sobhkhizi A, Adibian M, Abdollahi S, Rigi K. Influence of Humic acid on increase yield of plants and soil properties. International Journal of Farming and Allied Sciences. 2014;3(3):339-41.
51. Chaney K, Swift RS. Studies on aggregate stability. 11. The effect of Humic substances on the stability of re-formed soil aggregates. Journal of Soil Science. 1986 Jun;37(2):337-43.
52. Kapase PV, Deotale RD, Sawant PP, Sahane AN, Banginwar AD. 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. 2014;24(1):107-14.
53. Dinçsoy M, Sönmez F. 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. 2019 Dec 14;42(20):2757-72.
54. Mohajerani A, Kadir AA, Larobina L. A practical proposal for solving the world's cigarette butt problem: Recycling in fired clay bricks. Waste management. 2016 Jun 1;52:228-44.
55. Roy A. A review on the alkaloids an important therapeutic compound from plants. IJPB. 2017;3(2):1-9.
56. Olk HM. Cultural references in translation: A framework for quantitative translation analysis. Perspectives. 2013 Sep 1;21(3):344-57.
57. Asik I, Kocum AI, Goktug A, Turhan KS, Alkis N. Comparison of ropivacaine 0.2% and 0.25% with lidocaine 0.5% for intravenous regional anesthesia. Journal of clinical anesthesia. 2009 Sep 1;21(6):401-7.
58. Manal M, Chandrasekar MJ, Priya JG, Nanjan MJ. Inhibitors of histone deacetylase as antitumor agents: A critical review. Bioorganic chemistry. 2016 Aug 1;67:18-42.
59. Gumus E, Celikay F. R&D expenditure and economic growth: new empirical evidence. Margin: The Journal of Applied Economic Research. 2015 Aug;9(3):205-17.
60. Nardi S, Pizzeghello D, Muscolo A, Vianello A. Physiological effects of Humic substances on higher plants. Soil Biology and Biochemistry. 2002 Nov 1;34(11):1527-36.
61. Mahmoud SM, Paish EC, Powe DG, Macmillan RD, Grainge MJ, Lee AH, Ellis IO, Green AR. Tumor-infiltrating CD8+ lymphocytes predict clinical outcome in breast cancer. Journal of clinical oncology. 2011 May 20;29(15):1949-55.
62. Verma V, Ravindran P, Kumar PP. Plant hormone-mediated regulation of stress responses. BMC plant biology. 2016 Dec;16(1):1-0.
63. Prasad AK, Koseff JR. Reynolds number and end-wall effects on a lid-driven cavity flow. Physics of Fluids A: Fluid Dynamics. 1989 Feb;1(2):208-18.
64. Kauser A, Azam F. Effect of Humic acid on wheat seeding growth. Environ. Exp. Bot. 1985;25:245-52.
65. Sripriya M, Sri R. Inter-nucleon potential in a chiral quark-soliton model. InDAE symposium on nuclear physics: contributed papers. Vol. 36B (1993) 1993.
66. Balasubramanian V, Ross SF. Holographic particle detection. Physical Review D. 2000 Jan 24;61(4):044007.
67. Nandakumar N, Singh AK, Sharma RK, Mohapatra T, Prabhu KV, Zaman FU. Molecular fingerprinting of hybrids and assessment of genetic purity of hybrid seeds in rice using microsatellite markers. Euphytica. 2004 Apr;136(3):257-64.

68. Büyükkeskin T, Akinci Ş. The effects of Humic acid on above-ground parts of broad bean (Vicia faba L.) seedlings under Al 3+ toxicity. Fresenius Environmental Bulletin. 2011;20(3):539-48.
69. Celik E, Liu L, Choi H. Protein fouling behavior of carbon nanotube/polyethersulfone composite membranes during water filtration. water research. 2011 Oct 15;45(16):5287-94.
70. Masciandaro G, Ceccanti B, Ronchi V, Benedicto S, Howard L. Humic substances to reduce salt effect on plant germination and growth. Communications in soil science and plant analysis. 2002 Mar 25;33(3-4):365-78.
71. Ferrara N. Role of vascular endothelial growth factor in regulation of physiological angiogenesis. American Journal of Physiology-Cell Physiology. 2001 Jun 1;280(6):C1358-66.
72. Türkmen Ö, Dursun A, Turan M, Erdinç Ç. Calcium and Humic acid affect seed germination, growth, and nutrient content of tomato (*Lycopersicon esculentum* L.) seedlings under saline soil conditions. Acta Agriculture Scandinavica, Section B-Soil & Plant Science. 2004 Aug 1;54(3):168-74.
73. Sangeetha M, Singaram P. Effect of lignite Humic acid and inorganic fertilizers on growth and yield of onion. Asian Journal of Soil Science. 2007;2(1):108-10.
74. Haroon N, Inman RD. Endoplasmic reticulum aminopeptidases: Biology and pathogenic potential. Nature Reviews Rheumatology. 2010 Aug;6(8):461-7.
75. Selim AJ, Rogers W, Fleishman JA, Qian SX, Fincke BG, Rothendler JA, Kazis LE. Updated US population standard for the Veterans RAND 12-item Health Survey (VR-12). Quality of Life Research. 2009 Feb;18(1):43-52.
76. Farooq MS, Chaudhry AH, Shafiq M, Berhanu G. Factors affecting students' quality of academic performance: a case of secondary school level. Journal of quality and technology management. 2011 Dec;7(2):1-4.
77. Inaki Azcona, Pascual I, Aguirreolea J, Fuentes M, García-Mina JM, Sánchez-Díaz M. Growth and development of pepper are affected by Humic substances derived from composted sludge. Journal of Plant Nutrition and Soil Science. 2011 Dec;174(6):916-24.
78. Saruhan N, Terzi R. The relations between antioxidant enzymes and chlorophyll fluorescence parameters in common bean cultivars differing in sensitivity to drought stress. Физиология растений. 2011;58(1):58-66.
79. Tahir AA, Chevallier P, Arnaud Y, Neppel L, Ahmad B. Modeling snowmelt-runoff under climate scenarios in the Hunza River basin, Karakoram Range, Northern Pakistan. Journal of hydrology. 2011 Oct 28;409(1-2):104-17.
80. Magdi F MO, Ivan CO, Penny C, Akira KO. Electrochemical Characterization of Plasma Sprayed Alumina Coatings. Journal of Surface Engineered Materials and Advanced Technology. 2011 Oct 18;2011.
81. Maral T, Hani A, Bashar K. Evaluation of modified Alvarado score in the diagnosis of acute appendicitis at Baghdad teaching hospital; c2012.
82. Thakur VK, Thakur MK, Gupta RK. Rapid synthesis of graft copolymers from natural cellulose fibers. Carbohydrate polymers. 2013 Oct 15;98(1):820-8.
83. El-Gawad A, Hala H, Ahmed MM, El-Hussiny NA, Shalabi ME. Kinetics of reduction of low grade sinaimanganese ORE via hydrogen AT 800-950 °C. Journal of Ore Dressing. 2013 Jul 1;15(30).
84. Kumar K, Dasgupta CN, Das D. Cell growth kinetics of *Chlorella sorokiniana* and nutritional values of its biomass. Bioresource technology. 2014 Sep 1;167:358-66.
85. Abeer H, Abd_Allah EF, Alqarawi AA, Egamberdieva D. Induction of salt stress tolerance in cowpea [*Vigna unguiculata* (L.) Walp.] by arbuscular mycorrhizal fungi. Legume Res. 2015 Oct 1;38(5):579-88.
86. Asri H, Mousannif H, Al Moatassime H, Noel T. Big data in healthcare: challenges and opportunities. In2015 International Conference on Cloud Technologies and Applications (Cloud Tech) 2015 Jun 2 (pp. 1-7). IEEE.
87. Suntari R, Retnowati R, Soemarno S, Munir M. Determination of urea-Humic acid dosage of vertisols on the growth and production of rice. AGRIVITA, Journal of Agricultural Science. 2015 May 29;37(2):185-92.
88. Yigit MV, Mazumdar D, Lu Y. MRI detection of thrombin with aptamer functionalized superparamagnetic iron oxide nanoparticles. Bioconjugate chemistry. 2008 Feb 20;19(2):412-7.
89. Aydin S. A review of research on Facebook as an educational environment. Educational Technology research and development. 2012 Dec;60(6):1093-106.
90. Liu Y, Schiff M, Dinesh-Kumar SP. Virus-induced gene silencing in tomato. The Plant Journal. 2002 Sep;31(6):777-86.
91. Lodhi S, Singhai AK. Wound healing effect of flavonoid rich fraction and luteolin isolated from *Martynia annua* Linn. on streptozotocin induced diabetic rats. Asian Pacific journal of tropical medicine. 2013 Apr 13;6(4):253-9.