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Effect of Humic Acid on Growth, Yield and Soil Properties in Rice: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. Authors BB and KB have selected the topic for review and prepared the framework of the review paper. Authors BB and SA compiled all the research findings and completed the review writing. The final editing and proof reading were carried out by Authors KB and B. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Humic acids, natural organic compounds derived from decaying organic matter, have gained significant attention in agriculture due to their potential to promote plant growth, yield, and soil fertility. Humic acid additions boost plant metabolism, promote root development, and increase nutrient absorption, leading to enhanced growth and development. Furthermore, humic acids have a significant role in improving the structure, moisture retention, and availability of nutrients in soil, thereby creating a favorable environment for plant growth. Studies have illustrated that humic acid application can lead to increased yields in a wide range of crops. Humic acid application efficiently increases hormonal activities and various enzyme activities which helps in tricarboxylic acid cycle, glycolysis, and respiration process. The mechanisms underlying this enhancement involve the modulation of physiological processes, such as photosynthesis, nutrient assimilation, and stress tolerance. In addition to promoting plant growth and yield, humic acid amendments have been shown to positively influence on soil properties. These include increased microbial activity,

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enhanced soil aggregation, and improved nutrient cycling. Moreover, humic acids can mitigate soil degradation processes, such as salinization, thereby promoting sustainable agricultural practices. Through the utilization of humic acids, farmers may maximize crop yields while reducing their ecological footprint, therefore promoting food security and sustainable agriculture.

Keywords: Sustainable agriculture; nutrient cycling; stress tolerance; tricarboxylic acid cycle; glycolysis; respiration; salinization.

1. INTRODUCTION

Rice (*Oryza sativa* L.) represents one of the most important cereals in the world. China is the world's leading producer of rice, with India coming in second and being the world's largest exporter. It occupies one-third of the total cultivable land and grown as a major stable food crop in India [1]. It is one of the richest sources of carbohydrates, vitamins, proteins, and minerals; the endosperm of grains counts for about 90% of carbohydrates of its total produced dry weight [2, 3]. Milling products of rice yield contains 70 percent of the major product as rice (endosperm) and 30 percent of the by-product as 20 percent husk, 8 percent bran, and 2 percent germ [4]. In recent times, it has been investigated that rice bran is one of the important components which has various potential biological properties (i.e. anti-inflammatory action and antioxidant functions) which reduce the occurrence of cancer and cholesterol levels and impede coronary artery diseases and rice bran is also rich in phytic acid (59.4 - 60.9 gm per kg) [5,6,7]. The application of synthetic fertilizers alone under continuous practices of intensive cropping does not positively sustain the crop productivity status, but the addition of organic substances with applied chemical fertilizers effectively improves the physical properties of soil and maintains greater soil fertility status with better yield production [8]. Among the organic substances, humic acid is one of the greater organic molecules that have various important roles on many agronomic parameters and soil properties [9]. Humic acid is mainly produced from the degraded waste materials of plants and animals and plays some vital roles in agriculture systems such as increment in soil biochemical and physical properties through greater texture, structure, microbial activities, and water holding capacity [10,11]; enhance micronutrient nutrient availability in soil as a chelating agent and increase nutrients uptake to the plants [12]; decreases the intake of heavy metal which are toxic to the plants [13]. The application of humic acid also improved crop growth status by enhancing growth promoting hormones like cytokinin and auxin, which help in the metabolic process of nutrients, stress resistance, and photosynthesis activity [14,15]. Additionally, humic acid has positive effects on plant cell membranes which helps in greater transportation of minerals, higher protein synthesis, greater enzyme activities, lesser activity of toxic elements, and higher microbial population [16]. This review explores the effects of humic acid application on many aspects of agricultural productivity, soil properties, and plant physiology.

2. RELATIONSHIP BETWEEN STRUCTURES AND FUNCTIONALITY OF HUMIC ACIDS

The functionality of humic acid is directly associated with the structural composition, which is dependent on the type of sources [17]. Humic acid structure contains several functional groups, the most prevalent among them are the phenolic (OH) and carboxylic (COOH) groups [18]. These two functional groups act as major primary groups that help in the improvement of soil chemical and physical properties and promote greater growth of the plants (**Fig 1)** [18,19]. The disintegration of these two functional groups forms nonpolar and polar ends (hydrophobic and hydrophilic parts, respectively), which are involved in the beneficial processes of humic acid functions [20]. The hydrophobic end is associated with repelling activities, whereas the hydrophilic end is mostly engaged in chelating activities [21]. Once the disintegration of COOH and OH occurs, the cationic metals are retained in the soil by aggregation with the polar end (anionic parts) through electrostatic bonding [22]. The water-loving hydrophilic part forms micelle, which helps in the increment of water holding capacity of the soil. Similarly, the hydrophobic parts reduce the rate of water infiltration and improve the aggregation stability of clay particles [21]. Recently, a research study conducted by de Castro *et al*., (2021) [17], reported that the aliphatic and aromatic groups of humic acid effectively contributed to the increment of soluble sugars and nitrogen uptake, leading to enhancement in rice yield production. Garciá *et* *al*., (2016) [23] also reported that these functional groups of humic acid effectively stimulate the growth of the root system of rice seedlings.

3. MECHANISM OF HUMIC ACID ON PLANT GROWTH

Humic acid has an important role in plant growth by stimulating carbon and nitrogen metabolism. Humic acid triggered enzyme activities such as glutamine synthetase, nitrate reductase, and glutamate dehydrogenase, which are linked to the nitrogen assimilation processes [24]. Furthermore, humic substances stimulate nitric oxide (NO) at the emergence point of lateral roots. Nitric oxide is a bioactive substance that has a variety of roles in the physiological activities of plants, including the formation of their roots [25]. The incorporation of humic substances primarily increases NO accumulation, which helps in the morphological changes in the root system such as the increment of secondary roots, increment in thickness of the roots, and higher fresh weight of roots [26]. Canellas et al., (2014) [27] reported that humic acid increases the density and length of the root hairs as well as cell proliferation of root tissues. The humic substances also improve hormonal effects on plant's root and shoot system [28]. Humic substances can stimulate ion transport and H+ -ATPase activities in the plasma membranes of the root system [29]. Both these impacts are directly involved in nutrient acquisition and uptake of nutrients in the plant system. Nardi *et al*., [30] reported that humic substances increase enzyme activities those are involved in tricarboxylic acid cycle and glycolysis process. The enzyme activities related to the glycolysis process are pyruvate kinase, phosphofructokinase, glucokinase, phosphoglucose isomerase, and the enzyme activities related to the respiration process are malate dehydrogenase, NADP+-isocitrate dehydrogenase, and citrate synthase. Humic substance application in the root zone can trigger physiological responses for shoot development by the activation of auxin, like phospholipase A2 as a stomatal opening regulator [31].

Fig. 2. represents the activities of humic on plant growth by its various mechanisms

4. IMPACTS OF HUMIC ACID ON THE GROWTH PARAMETERS

Humic acid is one of the most effective biostimulants among the humic substances, which have many positive influences on rice growth and development. It efficiently promotes the photosynthesis rate, higher plant growth, greater amount of dry matter accumulation, and production and accumulation of more amount of organic matter [32, 33]. The addition of humic acid with various synthetic fertilizers increases plant growth with greater amount of nutrient uptake. Humic acid can improve soil's biochemical properties by enhancing enzyme activities, microbial population and their activities, water holding capacity (WHC) and cation exchange capacity (CEC) in the soil that ultimately improve plant's nutrient uptake and efficient plant growth [34]. This impact of humic acid ultimately reflects on plant height, leaf area index (LAI), and biomass production through greater photosynthesis [35]. Various scientific studies mentioned that humic acid also has an effect on chlorophyll content and root-shoot development of plants. It improves the growth of shoots and roots by increasing growth promoting hormones i.e. production of cytokinin and auxin, and enzyme activities in the plants [36, 37]. The increased uptake of plant nutrients (micro and macronutrients) through humic acid enhances the chlorophyll concentration in the leaf, which positively improves the shoot growth of the plants [38]. With the slow release of soil nutrients due to the humic acid, plants can uptake more amount of nutrients, which leads to the higher number of tillers in the plants [39]. **Table 1** shows that the addition of humic acid both in soil or foliar spray significantly increases growth attributing characteristics such as plant height, number of tillers, dry weight, etc. However, Saha *et al*., (2013) [40] reported that higher dose of humic acid@ 6 L ha^{-1} decreases plant growth attributes compared to humic acid@ 3 L ha^{-1}. It may be due to an imbalance in nutrients and toxic effects on plant metabolism, which damages plant physiological processes and nutrient uptake to the plants.

5. IMPACTS OF HUMIC ACID ON THE YIELD AND QUALITY ATTRIBUTES

The yield attributing characteristics of the plants are effectively influenced by humic acid application both as soil application and foliar spray. Humic acid enhances physical and chemical properties and microbial activities in the soil as well as increases hormonal activities, which leads to greater uptake of plant nutrients resulting in more production of photosynthates and greater source to sink translocation of assimilates, which finally produces higher

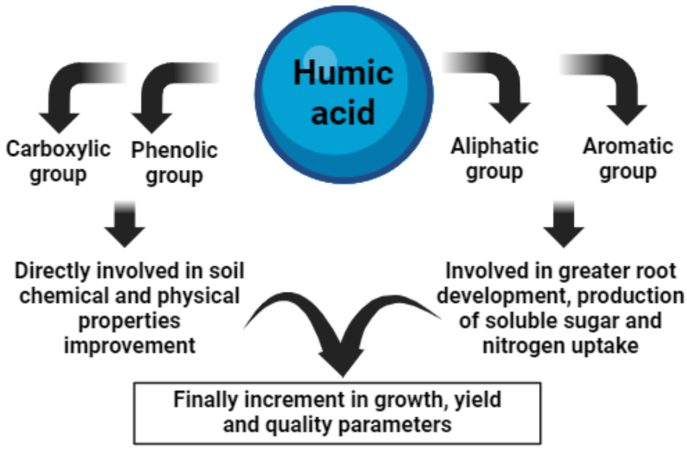

Fig. 1. Functions of humic acid on plant and soil attributing characters

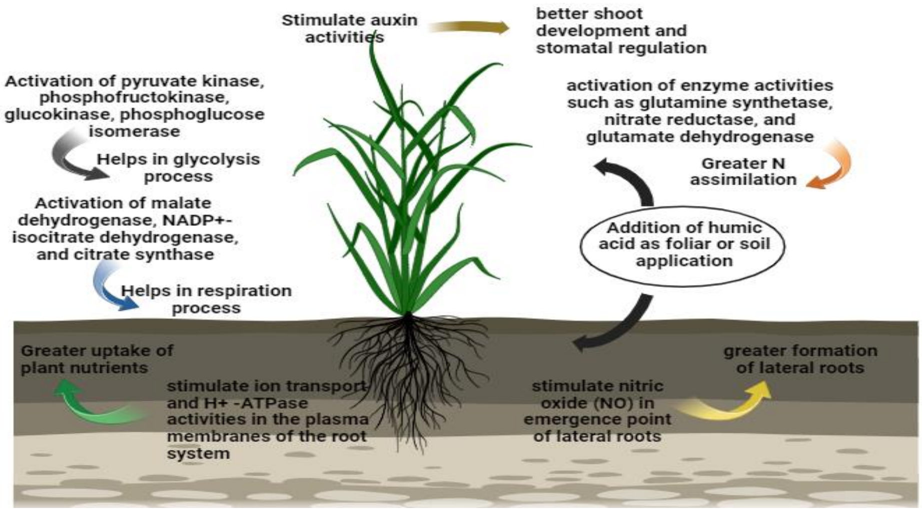

Fig. 2. Mechanisms of humic acid on plant growth

number of effective tillers, panicle length, number of grains panicle^{-1}, grain and straw yield, and the test weight of grains [46]. Sivakumar *et al*., (2007) [47] reported that humic acid application significantly increases N, P, and K uptake in plants, which helps in the greater accumulation of dry matter production and higher grain yield production. Additionally, it also functions as a naturally occurring biostimulant, improving plant resistance to abiotic stresses including drought and salinity, and minimizing production losses. On the other hand, humic acid increases protein content in the grains by improving nitrogen uptake in the sink [48, 49]. The increment in carbohydrate content also happens by humic acid, which helps in the improved rate of photosynthesis, finally leading to greater translocation of assimilates from the source to sink [50]. The application of humic acid produces better root system and increases cell membrane permeability, leading to greater uptake of plant nutrients, and finally, concentrations of nitrogen, potassium and phosphorus increase in the plants [51, 52]. Table 2 shows the effects of humic acid on grain and straw yield of rice, which indicates the impact of humic acid on yield attributing characteristics such as number of effective tillers, panicle length, number of grains panicle^{-1}, test weight, etc. However, according to Sivakumar *et al*., (2007) [47], soil application of humic acid up to 20 kg ha^{-1} significantly increases crop yield, but beyond this, it decreases yield production due to its toxic effects on plant metabolic processes.

Table 1. Effect of humic acid on various growth attributes of rice

Sl. No.	Treatments	Plant height (cm)	Number of tillers	Dry weight (g)	Reference
1	90 kg ha^{-1} nitrogen fertilizer + no humic acid	71.77	24.50	-	[39]
	90 kg ha^{-1} nitrogen fertilizer + 5 kg ha^{-1} humic acid	76.77	33.37	-	
2	No humic acid	86.11	10.33	-	[40]
	3 L ha^{-1} humic acid	86.33	11.56	-	
	6 L ha^{-1} humic acid	86.22	11.00		
3	RDF + 2.5 kg ha^{-1} humic acid-based biostimulant	75.98	14.50	33.23	[41]
	RDF + 5 kg ha^{-1} humic acid based biostimulant	77.39	14.81	34.49	
4	Without foliar spray	85.95	501.5	-	[42]
	Foliar spray of humic acid	91.45	552.5	-	
5	No humic acid	69.24	11.05	32.09	[43]
	6 kg ha^{-1} of humic acid	70.12	12.94	39.07	
6	Control	94.8 ± 2.19	-	3.44 ± 0.317	[44]
	Humic acid	103 ± 2.53	-	4.62 ± 0.373	
7	Control	114.33 ± 0.60	-	6.424 ± 0.299	[45]
	Humic acid	116.36 ± 0.30	-	7.784 0.622	

Table 2. Effect of humic acid on yield parameters of rice

Sl. No.	Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Reference
1	No humic acid	3.08	4.62	[47]
	20 kg ha^{-1} humic acid	3.63	5.45	
	30 kg ha^{-1} humic acid	3.48	5.22	
2	No humic acid	3.09	8.22	[40]
	3 L ha^{-1} humic acid	3.10	8.33	
	6 L ha^{-1} humic acid	3.20	8.45	
3	100% RDF	4.74	-	[53]
	100% RDF + Humic acid	5.12	-	
4	Humic acid based biostimulant @ 2.5 kg ha^{-1}	4.10	5.24	[41]
	Humic acid based biostimulant @ 5 kg ha^{-1}	4.17	5.39	
5	Without foliar spray	3.05	2.7	[42]
	Foliar spray of humic acid	3.82	3.4	
6	15 kg nitrogen fed^{-1}	2.98	2.89	[54]
	15 kg nitrogen fed^{-1} + humic acid	3.94	3.07	

6. IMPACTS OF HUMIC ACID ON THE SOIL PROPERTIES

Humic acid acts as a chelating agent by attracting positive ions and making the greater availability of nutrients to the plants by their slow release ability [52]. The chelating properties help in the prevention of fixation, oxidation, leaching, and precipitation of micronutrients in the soil [55]. The soil pH is also influenced by humic acid but it depends on the number of phenolic and carboxylic functional groups present in their structure [56]. Further, humic acid can stabilize ammonium in the soil, which leads to better nitrogen availability [57]. The nitrogen molecules are also present in humic substances which become accessible to the plants after their application in soil [21]. Apart from nitrogen, phosphorus content in the soil also improves by humic acid application due to their synergistic effects on phosphatase activity, leading to

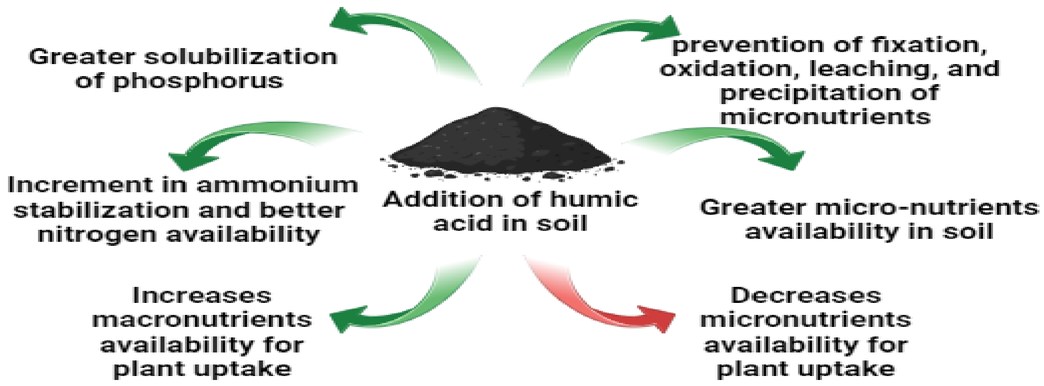

Fig. 3. Effect of humic acid on soil properties and availability of nutrients for plant uptake

greater solubilization of phosphorus in soil [58]. Zhu *et al.,* (2018) [59] mentioned that humic acid increases the desorption of phosphate ions and reduces sorption, which makes the availability of phosphorus in the soil solution. Humic acid also improves the plasma membrane permeability and increases nutrient absorption in plants [60]. While the higher rate of humic acid application improves soil's physical properties, its binding capability reduces micronutrient availability for plant uptake. The phenolic and carboxylic functional groups help in the chelating process, which makes metal complexes of humic acid in soil, leading to greater availability of micronutrients in the soil but their availability for plant uptake decreases [61]. However, the application of humic acid can effectively increase micronutrient availability in the soil but cannot be assumed to have a synergistic linear relationship with plant uptake due to the different compositions of physical and chemical properties of humic acid. Fig 3 shows the impacts of humic acid on soil properties.

7. CONCLUSION

This review paper has revealed that humic acid has greater potential impacts on various agronomic parameters and soil properties. It increases the intake of nutrients, strengthens the structure of the soil, reduces stress, encourages biological activity, and may even benefit farmers commercially. Although there may be an initial expense involved, it is overcome in the long term by its benefits to soil health and productivity. However, the current study suggests that introducing humic acid in cropping practices may help to create productive and sustainable agricultural systems.

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COMPETING INTERESTS

The authors have declared that there are no competing interests.

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