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Testing of comparative efficacy of different *Rhizobium* inoculants on growth and yield of soybean (*Glycine max* (L.) Merrill)

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Abstract
An experiment entitled "Testing of comparative efficacy of different *Rhizobium* inoculants on growth and yield of soybean" was conducted in *Kharif* season at student research field, College of Agriculture, Indore (M.P.). The soil of the experimental field was medium black in texture, neutral in reaction (pH 7.70) with normal EC (0.23 dS/m) and medium organic carbon contents (0.56 %) and analysing low in available N (225 kg/ha), medium in available P (9.60 kg/ha) and high in available K (508 kg/ha) contents. Due to dominance of montmorillonite clay content it has high capacity to swell and shrink and high CEC. A field experiment was consisted of 15 treatments replicated four times in randomized block design (RBD). As per treatment, the seed of soybean cv. JS 335 treated or not treated with fungicides and inoculated with *Rhizobium* culture before 15, 10, 05, 01 days of planting and on the day of sowing. The maximum number of nodules (63.90/plant) was recorded under [Thiram + Carbendazim 50 WP - Premax+ Rizo-liq (ODS)] (T_{10}) treatment while minimum number of root nodules (51.20/plant) was recorded in T_{15} absolute control (No fungicide, No culture). Maximum yield (2147 kg/ha) was recorded under [Thiram + Carbendazim 50 WP - Premax+ Rizo-liq (ODS)] (T_{10}) treatment and the minimum (1509 kg/ha) was recorded in absolute control (T_{15}) treatment. The application of *Rhizobium* with or without fungicides showed a synergic effect in increasing the seed yield of soybean per hectare. The maximum net return (Rs.16030/ha) as well as the benefit; cost ratio (2.72) were obtained from T_{10} having [Thiram + Carbendazim 50 WP - Premax + Rizo-liq (ODS)] treatment as compared to absolute control (T_{15}) treatment where as minimum net return (Rs.9035/ha) and the benefit; cost ratio (2.03) were obtained.

Keywords: Soybean, fungicide, *Bradyrhizobium japonicum* (Premax + Rizo-liq), seed treatment, nodulation, yield and economics

Introduction
Soybean (*Glycine max* (L.) Merrill) is a major legume crop recognized as the efficient producer of the two scarce quality characters i.e. the protein and oil, which are not only the major components in the diet of vegetarians mass but a boon to the developing countries as well. Soybean plays a vital role in the agricultural economy of India.

In Madhya Pradesh, Farmers generally apply unbalanced under dose of fertilizers and less use of FYM and bacterial cultures which lead to low production. Indiscriminate use of chemical fertilizers deteriorates the soil health with environmental pollution. Biofertilizers are the substitute or supplementary materials in addition to the chemical fertilizers. Biofertilizers are economically viable lever for realizing the ultimate goal of increasing productivity. These microbial systems siphon out appreciable amount of nitrogen from the atmospheric reservoir and enrich the soil with these important but scare nutrients.

Culture inoculation of legume seeds at the time of sowing was found helpful in increasing the *Rhizobia* population in the soil which resulted into increased number of root nodules and ultimately gave 20-70% more yield of the legume (Dadson and Acquash, 1984) [5]

The limitation of using the *Rhizobia* are that they cannot apply well in advance and in the other hand there is narrow window of soybean planting in India as it is rainy season crop. Soybean is becoming popular in Madhya Pradesh particularly in 'Malwa region' and hence efforts should be made to boost up the production of soybean by adopting modern techniques of crop production.

Material and Methods
An experiment entitled "Testing of comparative efficacy of different *Rhizobium* inoculants on growth and yield of soybean" was conducted in *Kharif* season at student research field, College of Agriculture, Indore (M.P.). The soil of the experimental field was medium black in texture, neutral in reaction (pH 7.70) with normal EC (0.23 dS/m) and medium organic carbon

contents (0.56 %) and analysing low in available N (225 kg/ha), medium in available P (9.60 kg/ha) and high in available K (508 kg/ha) contents. Due to dominance of montmorillonite clay content it has high capacity to swell and shrink and high CEC. A field experiment was consisted of 15 treatments replicated four times in randomized block design (RBD). It is located on latitude of 22.43ºN and longitude of 75.66ºE. It has subtropical climate having a temperature range of 23ºC to 41ºC and 4ºC to 29ºC in summer and winter season, respectively. The rainfall in the region is mostly inadequate and erratic. Late commencement, early withdrawal and two to three dry spells are the main features. The average rain is 964 mm and it was below normal (803 mm). The maximum temperature ranged from 25.7 ^{0}C to 40.8 ^{0}C while minimum temperature accelerated between 14.9 ^{0}C to 28.8 ^{0}C during the season.

Properties of fungicides and Bio-fertilizers

Thiram: Thiram is contact fungicide, most effective seed protectant, least phytotoxic and used for the control of many seed-borne or soil-borne diseases.

Carbendazim 50 WP (Bavistin): Carbendazim is systemic with prophylactic and curative action and also non-phytotoxic. It is used for the control of many internally and externally seed borne diseases. Besides the disease control, beneficial side effects like stimulation of growth, flowering and yield of plants on the treated hosts have been reported.

Premax (Protector): Premax protects Rhizobial population from the adverse effects of fungicides.

Rizo-liq: Rizo-liq (*Bradyrhizobium japonicum* Strain) is a liquid biofertilizer which is used well in advance to inoculate the seed and recommended for soybean crop.

***Rhizobium* cultures (Rh_1, Rh_2, Rh_3):** *Rhizobium* cultures (*Rhizobium japonicum* strain) are solid biofertilizers which are used to inoculate the seed of soybean.

Number of root nodules per plant

The effective root nodules of five randomly selected plants were counted at 30, 45, 60 DAS in all the plots.

Dry weight of root nodules per plant (g)

Dry weight of root nodule was taken at 45 DAS by separating the nodules from root of five randomly selected plants. The nodules were dried in oven at 65 ºC for 48 hours. The average weight of nodules per plant was thus computed.

Seed yield (kg per hectare)

The seed yield per net plot was recorded after drying the seed. The plot yield was later on converted into kg per hectare by multiplying it by conversion factor.

Stover yield (kg per hectare)

The stover yield per plot was obtained by subtracting grain yield from bundle weight of each plot. This was later on converted into kg per hectare.

Harvest index (%):

The harvest index is calculated by the following equation:

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

Results and Discussion

Number of root nodules per plant

Data showed that maximum (63.90) number of root nodules per plant was recorded in T_{10} [Thiram + Carbendazim 50 WP - Premax + Rizo-liq (ODS) treatment closely followed by T_{13} [Thiram + Carbendazim 50 WP - Rh_3 (ODS)] treatment and minimum (51.20) was recorded under T_{15} (control) treatment. Data revealed that the *Rhizobium* inoculated seed resulted into more number of nodules per plant than control. Irrespective of method of seed inoculation, seed inoculation with Rhizo-liq +premax at the time of sowing resulted in the highest number of nodules per plant as compared to seed inoculation prior to sowing (15, 10, 05, 1 DPS). Carbendazim having no antibacterial activity and did not inhibit the growth of *Rhizobium* and thereby promoted nodulation. This finding shows that *Rhizobium* inoculation with or without fungicides at the time of sowing increased higher number of root nodules per plant.

Table 1: Influence of different treatments on number of root nodules per plant

Treatment No.	Treatments	Number of Root nodules per plant		
		30 DAS	45 DAS	60 DAS
T_1	Premax + Rizo-liq (15 DPS)	16.55	33.90	54.30
T_2	Premax + Rizo-liq (10 DPS)	17.50	34.40	55.35
T_3	Premax + Rizo-liq (05 DPS)	17.60	36.60	55.90
T_4	Premax + Rizo-liq (01 DPS)	20.35	37.20	58.00
T_5	Premax + Rizo-liq (ODS)	22.45	42.60	59.35
T_6	Thiram + Carbendazim 50 WP - Premax + Rizo-liq (15 DPS)	17.60	36.15	54.50
T_7	Thiram + Carbendazim 50 WP - Premax + Rizo-liq (10 DPS)	17.85	37.40	55.30
T_8	Thiram + Carbendazim 50 WP - Premax + Rizo-liq (05 DPS)	17.90	38.60	56.40
T_9	Thiram + Carbendazim 50 WP - Premax + Rizo-liq (01 DPS)	21.80	40.20	58.55
T_{10}	Thiram + Carbendazim 50 WP - Premax + Rizo-liq (ODS)	24.60	49.60	63.90
T_{11}	Thiram + Carbendazim 50 WP - Rh_1 (ODS)	22.45	43.90	59.40
T_{12}	Thiram + Carbendazim 50 WP - Rh_2 (ODS)	21.95	42.55	58.60
T_{13}	Thiram + Carbendazim 50 WP - Rh_3 (ODS)	23.80	47.60	61.90
T_{14}	Uninoculated seed (but fungicidal treatment)	16.55	32.55	53.70
T_{15}	Absolute control (No fungicidal treatment and no inoculation)	14.35	29.30	51.20
SEm ±		1.31	1.82	1.67
CD at 5%		3.74	5.20	4.76

DPS: Days prior sowing, ODS: On days of sowing, DAS: Days after sowing

Dry weight of root nodules per plant

Data revealed that maximum (0.55 g) dry weight of root nodules per plant was observed in treatment T_{10} having seed treated with Thiram + Carbendazion 50 WP and inoculated with premax + Rizo-liq (ODS). This treatment (T_{10}**)** was found significantly superior to most of the other treatments except T_{13}, T_{11}, T_9, T_5 and T_{12} treatments having *Rhizobium* inoculation with or without fungicides (Thiram +Carbendazim 50 WP). Application of no fungicide and no *Rhizobium* inoculation (T_{15}) resulted in the lowest (0.27 g) dry weight of root nodules per plant.

Table 2: Influence of different treatments on dry weight of root nodules per plant

Treatment No.	Treatments	Dry weight of root nodules per plant (g)
		45 DAS
T_1	Premax + Rizo-liq (15 DPS)	0.30
T_2	Premax + Rizo-liq (10 DPS)	0.32
T_3	Premax + Rizo-liq (05 DPS)	0.33
T_4	Premax + Rizo-liq (01 DPS)	0.35
T_5	Premax + Rizo-liq (ODS)	0.46
T_6	Thiram + Carbendazim 50 WP - Premax + Rizo-liq (15 DPS)	0.33
T_7	Thiram + Carbendazim 50 WP - Premax + Rizo-liq (10 DPS)	0.35
T_8	Thiram + Carbendazim 50 WP - Premax + Rizo-liq (05 DPS)	0.36
T_9	Thiram + Carbendazim 50 WP - Premax + Rizo-liq (01 DPS)	0.47
T_{10}	Thiram + Carbendazim 50 WP - Premax + Rizo-liq (ODS)	0.55
T_{11}	Thiram + Carbendazim 50 WP - Rh_1 (ODS)	0.48
T_{12}	Thiram + Carbendazim 50 WP - Rh_2 (ODS)	0.46
T_{13}	Thiram + Carbendazim 50 WP - Rh_3 (ODS)	0.52
T_{14}	Uninoculated seed (but fungicidal treatment)	0.29
T_{15}	Absolute control (No fungicidal treatment and no inoculation)	0.27
SEm ±		0.04
CD at 5%		0.12

DPS: Days prior sowing, ODS: On days of sowing, DAS: Days after sowing

Number of branches per plant

Maximum number of branches per plant (4.02) was recorded in T_{10} [Thiram + Carbendazim 50 WP- Premax+Rizo-liq (ODS)] treatment and minimum (2.95) was recorded under T_{15} (Absolute control) treatment. The data revealed that *Rhizobium* inoculation with or without fungicide on the day of sowing increased the number of branches per plant as compared to control and uninoculated seed treatment at all the growth stages. However rest of the treatments produced more number of branches per plant than absolute control.

Table 3: Number of branches per plant as affected by various treatments at successive stages of plant growth

Treatment No.	Treatments	Number of branches per plant		
		45 DAS	60 DAS	At Harvest
T_1	Premax + Rizo-liq (15 DPS)	1.65	3.10	3.10
T_2	Premax + Rizo-liq (10 DPS)	1.80	3.20	3.20
T_3	Premax + Rizo-liq (05 DPS)	1.85	3.20	3.20
T_4	Premax + Rizo-liq (01 DPS)	1.90	3.80	3.80
T_5	Premax + Rizo-liq (ODS)	2.15	3.95	3.95
T_6	Thiram + Carbendazim 50 WP - Premax + Rizo-liq (15 DPS)	1.85	3.15	3.15
T_7	Thiram + Carbendazim 50 WP - Premax + Rizo-liq (10 DPS)	1.90	3.25	3.25
T_8	Thiram + Carbendazim 50 WP - Premax + Rizo-liq (05 DPS)	1.95	3.30	3.30
T_9	Thiram + Carbendazim 50 WP - Premax + Rizo-liq (01 DPS)	2.10	3.80	3.80
T_{10}	Thiram + Carbendazim 50 WP - Premax + Rizo-liq (ODS)	2.60	4.02	4.02
T_{11}	Thiram + Carbendazim 50 WP - Rh_1 (ODS)	2.20	3.85	3.85
T_{12}	Thiram + Carbendazim 50 WP - Rh_2 (ODS)	2.25	3.80	3.80
T_{13}	Thiram + Carbendazim 50 WP - Rh_3 (ODS)	2.55	3.95	3.95
T_{14}	Uninoculated seed (but fungicidal treatment)	1.60	3.05	3.05
T_{15}	Absolute control (No fungicidal treatment and no inoculation)	1.55	2.95	2.95
SEm ±		0.23	0.31	0.31
CD at 5%		NS	NS	NS

DPS: Days prior sowing, ODS: On days of sowing, DAS: Days after sowing

Seed yield per hectare

Yield of the crop is the result of the various biotic and environmental factors, which are responsible for changes brought about in the productivity. Effectiveness of any treatment could be judged by the magnitude of changes in the productivity brought about by that particular treatment. The seed yield was recorded per net plot and then it was converted into kg/ha. Perusal of data in Table 4 revealed that the maximum (2147 kg/ha) seed yield of soybean in entire experiment was recorded in T_{10} [Thiram+carbendazim 50 WP - Premax+ Rizo-liq (ODS)] treatment which was appreciably higher than all other treatments, immediately followed by T_{13} [Thiram + Carbendazim 50 WP - Rh_3 (ODS)] (2115 kg/ha) treatment. Minimum (1509 kg/ha) seed yield was recorded in T_{15} (Absolute control) treatment.

Stover yield per hectare

The stover yield obtained was statistically analysed in order to find out the effect of different treatments. The stover yield was calculated by subtracting the seed yield from the

biological yield. The maximum (2846 kg/ha) stover yield in entire experiment was recorded in T_{10} [Thiram+Carbendazim 50 WP- Premax+ Rizo-liq (ODS)] treatment. T_{10} [Thiram+Carbendazim 50 WP- Premax+ Rizo-liq (ODS)] was found to be at par with all the treatments except T_1, T_2, T_{14}, and T_{15} (Absolute control). The lowest stover yield (2080 kg/ha) was noted in T_{15} (Absolute control) treatment.

Harvest index (%)

Data revealed that all the treatments increased the harvest index of soybean as compared to T_{15} (Absolute control) treatment. The differences in harvest index among the treatments were non significant. The maximum harvest index up to 43.62% equally found inT_{11} [Thiram + Carbendazim 50 WP - Rh_1 (ODS)] and T_1 [Premax+Rizo-liq (15 DPS)] treatments whereas the minimum harvest index (39.56%) was recorded in T_{15} (Absolute control).

Table 4: Seed yield, Stover yield (kg / ha) and harvest index (%) as affected by different treatments

Treatment No.	Treatments	Seed Yield (kg/ha)	Stover Yield (kg/ha)	Harvest Index (%)
T_1	Premax + Rizo-liq (15 DPS)	1845	2388	43.61
T_2	Premax + Rizo-liq (10 DPS)	1845	2417	43.33
T_3	Premax + Rizo-liq (05 DPS)	1898	2539	42.84
T_4	Premax + Rizo-liq (01 DPS)	1995	2606	43.43
T_5	Premax + Rizo-liq (ODS)	2065	2728	43.32
T_6	Thiram+Carbendazim 50 WP-Premax + Rizo-liq (15 DPS)	1904	2528	43.00
T_7	Thiram+Carbendazim 50 WP-Premax + Rizo-liq (10 DPS)	1935	2646	42.15
T_8	Thiram+Carbendazim 50 WP-Premax + Rizo-liq (05 DPS)	1979	2652	42.69
T_9	Thiram+Carbendazim 50 WP-Premax + Rizo-liq (01 DPS)	2022	2672	43.37
T_{10}	Thiram+Carbendazim50 WP-Premax + Rizo-liq (ODS)	2147	2846	43.20
T_{11}	Thiram + Carbendazim 50 WP - Rh_1 (ODS)	2025	2622	43.62
T_{12}	Thiram + Carbendazim 50 WP - Rh_2 (ODS)	1925	2722	41.42
T_{13}	Thiram + Carbendazim 50 WP - Rh_3 (ODS)	2115	2763	43.36
T_{14}	Uninoculated seed (but fungicidal treatment)	1635	2174	43.03
T_{15}	Absolute control (No fungicidal treatment and no inoculation)	1509	2080	39.56
SEm ±		71.73	127.11	1.67
CD at 5%		204.60	362.56	NS

DPS: Days prior sowing, ODS: On days of sowing, DAS: Days after sowing

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