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Effect of biofertilizers and foliar application of organic acids on growth and yield of soybean [*Glycine max* (L.) Merrill]

The world population is increasing day by day; hence there is a need for plenty of food crops to meet the requirement of growing population. Crops need several nutrients to reach their maximum yield potential. Presently, the chemical fertilizers are the major source of nutrients but escalating cost, coupled with increasing demand for chemical fertilizers and depleting soil health necessitates the safe and efficient use of biofertilizers in crop production. Phosphorus is an important plant nutrient involved in several energy transformation and biochemical reactions including biological nitrogen fixation. Phosphatic fertilizers have low efficiency of utilization due to chemical fixation in soil and due to poor solubility of native soil phosphorus. Soil microorganisms play a key role in soil P dynamics and subsequent availability of phosphate to plants. Coinoculation of phosphate-solubilizing microorganism (PSM) and arbuscular mycorrhizas (AM) may enhance plant acquisition of P from insoluble P sources. On the other hand use of organic-mineral fertilizers like humic acid has increased with increasing the agricultural production and is the most economical. Humic acid is almost applied directly to the soil or as a foliar application to the plants. It is one of the major components of humic substances. The effects of humic substances on plant growth depend on the source and concentration, as well as on the molecular fraction weight of humus. Lower molecular size fraction easily reaches the plasma lemma of plant cells, determining a positive effect on plant growth, as well as a later effect at the level of plasma membrane (nutrient uptake).

The present investigation was conducted at the Main Agricultural Research Station, Dharwad during *kharif* 2012. The pH of the soil was neutral (7.3) and low in available nitrogen (238.8 kg ha^{-1}), medium in available phosphorous (35.22 kg ha^{-1}) and high in available potassium (341.3 kg ha^{-1}). The experiment was laid out in a factorial randomized complete block design having twenty treatment combinations and replicated thrice. Soybean variety DSb-21 was used for the study. The experiment consisted of four P-Solubilizing biofertilizers (PSB, VAM, PSB + VAM and Control) and five foliar spray of organic acid (Humic acid, Lecithin, Citric acid, Maleic acid and control). Recommended fertilizer dose of 40:80:25 kg N, P_2O_5 and K_2O per hectare in the form of Urea, DAP and MOP was applied as a basal dose at the time of sowing. PSB (*Pseudomonas striata*) obtained from the Department of Agricultural Microbiology, U. A. S., Dharwad was treated at the rate of 6 g kg^{-1} of seeds. *Rhizobium* (Sb-120) was also applied at the rate of 6 g kg^{-1} of seeds. VAM @ 20 kg ha^{-1} was applied to soil at the time of sowing. Five plants from net plot area were randomly selected and observations on growth and yield parameters were recorded. All the data pertaining to the present investigation were statistically analyzed as per the method described by Panse and Sukhatme (1985). The level of significance used in 'F' and 'T' test was P= 0.05. The means differences among the treatments were compared by Duncan Multiple Comparison Test (DMRT) at 0.05 level of probability.

Results revealed that higher seed yield of soybean (35.96 q ha^{-1}) was obtained with the treatment combination of dual inoculation of PSB+VAM with foliar spray of 0.1% humic acid at flower initiation and was higher to an extent of 28 per cent compared to control (27.90 q ha^{-1}) (Table 2). The higher seed yield was mainly due to positive association between growth and yield attributing characters *viz.,* plant height (64.04 cm), total dry matter production (25.29 g) and number of pods per plant compared to uninoculated control (Tables 1 and 2). Significantly higher number of pods per plant (92.10 g $plant^{-1}$) and seeds were recorded by inoculation of PSB + VAM with foliar spray of 0.1% humic acid at flower initiation compared to control (64.9 pods $plant^{-1}$). Biofertilizers play a key role in enhancing the efficiency of utilization of native as well as applied nutrients. The greater yield response due to dual inoculation of VAM fungus and PSB than with PSB alone can be attributed to the activity of the VAM fungus in transporting extra phosphorus solubilized by PSB from and beyond the root zone into the plant roots which in the absence of VAM hyphae gets refixed by soil constituents during the course of slower diffusion towards plant roots. These results are in accordance with the findings of Suri *et al.* (2011) and Chitale *et al.* (2012) in soybean. They reported that higher seed yield of soybean was due to inoculation of PSB + VAM than inoculation of PSB and VAM alone. Foliar spray of 0.1% humic acid helps in quick absorption of nutrients, which enhanced the growth of root and shoot effectively resulting in higher uptake of nutrients. Spraying of humic acid mainly reduced the flower drop and ultimately enhanced the pod setting and resulted in higher seed yield. The results are in line with the findings of Dixit and Elemathi (2007). Combined application of PSB+VAM with foliar spray of 0.1% humic acid might have helped to enhance the biological activity in the soil, soil characters improvements, better root development, improved transport of nutritional elements, enhanced chlorophyll content, protein synthesis and photosynthesis, solubilization of nutrients resulting in higher nutrients uptake by soybean compared to other treatments (Lee and Bartlett, 1976) suggesting existence of synergetic effect of combined applications of mineral nutrients and humic acid substances. At harvest, significantly higher plant height (64.04 cm) and total dry matter production (25.29 g $plant^{-1}$) (Table 1) were recorded with dual inoculation of PSB+VAM with foliar application of humic acid at flower initiation stage. Higher total dry matter production per plant with application of PSB + VAM was due to higher dry matter accumulation in stem, leaves and reproductive parts over control at different growth stages. Dry matter production depends on the photosynthetic capacity of the plant which in turn depends on the dry matter

Table 1. Plant height, total dry matter production and pods per plant in soybean at harvest as influenced by biofertilizers and foliar application of organic acids

Biofertilizers \ Foliar sprays	Plant height (cm)						Total dry matter production (g)						Pods plant^{-1}					
	F_1	F_2	F_3	F_4	F_5	Mean	F_1	F_2	F_3	F_4	F_5	Mean	F_1	F_2	F_3	F_4	F_5	Mean
B_1	57.22^{bf}	54.00^{dg}	54.66^{dg}	57.22^{bf}	54.10^{dg}	55.44^{b}	22.38^{ad}	20.71^{ce}	22.27^{ad}	21.27^{be}	19.38^{dg}	21.20^{b}	71.1^{df}	67.7^{ef}	70.2^{df}	69.9^{ef}	67.5^{ef}	69.3^{bc}
B_2	54.00^{dg}	53.04^{eg}	52.66^{eg}	53.66^{eg}	52.04^{g}	53.08^{b}	21.82^{bd}	21.01^{be}	21.38^{be}	21.16^{be}	20.16^{cf}	21.11^{b}	74.5^{ce}	68.5^{ef}	72.0^{df}	71.0^{df}	68.3^{ef}	70.9^{b}
B_3	64.04^{a}	59.10^{cg}	61.07^{ab}	59.00^{abc}	60.10^{bcd}	60.66^{a}	25.29^{a}	22.33^{ad}	24.40^{ab}	23.30^{abc}	21.53^{be}	23.37^{a}	92.1^{a}	78.3^{bd}	85.1^{ab}	81.3^{bd}	78.2^{ef}	83.1^{a}
B_4	57.99^{be}	55.10^{dg}	56.88^{dg}	56.22^{cg}	54.22^{dg}	56.08^{c}	18.16^{eg}	16.82^{fg}	17.95^{eg}	18.04^{eg}	16.04^{g}	17.40^{c}	68.7^{ef}	65.6^{f}	67.3^{ef}	66.2^{ef}	64.9^{f}	66.5^{c}
Mean	58.31^{a}	55.31^{b}	56.32^{ab}	56.53^{ab}	55.11^{b}	-	21.91^{a}	20.22^{bc}	21.50^{b}	20.94^{b}	19.28^{c}	-	76.6^{a}	70.1^{b}	73.6^{ab}	72.1^{b}	69.8^{b}	-

Table 2. Seed yield and haulm yield of soybean as influenced by biofertilizers and foliar application of organic acids

Biofertilizers \ Foliar sprays	Seed yield (g plant^{-1})						Seed yield (q ha^{1})						Haulm yield (q ha^{-1})					
	F_1	F_2	F_3	F_4	F_5	Mean	F_1	F_2	F_3	F_4	F_5	Mean	F_1	F_2	F_3	F_4	F_5	Mean
B_1	16.33^{cf}	15.10^{fi}	15.75^{dg}	15.44^{eh}	14.38^{hi}	15.40^{c}	31.66^{bf}	29.86^{ei}	31.05^{cg}	30.81^{fi}	29.34^{be}	30.54^{b}	52.39^{ac}	49.41^{be}	50.67^{bd}	49.03^{be}	46.93^{df}	49.68^{b}
B_2	17.39^{bc}	15.20^{fi}	16.66^{ce}	16.29^{cf}	14.88^{gi}	16.08^{b}	32.21^{di}	30.07^{bf}	31.44^{bf}	30.67^{ch}	29.58^{fi}	30.79^{b}	53.05^{ab}	49.69^{be}	50.91^{bd}	50.42^{bd}	47.49^{cf}	50.31^{b}
B_3	19.51^{a}	16.90^{bd}	18.09^{b}	17.22^{bc}	16.22^{cf}	17.59^{a}	35.96^{a}	32.71^{bc}	33.81^{b}	32.94^{bc}	32.47^{bd}	33.58^{a}	55.75^{a}	51.52^{ad}	53.01^{ab}	52.35^{ac}	49.80^{bd}	52.48^{a}
B_4	15.33^{fh}	13.95^{ij}	14.68^{gi}	14.22^{hj}	13.10^{j}	14.26^{d}	30.28^{di}	28.27^{hi}	29.33^{fi}	28.61^{gi}	27.90^{i}	28.88^{c}	46.54^{df}	46.98^{df}	44.82^{ef}	43.07^{f}	43.71^{f}	45.03^{c}
Mean	17.14^{a}	15.29^{c}	16.29^{b}	15.79^{bc}	14.65^{d}	-	32.53^{a}	30.23^{c}	31.41^{b}	30.76^{bc}	29.82^{c}	-	51.93^{a}	49.40^{b}	49.85^{ab}	48.72^{bc}	46.98^{c}	-

Means followed by the same lower case letters in a column do not differ significantly by DMRT (P=0.05)

B_1 - PSB, B_2 - VAM, B_3 - PSB+VAM, B_4 - Control, F_1- Foliar spray of Humic acid @ 0.1% at flower initiation stage, F_2- Foliar spray of Lecithin @ 0.1% at flower initiation stage, F_3- Foliar spray of Citric acid @ 0.1% at flower initiation stage, F_4- Foliar spray of Maleic acid @ 0.1% at flower initiation stage, F_5- Control

accumulation in leaves and stem. These results are in agreement with the findings of Chitale *et al.* (2012) who reported that higher dry matter production was due to higher plant height, more number of branches per plant, more number of leaves per plant and increase in leaf area index. These results are in accordance with the findings of Ayman *et al.* (2009). Increase in dry matter production with humic acid might be due to direct action on plant growth auxin activity, contributing to increase in dry matter. From the above investigations it can be inferred that combined application of biofertilizers and organic acids (PSB+VAM in combination with foliar spray of 0.1% humic acid) along with RDF proved effective in significantly enhancing the growth and yield of soybean.

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