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Effect of humic acid on growth and available soil nutrient of soybean (*Glycine max* L.)

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Abstract
The field experiment was carried out to study "Effect of humic acid on soil nutrient dynamics, yield and quality Soybean (*Glycine max* L.)", cultivar MAUS-158 during *kharif* season of the year 2021 at departmental farm of Soil Science and Agricultural Chemistry, College of Agriculture, Latur. The experiment was laid in randomized block design with three replications and eight treatments *viz.*,T_1 (control), T_2 (RDF), T_3 (RDF + soil application of humic acid @ 5 kg ha^{-1}), T_4 (RDF+ soil application of humic acid @ 10 kg ha^{-1}), T_5 (RDF+ soil application of humic acid @ 15 kg ha^{-1}), T_6 (T_3 + foliar application of humic acid @ 0.2% at 30 & 45 DAS), T_7 (T_4 + foliar application of humic acid @ 0.2% at 30 & 45 DAS), T_8 (T_5 + foliar application of humic acid @ 0.2% at 30 & 45 DAS). The field study indicated that growth and available nutrients of soybean crop were significantly influenced due to humic acid and RDF. The growth parameter *viz.*, plant height, number of branches plant^{-1}, nodulation, root length was significantly affected due to T_8 (RDF + soil application of humic acid @ 15 kg ha^{-1}+ foliar application of humic acid @ 0.2% at 30 and 45 DAS). Available N, P, K and S were recorded at flowering, pod formation and harvest. Significant and maximum contents of available N, P, K and S were noticed with application of treatment T_8 (RDF + soil application of humic acid @ 15 kg ha^{-1}+ foliar application of humic acid @ 0.2% at 30 and 45 DAS), whereas the T_1 (control) showed least values.Thus, it can be concluded that soil and foliar application of humic acid increase growth and available nutrients parameters. The significantly superior result recorded by treatment T_8 (RDF + soil application of humic acid @ 15 kg ha^{-1}+ foliar application of humic acid @ 0.2% at 30 and 45 DAS) next to this treatment T_7 (RDF + soil application of humic acid @ 10 kg ha^{-1} + foliar application of humic acid @ 0.2% at 30 and 45 DAS) was best option.

Keywords: Humic acid, plant height, number of branches, nodules, available nutrient

Introduction

The soybean (*Glycine max* L.) is a species of legume, popularly known as the "golden bean" or miracle bean" of the 21st century grown in 95 countries of the world. The plant is classed as an oilseed rather than a pulse. Due to its high nutritional quality, higher productivity and its industrial importance, there is lot of scope for its cultivation in India. It is an environment friendly legume and has now become a major source of protein, oil and health promoting phyto-chemicals for human nutrition and livestock feed around the globe. Soybean is a rich source of nutrition. From nutritional point of view, it contains about 40-45% protein, well balanced amino acids, 18-22% cholesterol free oil with 85% unsaturated fatty acids, especially omega 6 and omega 3 fatty acids, 6-7% total mineral, 5-6% crude fibre, 24-26% carbohydrates and good amount of vitamins in its seed. Soybean is the leading source of edible oils constituting about 30% of the world supply among other oilseed crops. Soybean oil is considered a future fuel source and efforts are made to increase soybean-derived diesel production. Being a leguminous crop, soybean is also capable of with stand moisture stress and helps in improving the soil fertility and productivity. Soybean cultivation improves soil health because of its atmospheric nitrogen fixing ability and deep root system. Symbiotically soybean fixes 125-150 kg N ha^{-1} and leaves about 30-40 kg N ha^{-1} for succeeding crop (Ryan *et al*. 2018) [11]. Soybean oil, tofu, soy milk and soy sauce are the top edible commodities. One of the major uses of soybean globally is as livestock feed in various form and also used in preparation of various industrial products. Humic substances are natural constituents of the soil organic matter, resulting from the decomposition of plant, animal and microbial residues, but also from the metabolic activity of soil microbes using these substrates and represent the major pool of organic carbon at the earth's surface. Humic substances are chemically nothing more than a product of a saponification reaction by alkaline extraction from soils and sediments

(Canellas *et al*. 2015) [2]. Humic substances are divided into three fractions on the basis of their solubility characteristics. The first fraction, humic acid, is not soluble in water under acidic conditions (pH<2), but is soluble at higher values. Humic acid is the major extractable fraction of humic substances and ranges from dark brown to black in colour. Fulvic acid is soluble in water under all pH conditions and ranges from light yellow to yellow-brown in colour. After the first two fractions have been extracted, the third fraction, called humin, remains. This fraction is black in colour, not soluble in water at any pH and in any alkali solution. Humic acid has a higher molecular weight, fewer functional groups that are acidic in nature (e.g., COOH and OH), greater carbon content, and lower oxygen content than fulvic acid. Humic substances have been recognized for long as essential contributors to soil fertility, acting on physical, physico-chemical, chemical and biological properties of the soil. Generally, humic acids are considered to be aromatic in structure with amino acids, amino sugars, peptides, and aliphatic compounds linking the aromatic groups. It is believed to consist of free and bound phenolic hydroxyl groups, quinines, oxygen and nitrogen bridges, and carboxy groups. They are extracted from naturally humified organic matter (e.g., from peat or volcanic soils), from composts and vermicompost's, or from mineral deposits (leonardite, an oxidation form oflignite), also from agricultural by-products (Jardin 2015) [7]. Humic acid are hydrophilic groups attract hydration, thus increasing the water retention capacity in soil, involved in secondary metabolism and in a wide range of stress responses. Humic acid prevents soil cracking, surface water runoff and soil erosion by increasing the ability of colloids to combine. It also helps the soil loosen and crumble, and thus increases aeration of soil as well as soil workability, darkens the colour of the soil and thus helps absorption of the sun's energy and stimulates growth and proliferation of desirable micro-organisms in soil. In recent years, applications of solution and solid state product of humic acid received the most attention for higher crop yield, savings of fertilizers and reduced losses to the environment on several crops. Therefore, present investigation entitled "Effect of humic acid on soil nutrient dynamics, yield and quality of soybean (*Glycine max* L.)" was conducted on research farm, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Latur.

Material and Methods

The present experiment was carried out in *kharif* season at College of Agriculture, Latur during 2021-22 on soybean variety MAUS-158. The details of the material used to study "Effect of humic acid on soil nutrient dynamics, yield and quality Soybean (*Glycine max* L.)". Randomized Block Design (RBD) was followed with 8 treatments each replicated thrice. The treatment details are [T_1 – Control, T_2 - RDF, T_3 - RDF + soil application of humic acid @ 5 kg ha^{-1}, T_4 - RDF+ soil application of humic acid @ 10 kg ha^{-1}, T_5 - RDF + soil application of humic acid @ 15 kg ha^{-1}, T_6 - T_3 + foliar application of humic acid @ 0.2% (30 & 45 DAS), T_7 - T_4 + foliar application of humic acid @ 0.2% (30 & 45 DAS), T_8 - T_5 + foliar application of humic acid @ 0.2% (30 & 45 DAS)]. The RDF-Recommended dose of fertilizer is 30:60:30:20 kg N, P_2O_5, K_2O, S ha^{-1}. The experiment was laid out in Randomized Block Design with three replications. The size of each plot treatment was 4.05 m ×3 m. There are four factors which are RDF (Recommended Dose of Fertilizers), humic acid @ 5, 10 & 15, foliar application of humic acid 0.2% @ 30-45 DAS. The variety MAUS-158 of soybean was sown on 13th July 2021 by maintaining a spacing of 45 × 5 cm^2. The growth analysis were plant height, number of branches, nodules and root length and chemical analysis of soil available nutrients. The results were statistically analyzed as per the "statistical methods for Agricultural workers" by Panse and Sukhatme (1985) [7].

Fertilizer Application

Recommended dose of fertilizer were applied in respective plot as per the recommendation through urea, SSP, MOP and Bensulf. 2.5 t ha^{-1} of FYM and full dose of RDF will be applied uniformly throughout the experimental plot. N applied through urea, P applied through SSP and K is applied through MOP as well as S is applied through Bensulf. Soil application of humic acid also carried out along with fertilizer application.

Table 1: Fertilizer concentration and its time of application

Fertilizers	%N	%P_2O_5	%K_2O	%S	% Humic acid	Time of application
FYM	0.5	0.25	0.5	-	-	Before sowing
Urea	46	-	-	-	-	At the time of sowing
SSP	-	16	-	11.5	-	At the time of sowing
MOP	-	-	58	-	-	At the time of sowing
Bensulf	-	-	-	90	-	At the time of sowing
Humic acid (Root Fast 98%)	-	-	08	-	80	Soil application at the time of sowing

Foliar application

Fertilizer Trade name% Humic acid Time of application	Fertilizer Trade name% Humic acid Time of application	Fertilizer Trade name% Humic acid Time of application	Fertilizer Trade name% Humic acid Time of application
Humic acid Humico 12% 12 at 30 and 45 DAS	Humic acid Humico 12% 12 at 30 and 45 DAS	Humic acid Humico 12% 12 at 30 and 45 DAS	Humic acid Humico 12% 12 at 30 and 45 DAS

Result and Discussion

Influence of humic acid on biometric observation of soybean

Plant height

The plant height was recorded at 30, 45, 60 DAS and at harvest of soybean crop and result indicated that plant height was significantly increased due application of humic acid as soil and foliar application, which presented in table 1. Plant height were varied from 21.3 to 31.4 cm, 24.7 to 42.6 cm, 35.8 to 59.2 cm and 45.1 to 72.0 cm at 30, 45, 60 DAS and harvest stage respectively. Application of full dose of RDF and only soil application of humic acid showed significant increase in plant height of crop as compared to control. Treatment T_5 (RDF + soil application of humic acid @ 15 kg ha-1) (31.2, 36.4, 48.5 and 60.0 cm respectively) shows significant effect on treatments T_3 (RDF + soil application of humic acid @ 5 kg ha^{-1}) (26.5, 31.1, 42.4 and 51.3 cm respectively), T_2 (RDF) (24.5, 28.0, 39.9 and 49.5 cm respectively) and T_1 (Control) (21.3, 24.7, 35.8 and 45.1 cm respectively), where treatment T_4 (RDF + soil application of humic acid @10 kg ha^{-1}) (28.3, 34.7, 44.7 and 56.8 cm respectively) was at par with T_5 and T_3 (RDF + soil application of humic acid @ 5 kg ha-1) followed to T_5 (26.5, 31.1, 42.4 and 51.3 cm respectively) at 30, 45, 60 DAS and at harvest respectively. Similarly, data revealed that application of RDF and application of both soil and foliar application of humic acid shows better result over all treatment. Among all the treatment T_8 is RDF + soil application of 15 kg ha^{-1} HA and foliar application @ 0.2% recorded significant and highest value of height were 31.4, 42.6, 59.2 and 72.0 cm at 30, 45, 60 and harvest stages respectively. Whereas treatment T_7 was found at par with T_8 and followed by treatment T_6. Lowest plant height was recorded by control (21.3, 24.7, 35.8 and 45.1 cm) at 30, 45, 60 DAS and at harvest respectively. This increase in plant height might be due to application of humic acid. Soil application of humic acid causes adequate availability of nutrients due to chelation. HA improves soil physical properties. Foliar application of HA enhances the absorption and translocation of nutrients, due to which had resulted greater meristematic cell division, cell elongation and internodes elongation. These results are in conformity with the findings of Ryan *et al*. (2018) [11] found that plant height (65.4 cm) measured due to application recommended dose of fertilizer and humic acid @ 3.0 kg ha1 was significant as compared to plant height (55.0 cm) shown due to application of only RDF (25:60:25 kg N, P_2O_5, K_2O ha^{-1}).

Table 1: Plant height (cm) of soybean at 30, 45, 60 DAS and at harvest as influenced with application of humic acid

Treatments	Plant height (cm)			
	30 DAS	45 DAS	60 DAS	At harvest
T_1: Control	21.3	24.7	35.8	45.1
T_2: RDF	24.53	28.0	39.9	49.5
T_3: RDF + soil application of humic acid @ 5 kg ha-1	26.5	31.1	42.4	51.3
T_4: RDF+ soil application of humic acid @10 kg ha^{-1}	28.3	34.7	44.7	56.8
T_5: RDF + soil application of humic acid @ 15 kg ha-1	31.2	36.4	48.5	60.0
T_6: T_3 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	27.1	37.5	51.6	63.3
T_7: T_4 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	29.6	39.0	55.1	67.0
T_8: T_5 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	31.4	42.6	59.2	72.0
SE±	1.021	1.208	2.218	1.688
CD at 5%	3.099	3.665	6.729	5.121

Number of branches plant^{-1}

The data regarding number of branches per plant recorded at 30, 45, 60 DAS and at harvest which was presented in table 2. It was obvious from results that number of branches per plant recorded significantly better result as compared to treatment which was not received humic acid. The number of branches per plant were varied from 3.77 to 3.97, 5.16 to 6.97,6.19 to 7.67 and 8.05 to 9.90 at 30, 45, 60 DAS and at harvest stages respectively. Significant and highest number branches per plant were recorded due to application of T_8 (RDF + foliar application of HA @ 0.2% at 30 and 45 DAS + soil application of humic acid @ 15 kg ha^{-1} and values were recorded as 6.97 and 7.67 at 45 and 60 DAS respectively. Treatment T_7 which received soil application (10 kg ha^{-1}) and 0.2% foliar spraying along with RDF was found at par with T_8 and recorded as 6.59 and 7.47 number of branches at 45 and 60 DAS respectively. Least number of branches counted in control (T_1) and recorded as 5.16 and 6.19 number of branches at 45 and 60 DAS respectively, whereas at 30 DAS variations were not statistically significant. Treatment T_8 were significantly superior at harvest number of branches recorded as 9.90 counted due to soil application (15 kg ha^{-1}) and 0.2% foliar spraying along with RDF. Treatment T_7 found at par with T_8, recorded as 9.65 numbers of branches at harvest. Whereas least number of branches counted by control (8.05) at harvest of soybean crop. It was due to the role of humic acid improving the soil fertility and increasing the availability of nutrient elements and consequently increased plant growth. Also, liquid spray accelerated the metabolic and physiological activities of plant which increases uptake of nutrient ultimately into maximum branches. The preceding findings are agreement with Abd-Rabboh *et al.* (2020) [1] concluded that Spraying with humic acid at the level of 7.5 g $litre^{-1}$ water on soybean plants intercropped with maize resulted in the highest values of number branches $plant^{-1}$.

Table 2: Number of branches of soybean at 30, 45, 60 DAS and at harvest as affected with application of humic acid

Treatments	Number of branches			
	30 DAS	45 DAS	60 DAS	At harvest
T_1: Control	3.77	5.16	6.19	8.05
T_2: RDF	3.62	5.36	6.48	8.37
T_3: RDF + soil application of humic acid @ 5 kg ha^{-1}	3.53	5.68	6.71	8.59
T_4: RDF+ soil application of humic acid @ 10 kg ha^{-1}	3.76	5.97	6.98	8.78
T_5: RDF + soil application of humic acid @ 15 kg ha^{-1}	3.94	6.08	7.21	9.12
T_6: T_3 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	3.69	6.27	7.29	9.37
T_7: T_4 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	3.78	6.59	7.47	9.65
T_8: T_5 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	3.97	6.97	7.67	9.90
SE±	0.120	0.192	0.120	0.259
CD at 5%	NS	0.583	0.366	0.763

Nodulation

Results obtained due to application humic acid in terms of nodulations were recorded at 30, 45 and 60 DAS represented in table 3. Humic acid shows significant impact on nodulation as compared to control, it ranged from 8.66 to 22.33 at 30 DAS, 24.00 to 50.66 at 45 DAS and 37.3 to 66.6 at 60 DAS. Result revealed that, RDF and combined application of soil and foliar application of humic acid showed higher number of nodules per plant. At 30 DAS, treatment T_8 (T_5 + foliar application of humic acid @ 0.2%) were recorded significantly superior result as compared to other, which recorded as 8.66 nodules per plant. Treatment T_8 (T_5 + foliar application of humic acid @ 0.2%) were recorded significantly superior result as compared to other recorded as 50.66 and 66.6 nodules per plant at 45 and 60 DAS respectively. Treatment T_7 (T_4 + Foliar application of humic acid @ 0.2%) is at par with above treatment at 45 (47.00) and 60 (63.6) DAS. T_6 (T_3 + foliar application of humic acid @ 0.2%) was second next treatment to T_7 shows maximum root nodules at 45 (42.66) and 60 (57.3) DAS. Least number of nodulations computed due to T_1 (Control) at 45 (24.66) and 60 (40.3) DAS. This result may get due to, humic acid increases microelements uptake, which play significant role in nodulations also soil application causes increases in microbial count. similar result was evaluated by Morsy*et al.* (2014) [8] found root nodules (37.50 at 45 DAS and 112.5 at 75 DAS) were significantly higher in almost all treatments in which plant were inoculated two yeast species *Rhodotorula mucilaginosa* MB151 and *Saccharomyces cerevisiae* 66 and humic acid (4%) as compared to control (10.00 at 45 DAS and 25.00 at 75 DAS).

Table 3: Nodulation of soybean at 30, 45 and 60 DAS as influenced with application of humic acid

Treatments	Nodulation		
	30 DAS	45 DAS	60 DAS
T1: Control	8.66	24.00	37.3
T2: RDF	12.33	29.66	42.6
T3: RDF + soil application of humic acid @ 5 kg ha-1	14.00	33.00	49.3
T4: RDF+ soil application of humic acid @ 10 kg ha-1	18.00	35.33	51.3
T5: RDF + soil application of humic acid @ 15 kg ha-1	21.33	39.33	54.3
T6: T3+ foliar application of humic acid @ 0.2% (30 & 45 DAS)	14.66	42.66	57.3
T7: T4+ foliar application of humic acid @ 0.2% (30 & 45 DAS)	18.66	47.00	63.6
T8: T5+ foliar application of humic acid @ 0.2% (30 & 45 DAS)	22.33	50.66	66.6
SE±	0.76	1.22	1.53
CD at 5%	2.32	3.70	4.65

Root length

Different treatment greatly affected by humic acid in terms of root length, which was recorded at 30, 45 and 60 DAS. Data represented in table 4. Humic acid shows significant impact on root length as compared to control. It varied from 10.6 to 21.6 cm at 30 DAS, 18.3 to 35.3 cm at 45 DAS and 36.6 to 55.1 cm at 60 DAS. Treatment which has soil and foliar application both showed better result than other treatments. At 30 DAS, T_8 (T_5 + foliar application of humic acid @ 0.2%) was significant over all treatment and recorded as 21.6 cm root length, whereas treatment T_5 and T_7 were found to be at par with T_8 and recorded as 21.3 and 19.6 cm root length respectively. T_1 (control) shows least root length recorded as 10.6 cm root length. At 45 and 60 DAS, T_8 (T_5 + foliar application of humic acid @ 0.2%) gave root length 35.3 and 55.1 cm respectively which was significant over all treatment, where T_7 (T_4 + Foliar application of humic acid @ 0.2%) recorded as 33.0 and 52.6 cm respectively and statistically at par with T_8. T_6 (T_3 + foliar application of humic acid @ 0.2%) is followed by T_8 which showed 30.6 and 48.8 cm root length respectively. T_1 (control) showed least root length was 18.3 and 36.6 cm root length respectively at 45 and 65 DAS. The increase in growth characteristics of crop in response to HA may be due the presence of growth promoting substances like indole acetic acid (IAA), gibberellins and auxin in its contents that are directly involved in cell respiration, photosynthesis, oxidative phosphorylation, protein synthesis, and various enzymatic reactions. This increase may also be owing to the effect of HA on root development. Stimulation of root hairs and enhancement of root initiation by HA may increase nutrients uptake that eventually affected the growth characteristics of plant as reported earlier. Similar result was reported by Dange *et al.* (2016) [4], where application of 100% recommended dose of fertilizers with humic acid 6% @ 2.5 litre ha^{-1} show maximum root length.

Table 4: Root length (cm) of soybean at 30, 45 and 60 DAS as influenced with application of humic acid

Treatments	Root length (cm)		
	30 DAS	45 DAS	60 DAS
T_1: Control	10.6	18.3	36.6
T_2: RDF	13.6	21.6	49.3
T_3: RDF + soil application of humic acid @ 5 kg ha-1	16.3	24.6	43.3
T_4: RDF+ soil application of humic acid @ 10 kg ha^{-1}	18.3	26.3	45.0
T_5: RDF + soil application of humic acid @ 15 kg ha-1	21.3	29.6	47.4
T_6: T_3 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	17.3	30.6	48.8
T_7: T_4 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	19.6	33.0	52.6
T_8: T_5 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	21.6	35.3	55.1
SE±	0.854	1.176	1.776
CD at 5%	2.591	3.567	5.386

Effect of humic acid on nutrient status of soybean grown soil

Nitrogen availability

The data showed significant result in availability of nitrogen at flowering, at pod formation and at harvest due to humic acid application. Available nitrogen at flowering stage ranges between 191.9 to 363.56 kg ha^{-1}. At the flowering stage available nitrogen (363.53 kg ha^{-1}) was found significant and maximum in treatment T_8 (RDF + soil application @ 15 kg ha^{-1} + foliar application of humic acid @ 0.2%). The treatment T_8 was found significantly superior over other treatment and at par with T_7 (T_4 + foliar application of humic acid @ 0.2%) (354.73 kg ha^{-1}), which followed by T_6 (T_3 + foliar application of humic acid @ 0.2%) (337.06 kg ha^{-1}). While, lowest available nitrogen (191.9 kg ha^{-1}) was observed in control. Available nitrogen at pod formation stage ranged between 147.46 to 199.13 kg ha^{-1}. The data revealed that the at pod formation stage available nitrogen (199.14 kg ha^{-1}) was found statistically significant and maximum in treatment T_8 (T_5 + foliar application of humic acid @ 0.2%), which at par T_7 (T_4 + foliar application of humic acid @ 0.2%) (190.88 kg ha^{-1}) and followed by T_6 (T_3 + foliar application of humic acid @ 0.2%) (183.26 kg ha^{-1}). While, lowest available nitrogen (147.46 kg ha^{-1}) was observed in control. Availability of nitrogen at harvest due to humic acid application varies from 128.88 to 178.32 kg ha^{-1}. Where, treatment T_8 (T_5 + foliar application of humic acid @ 0.2%) significantly superior over all treatments recorded as178.32 kg ha^{-1} N, which is followed by T_7 (T_4 + foliar application of humic acid @ 0.2%) and value recorded as 172.80 kg ha^{-1}. Lowest availability of N recorded in control *i.e.*, 128.88 kg ha^{-1}. Only RDF added treatment recorded 132.96 kg ha^{-1} of available N. Application of full dose RDF with combined soil application and foliar spraying shows better result as compared to only soil applied humic treatments. Humic acid application significantly reduces the unusual activity led to reduce volatilization of nitrogen, reduces the phosphorus fixation and increases its availability through chelation effect. Applied FYM increase N in soil after harvest of crop. Similar result was examined by, Hyder *et al.* (2019) studied the highest concentration N (3.1 mg kg^{-1}) was found with the application of HA at 30 kg ha^{-1} along with 50 kg ha^{-1} DAP.

Table 5: Available nitrogen in soil as influenced by application of humic acid at critical growth stages of soybean

Treatments	Available nitrogen (kg ha^{-1})		
	At flowering	At pod formation	At harvest
T_1: Control	191.93	147.13	128.88
T_2: RDF	208.23	158.03	132.96
T_3: RDF + soil application of humic acid @ 5 kg ha-1	287.29	166.03	148.64
T_4: RDF+ soil application of humic acid @ 10 kg ha^{-1}	299.5	173.63	156.40
T_5: RDF + soil application of humic acid @ 15 kg ha-1	323.11	179.46	160.25
T_6: T_3 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	337.06	183.26	166.91
T_7: T_4 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	354.73	190.88	172.80
T_8: T_5 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	363.56	199.14	178.32
SE±	3.418	3.045	1.964
CD at 5%	10.36	9.237	2.185

Phosphorus availability

The data showed (table 6) significant result in availability of phosphorus at flowering, at pod formation and at harvest due to humic acid application. Available phosphorus at flowering stage varies from 17.99 to 24.74 kg ha^{-1}. The data revealed that at flowering stage available phosphorus was found maximum in treatment T_8 (RDF + soil application @ 15 kg ha^{-1} + foliar application of humic acid @ 0.2%) recorded as 24.74 kg ha^{-1}. The treatment T_8 was found significantly superior over other treatment except T_7 (RDF + soil application @ 10 kg ha^{-1} + foliar application of humic acid @ 0.2%) and T_6 (RDF + soil application @ 5 kg ha^{-1} + foliar application of humic acid @ 0.2%) and recorded as 23.87 and 22.66 kg ha^{-1} of available P respectively. While, lowest available phosphorus recorded as 17.99 kg ha^{-1} was observed in control. Available phosphorus at pod formation stage ranges from 8.24 to 14.03 kg ha^{-1}. The data revealed that the at pod formation stage available phosphorus was found maximum in treatment T_8 (T_5 + foliar application of humic acid @ 0.2%) recorded as 14.03 kg ha^{-1}. The treatment T_8 was found significantly superior over other treatment and T_7 (T_4 + foliar application of humic acid @ 0.2%) were at par with above treatment and recorded as 13.44 kg ha^{-1}. While, lowest available phosphorus recorded as 8.24 kg ha^{-1} was observed in control. The data shows significant result in availability of phosphorus at harvest due to humic acid application which ranges from 5.78 and 10.44 kg ha^{-1}. Where, treatment T_8 (T_5 + foliar application of humic acid @ 0.2%) significantly superior over all treatments recorded as 10.44 kg ha^{-1}, where T_7 (T_4 + foliar application of humic acid @ 0.2%) at par with superior treatment and value recorded as 9.82 kg ha^{-1}. Lowest availability of P recorded 5.78 kg ha^{-1} due to control. Only RDF added treatment recorded 6.91 kg ha^{-1} of available phosphorus. Application of full dose RDF with soil application and foliar spraying shows better result as compared to only soil applied humic treatments. Humic acid seems to be more conducive for P availability and suppress P fixation either through chelation or acidifying mechanism induced mineralization processes thus increases P in soil. HA reduces the reactions of phosphorus with Ca, Fe, Mg and Al and liberates it into form that is available and beneficial to plant. The productivity of particular mineral fertilizer is increased considerably. Similar result was examined by Savita*et al.* (2018) [12] also found soil application of humic acid substances @ 2.5 kg ha^{-1} at sowing + foliar application of commercial humic acid (0.2%) at 40 DAS for phosphorus (98.04 kg ha^{-1}) which are statistically significant.

Table 6: Available phosphorus in soil as influenced by application of humic acid at critical growth stages of soybean

Treatments	Available phosphorus (kg ha^{-1})		
	At flowering	At pod formation	At harvest
T_1: Control	17.99	8.24	5.78
T_2: RDF	19.25	9.64	6.91
T_3: RDF + soil application of humic acid @ 5 kg ha-1	21.03	11.06	7.75
T_4: RDF+ soil application of humic acid @ 10 kg ha^{-1}	21.40	11.85	8.19
T_5: RDF + soil application of humic acid @ 15 kg ha-1	22.08	12.37	8.82
T_6: T_3 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	22.66	12.95	9.02
T_7: T_4 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	23.87	13.44	9.82
T_8: T_5 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	24.74	14.03	10.44
SE±	0.702	0.304	0.245
CD at 5%	2.131	0.923	0.744

Potassium availability

The data shows (table 7) significant variations in availability of potassium at flowering, at pod formation and at harvest due to humic acid application. Available potassium at flowering stage ranges from 310.65 to 454.33 kg ha^{-1}. The data revealed that the at flowering stage available potassium recorded as 454.33 kg ha^{-1} was found maximum in treatment T_8 (T_5 + foliar application of humic acid @ 0.2%). The treatment T_8 was found significantly superior over other treatment and except by T_7 (T_4 + foliar application of humic acid @ 0.2%) and T_6 (T_3 + foliar application of humic acid @ 0.2%) recorded as 431.83 and 424.33 kg ha^{-1}. While, lowest available potassium recorded as 310.65 kg ha^{-1} was observed in control. Available potassium at pod formation stage ranges from 260.9 to 431.01 kg ha^{-1}. At the pod formation stage available potassium recorded as 431.01 kg ha^{-1} was found maximum in treatment T_8 (T_5 + foliar application of humic acid @ 0.2%). The treatment T_8 was found significantly superior over other treatment and at par with T_7 (T_4 + foliar application of humic acid @ 0.2%) and recorded as 402.05 kg ha^{-1} and T_6 (T_3 + foliar application of humic acid @ 0.2%) recorded as 393.60 kg ha^{-1} followed to T_8. While, lowest available potassium recorded as 260.93 kg ha^{-1} was observed in control. The data shows significant result in availability of potassium at harvest due to humic acid application which ranges from 246.72 to 419.28 kg ha^{-1}. Where, treatment T_8 (T_5 + foliar application of humic acid @ 0.2%) significantly superior over all treatments and recorded as 419.28 kg ha^{-1}. T_7 (T_4 + foliar application of humic acid @ 0.2%) were at par with T_8 recorded as 384.97 kg ha^{-1}. Lowest availability of K recorded as 246.72 kg ha^{-1}. Only RDF added treatment recorded 295.51 kg ha^{-1} of available potassium. Similar result was obtained by Suryawanshi (2021) studied that treatment T8 (soil application of 15 kg ha^{-1} + foliar application of 0.2% of HA) had a considerably greater available K (522.27 kg ha^{-1}) levels in soil.

Table 7: Available potassium in soil as influenced by application of humic acid at critical growth stages of soybean

Treatments	Available potassium (kg ha^{-1})		
	At flowering	At pod formation	At harvest
T_1: Control	310.65	260.93	246.72
T_2: RDF	330.36	306.19	295.51
T_3: RDF + soil application of humic acid @ 5 kg ha-1	361.86	342.53	324.8
T_4: RDF+ soil application of humic acid @ 10 kg ha^{-1}	382.23	367.86	349.96
T_5: RDF + soil application of humic acid @ 15 kg ha-1	407.04	388.36	369.46
T_6: T_3 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	424.33	393.60	375.70
T_7: T_4 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	431.83	402.05	384.97
T_8: T_5 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	454.33	431.01	419.28
SE±	13.05	9.61	10.58
CD at 5%	39.58	29.17	32.11

Sulphur availability

The numerical values impact of humic acid on available sulphur of soybean at various growth stages was presented in table 4.15 and depicted 4.14. The data showed significant result in availability of sulphur at flowering, at pod formation and at harvest due to humic acid application. Available sulphur at flowering stage varied from 27.96 to 32.31 kg ha^{-1}. The data revealed that the at flowering stage available sulphur recorded as 32.31 kg ha^{-1} and was found maximum in treatment T_8 (T_5 + foliar application of humic acid @ 0.2%). The treatment T_8 was found significantly superior over other treatment. While, lowest available sulphur (29.96 kg ha^{-1}) was observed in control. Available sulphur at pod formation stage ranges from 16.62 to 21.19 kg ha^{-1}. The data revealed that the at pod formation stage available sulphur recorded as 21.19 kg ha^{-1} and was found maximum in treatment T_8 (T_5 + foliar application of humic acid @ 0.2%). The treatment T_8 was found significantly superior over other treatment (T_7, T_6 and T_5). While, lowest available sulphur recorded as 16.62 kg ha^{-1} was observed in control. The data shows significant result in availability of sulphur at harvest due to humic acid application, which ranges from 9.47 to 13.62 kg ha^{-1}. Where, treatment T_8 (T_5 + foliar application of humic acid @ 0.2%) significantly superior over all treatments and recorded the vales as 13.62 kg ha^{-1}. Lowest availability of sulphur recorded as 11.47 kg ha^{-1}. Only RDF added treatment recorded 10.84 kg ha^{-1} of available sulphur. This may be happened due, humic substances bind itself with cation because, they have high cation exchange capacity so they do not cause any nutrient loss and make available to plant for further use.

Table 8: Available sulphur in soil as influenced by application of humic acid at critical growth stages of soybean

Treatments	Available sulphur (kg ha-1)		
	At flowering	At pod formation	At harvest
T_1: Control	27.96	16.62	9.47
T_2: RDF	28.99	17.61	10.84
T_3: RDF + soil application of humic acid @ 5 kg ha-1	30.59	19.58	11.68
T_4: RDF+ soil application of humic acid @ 10 kg ha^{-1}	30.80	19.75	12.16
T_5: RDF + soil application of humic acid @ 15 kg ha-1	30.92	20.13	12.71
T_6: T_3 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	31.42	20.42	12.98
T_7: T_4 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	31.71	20.78	13.21
T_8: T_5 + foliar application of humic acid @ 0.2% (30 & 45 DAS)	32.31	21.19	13.62
SE±	0.480	0.389	0.195
CD at 5%	1.458	1.181	0.594

Conclusion

The growth characters like plant height, number of branches plant^{-1}, nodulation, root length, were increased due to application of humic acid. The increased availability of nutrients leads good absorption and activity in plant resulted in greater apical growth which was further responsible for higher photosynthetic activity, thus leads to better morphological development of crop. Parameter related to root development such as root length and nodulations where significantly influenced due to humic acid. Availability of nutrients causes lateral root growth for absorption. Adequate amount of moisture and aeration leads microbial growth. The higher availability of N, P, K and S was found at flowering, pod formation and harvest of crop. Addition of FYM, RDF increased mineralization and humic substances binds with mineral nutrients and prevent leaching which resulted in maximum availability of nutrients. Thus, application of RDF + soil application of humic acid @ 15 kg ha^{-1} + Foliar application of humic acid @ 0.2% at 30 and 45 DAS showed significantly superior result on growth, available nutrients parameters and next to it application of RDF + soil application of humic acid @ 10 kg ha^{-1} + Foliar application of humic acid @ 0.2% at 30 and 45 DAS was best option.

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