

Original Research Article

Effect~~Influence~~ of Microbial Consortia Inoculation and Chemical Fertilizers on Growth Parameters and Nodulation of Soybean (*Glycine max* L. merill.) and Chickpea (*Cicerarietinum*L.)-Crop

ABSTRACT

Microbial consortia inoculation and chemical fertilizers significantly impact plant growth parameters. Microbial consortia contribute to soil health by enhancing nutrient availability and promoting plant growth, while chemical fertilizers provide essential nutrients. In this study, Field experiments were conducted during kharif seasons of 2020 and 2021 at Research Farm of Department of Soil Science and Agricultural Chemistry, VasantraoNaikMarathwadaKrishiVidyapeeth, Parbhani to assess~~study~~ the effect~~influence~~ of microbial consortia inoculation and chemical fertilizer on growth parameters and nodulation of soybean (*Glycine max* L. Merill.) and Chickpea~~(Cicerarietinum L.)~~. The experimental site of present investigation was classified as Vertisol soil order belonging to Parbhani soil series. The soils were dominant in montmorillonite m~~M~~ineral followed by moderate amount of kaolinite type and traces of illite mineral. Soil was clayey with alkaline in reaction (pH 8.29), low in salt content (0.29 dSm^{-1}) with high calcium carbonate content (132.3 g kg^{-1}). The organic carbon status of soil was medium (4.86 per cent). The soil available nitrogen was low ($159.94 \text{ kg ha}^{-1}$), available phosphorus was medium (10.71 kg ha^{-1}), available potassium was very high (578 kg ha^{-1}). The experiments were laid out in factorial randomized block design with three replications. Results obtained from the study indicated that growth parameters like plant height, shoot weight, root length, root weight, number of branches and nodulation was significantly improved with combined effect of microbial consortia inoculation Rhizobium species + Pseudomonas striata, Bacillus megaterium and Thiobacillusthiooxidans~~s~~ along with chemical fertilizers 100 % RDF as compared to uninoculated control and control (without fertilizers) treatment.

Key words : Microbial consortia inoculation, chemical fertilizers, growth parameters, nodulation, soybean.

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INTRODUCTION

Modern agriculture has to be more productive sustainable and environmentally friendly. While macronutrients such as nitrogen (N), phosphorus (P), potassium (K) and sulfur (S) supplied directly by mineral fertilizers are vital to crop production, etc. or indirectly (i.e. antimicrobial compounds biosynthesis and elicitation of induced systemic resistance, etc.) to crop improvement fertilizers efficiency, microbial based bioformulations that increase plant performance are greatly needed and in particular bioformulations that exhibit complementary and synergistic effects with mineral fertilization. Such an integrated soil fertility management strategy has been demonstrated through several controlled and non controlled experiments, but more efforts have to be made in order to thoroughly understand the multiple functions of beneficial microorganisms within the soil microbial community itself and in interaction with plants and mineral resources. In fact, the combined usage of microbial (i.e. beneficial microorganisms: nitrogen fixing (NF), P-solubilizing and P-mobilizing, etc.) and mineral resources is an emerging research area that aims to design and develop efficient microbial formulations which are highly compatible with mineral resources is an emerging research area that aims to design and develop efficient microbial formulations which are highly compatible with mineral inputs with positive impacts on both crops and environment. This novel approach is likely to be of a global interest, especially in most N and P deficient agro-ecosystems. In this review, we report on the importance of NF bacteria and P solubilizing / mobilizing microbes as well as their interactions with mineral fertilization in improving crop productivity and fertilizers efficiency. Improving use of mineral nutrients is a must to securing higher yield and productivity in a sustainable manner therefore continuously desiring, developing and testing innovative integrated plant nutrient management systems based on relevant biological resources (crops and microorganisms) is highly required. Several

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reports indicated that dual or triple inoculation of *Rhizobium* PSB, [Plant growth promoting rhizobacteria \(PGPR\)](#) is better than inoculation with *Rhizobium* alone in different pulse crops (Gupta, 2006). Bacteria is most plentiful microbial community in soil followed by fungi (Kaure *et al.*, 2020; Rana *et al.*, 2020).

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Soybean (*Glycine max* (L.) Merrill.) is an annual leguminous species cultivated mainly for its seed. Soybean seed consists of 35 % carbohydrate, 5 % ash, 40 % protein and 20 % oil and is a major source of protein and oil for commercial products. About 40 % of the world's edible vegetable oil comes from soybean (Hildebrand *et al.*, 1986). Soybean ranks first among the major oil seed crops of the world and has now found a prominent place in India (Mahana, *et al.*, 2005). Chouhan *et al.* (2008) reported that soybean has occupied first rank among oilseed crops in India 2005 onwards. In India production of soybean is dominated by Maharashtra and Madhya Pradesh and it contributes 89 per cent of total production. Area of soybean in India is 11.8 million ha, production is 11.94 million tonnes with average productivity 1050 kg ha⁻¹ (Anonymous, 2019). Symbiotic *Rhizobium* species associated with soybean root nodules benefit plant growth via mediating biological N-fixation (Jaiswal *et al.*, 2021). However, it has been demonstrated that extension of premature senescence is mediated by the induction of high glutathione reductase in soybean roots and nodules. Glutathione reductase activity likely exerts its influence by reducing oxidative damage to biomolecules (Porcel and Ruiz Lozano, 2004; Prabhakar and Sharadamma, 2019; Meena *et al.*, 2021).

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Further, chickpea (*Cicer arietinum* L.) is the second most important pulse crop globally, after common bean (*Phaseolus vulgaris*). Chickpea is a quality food source rich in proteins, minerals, vitamins and fibers that benefit the health of domestic stock and humans (Graham and Vance, 2003; Jukanti *et al.*, 2012; Bohra *et al.*, 2014). The global area of chickpea is average 13.0 million hectares across 56 countries (2015-17) ([Food and Agricultural Organization of the United Nations, FAOSTAT](#), 2020). India is the largest global producer, consumer and importer of chickpea whereas Australia is the main exporter of desi type (outlined later) chickpea to India. India mostly imports Desi

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chickpea but also emerges as an exporter to some Kabuli type over the past decade.

The progress on increasing chickpea yields has stagnated in India and Australia average around 1.0 to 2 t ha⁻¹. Moreover, the estimated realizable potential is over 2 t ha⁻¹. The current yields of chickpea are insufficient for meeting the growing demand of plants based food specially dietary protein (Millanet *al.*, 2006; Jhaet *al.*, 2019). Overall, legumes are more sensitive to environmental stress than cereals, with chickpea often exposed to terminal drought and high temperature. In addition, chickpea may not be able to absorb enough from the soil, specially under drought to influence yield due to its low N-fixation ability and low nutrient used efficiently (Sadras *et al.*, 2016). Chickpea and soybean contributes a significant amount of residual nitrogen to the soil and adds organic matter thereby improving soil health and fertility. On the basis of seed colour and geographical distribution, chickpea is grouped into two types :desi (Indian origin) and Kabuli (Mediterranean) and middle eastern origin (Bampidisa and Christodolu, 2011). Chickpea also play important role in maintaining soil fertility by fixing nitrogen at the rate upto 140 kg ha⁻¹ year⁻¹ (Flowers *et al.*, 2010).

MATERIAL AND METHODS

Experimental Site

Present investigation was carried out at Research Farm, Department of Soil Science and Agricultural Chemistry, Vasant Rao Naik Marathwada Krishi Vidyapeeth, Parbhani on Vertisol (Typic Haplusterts). The initial soil pH 8.29, organic carbon 4.86 per cent, available N 159.94 kg ha⁻¹, available phosphorus 10.71 kg ha⁻¹ and available potassium 578 kg ha⁻¹. The soil was clayey in texture, medium in organic carbon, available nitrogen was low, medium available P₂O₅ and available K₂O was very high 578 kg ha⁻¹.

Experimental Design

The experiment comprising four treatments of microbial consortia inoculation *Rhizobium* species + *Bacillus megaterium*, *Rhizobium* species + *Pseudomonas striata*, *Rhizobium* species + *Thiobacillus thiooxidans* and uninoculated control and four levels of chemical fertilizers (100 % RDF, 75 % RDF, 50% RDF and control i.e. without fertilizer treatment. The

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experiment was laid out in Factorial Randomized Block Design with three replications.

Seed Inoculation and Sowing

Seed inoculation was done with consortia *Rhizobium* species, *Bacillus megaterium*, *Pseudomonas striata*, *Thiobacillus thiooxidans* @ 100 ml for each 10 kg⁻¹ seed as seed treatment before sowing. The variety of soybean Cv. MAUS 162 and chickpea Cv. *PhuleVikram*. The recommended dose of fertilizer (RDF) as basal dose was applied N:P₂O₅:K₂O 30:60:30 kg ha⁻¹ for soybean and N:P₂O₅:K₂O 25:50:0 kg ha⁻¹ for chickpea, through urea, SSP and MOP respectively at the time of sowing soybean in kharif and chickpea in rabi season. Irrigation is given as per crop need and of chickpea crop only and package of practices were followed for both soybean and chickpea crops. The biometric observations were recorded at 60 and 90 DAS of both soybean, chickpea and average were computed.

Plants Sampling and Measurement of Growth Parameters

Five plants sampling technique were adopted and randomly selected from each plot tagged and biometric observations viz., plant height, shoot weight, root length, root weight number of branches and nodulation i.e. number of nodules (plant⁻¹), fresh weight of nodules (g plant⁻¹), dry weight of nodules (g plant⁻¹). The total number of nodules were recorded from five plants in each plot of soybean and chickpea. Fresh weight of nodules of soybean and chickpea was taken (g plant⁻¹) on digital electronic balance. The dry weight of nodules of soybean and chickpea were air dried, after air drying oven drying was carried out at 65C⁰. Dry weight of nodules was recorded (g plant⁻¹) on a digital electronic balance.

RESULTS AND DISCUSSION

Plant height (cm plant⁻¹) of soybean and chickpea

Plant height was increased with effect of microbial consortia inoculation and chemical fertilizers during the years 2020-21 and 2021-22 and pooled mean of experiment (Table 1 and 2). Plant height of soybean and chickpea was significantly highest at 60, 90 days with treatment *Rhizobium* species + *Pseudomonas striata* inoculation II (S3) 69.31, 74.79 and 46.38, 71.95 and lowest was noted in uninoculated control (S1) during both the years

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of experimentations and pooled mean, respectively. Treatment after (S3) consortia (II) found at par with *Rhizobium* species + *Bacillus megaterium* inoculation (consortia I) (S2) at both the stages during 2020-21, 2021-22 and pooled data. The treatment chemical fertilizers with 100 % RDF (T4) was found significant to increase plant height of soybean and chickpea. Significantly highest at 60 and 90 DAS with treatment 100 % RDF 61.45, 66.38 and 43.54, 64.22 and lowest was found without fertilizers (T1) during both the years of experiment and pooled mean respectively.

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Shoot weight (g plant⁻¹) of soybean and chickpea

Shoot weight was increased with treatment microbial inoculants and chemical fertilizers (Table 3 and 4). Shoot weight of soybean and chickpea crop was significantly highest at 60 and 90 DAS 40.95, 57.66 and 55.12, 86.11, respectively with treatment *Rhizobium* species + *Pseudomonas striata* (S3) and lowest was observed in treatment uninoculated control (S1) during both the experimentation years and pooled data. Chemical fertilizer with 100 % RDF improved shoot weight of both soybean and chickpea crops at 60 and 90 DAS 37.44, 50.67 and 50.37, 72.21 with treatment (T4) and lowest in treatment without fertilizers (T1).

Significantly highest shoot weight was recorded 108.40 g in *Mesorhizobium* + *Pseudomonas striata* along with 100 % RDF treatment at 90 DAS stage and it was at par with *Mesorhizobium* + *Pseudomonas striata* with 75 % RDF. The plant height and shoot weight of both soybean, chickpea crops was increased with 100 % NPK along with consortium of bioinoculants might be due to easily available all nutrients to plant roots and improve the plant height and shoot weight and crop growth. Results are in line with Naiket *et al.* (2020), when applied EM formulations reported have positive effect on several crop growth parameters. Solankiet *et al.* (2017) reported enhancement of P availability increased better root growth, plant vegetative growth. Also, Sainiet *et al.* (2017) reported similar results.

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Root weight (g plant⁻¹) of soybean and chickpea

The highest root weight (g plant⁻¹) of soybean and chickpea (Table 5 and 6) was recorded in *Rhizobium* species + *Pseudomonas striata* (S3) 10.58,

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11.54 and 9.97, 11.05 g plant⁻¹ at 60 and 90 DAS of pooled. Treatment S3 was found at par with *Rhizobium* species + *Bacillus megaterium* (S2) and lowest root weight was in uninoculated control. Further chemical fertilizers 100 % RDF also increase root weight at 60 and 90 DAS 9.51, 10.46 and 8.01, 9.74 g plant⁻¹ in pooled, and it was at par with treatment 75 % RDF and lowest root in treatment control (without fertilizer) (T1).

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Root length (cm plant⁻¹) of soybean and chickpea

Table 7 and 8 indicates the effect of microbial inoculants on root length of soybean and chickpea crops during the years 2020-21, 2021-22 and pooled were highest root length 31.80, 35.23 and 18.77, 20.36 cm plant⁻¹ at 60 and 90 DAS and maximum root length was noted in treatment *Rhizobium* species + *Pseudomonas striata* (S3) and least was noticed treatment uninoculated control (S1) during both the years of and pooled. Chemical fertilizers showed significantly highest root length 27.84, 32.79 and 17.13, 17.62 cm plant⁻¹ at 60 and 90 DAS in 100 % RDF treatment of both soybean and chickpea crop respectively, and was minimum root length was in treatment without fertilizer application (T1).

Shoot weight and root length of soybean and chickpea plants significantly increased might be due to *Bradyrhizobium*, *Mesorhizobium* and *Pseudomonas striata*, *Bacillus megaterium* is able to synthesized growth regulators indole acetic acid (IAA), Gibberellins, Auxins, Vitamins and Cytokinins, antagonistic metabolites such as HCNM and siderophore through its ability to provide nutrients through biological nitrogen fixation and phosphorus solubilization / mobilization and ion chelation (Bashan *et al.*, 2014; Tufenkiet *al.*, 2005). Ruet *al.* (2012) reported that single inoculation with AM (*Arbuscular mycorrhiza*) fungus and *R. irregularis* significantly increased shoot weight of chickpea over uninoculated control. Elcokaet *al.*, 2007) observed on chickpea seed inoculants with *Rhizobium* N₂-fixing *Bacillus subtilis* and P solubilizing *Bacillus megaterium* was highest plant height, shoot weight over control treatment.

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Nodulation in soybean and chickpea

The number of nodules in soybean and chickpea were significantly improved by microbial consortia inoculants and chemical fertilizers (Table 9 and 10). Maximum nodules, fresh weight of nodules were recorded in treatment (S3) *Rhizobium* species + *Pseudomonas striata* 100.30, 897.84, 570.87 and 41.79, 478.55, 309.37 respectively and lowest number of nodules plant⁻¹, fresh weight of nodules mg plant⁻¹ and dry weight of nodules mg plant⁻¹ were recorded in treatment (S1) uninoculated control. Chemical fertilizer increased nodule number plant⁻¹, fresh weight mg plant⁻¹ and dry weight mg plant⁻¹ of nodule in both soybean and chickpea i.e. 80.29, 741.88, 492.58 and 35.54, 417.09, 291.89 significantly maximum in treatment (T4) and minimum was in control (without fertilizer) and treatment (T1) both the soybean and chickpea crop.

Application of dual or more inoculants i.e. *Rhizobium* species, PSB, phosphate solubilizing and mobilizing bacteria might be due to greater availability of nitrogen and phosphorus in soil which results in better nodulation, increase number of nodules improve number of nodules improves fresh weight and dry weight of nodules growth and development of plant growth. These results are finding with Hungria *et al.* (2018) application of *Bradyrhizobium* + strains of *Azospirillum* and PSM the nodulation of soybean plants were promoted. Masciarelli *et al.* (2014) found that co-inoculation of *Bradyrhizobium japonicum* with PSB has better nodulation and could be due to phytohormone production which resulted in increased nodule number and its dry biomass. Co-inoculation of rhizobia with PGPR enhanced nodulation in pigeonpea and other legumes (Gupta *et al.* 2015; Sekar *et al.*, 2016; Nasimento *et al.*, 2019). Sibpankrung *et al.* (2020) also reported the similar results.

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Table 1. Effect of microbial consortia inoculation and chemical fertilizers on plant height (cm plant⁻¹) of soybean

Treatments	2020-21		2021-22		Pooled	
	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS
Microbial consortia inoculation (S)						
S ₁ - Uninoculated control	44.08	49.60	44.68	48.48	44.38	49.04
S ₂ - <i>BradyRhizobium</i> + <i>Bacillus megaterium</i> inoculation (Consortia-I)	63.75	69.28	59.71	63.72	61.73	66.50
S ₃ - <i>BradyRhizobium</i> + <i>Pseudomonas triatoinoculati</i> on (Consortia-II)	73.58	74.85	65.05	74.74	69.31	74.79
S ₄ - <i>BradyRhizobium</i> + <i>Thiobacillus thiooxidans</i> inoculation (Consortia-III)	57.75	63.72	55.54	60.39	56.64	62.05
S.E.m±	0.79	2.49	0.67	0.88	0.73	1.68
C.D. at 5%	2.29	7.19	1.94	2.55	2.11	4.87
Chemical fertilizers (T)						

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T ₁ - Control (without fertilizer)	56.7 5	62.06	53.0 0	57.4 8	55.29	59.7 7
T ₂ - 50% RDF	57.5 8	62.67	56.2 0	60.9 0	56.47	61.7 8
T ₃ - 75% RDF	60.9 2	66.08	56.8 0	62.8 2	58.86	64.4 5
T ₄ - 100% RDF	63.9 2	66.65	58.9 8	66.1 2	61.45	66.3 8
S.E.m \pm	0.79	2.49	0.67	0.88	0.73	1.68
C.D. at 5%	2.29	7.19	1.94	2.55	2.115	4.87
Interaction (S x T)						
S.E.m \pm	1.58	4.98	1.34	1.76	1.46	3.37
C.D. at 5%	4.58	NS	NS	NS	NS	NS

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Table 2. Effect of microbial consortia inoculation and chemical fertilizers on plant height (cm plant⁻¹) of chickpea

Treatments	2020-21		2021-22		Pooled	
	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS
Microbial consortia inoculation (S)						
S ₁ - Uninoculated control	35.34	44.14	32.24	41.40	33.79	42.77
S ₂ - <i>Mesorhizobium</i> + <i>Bacillus megaterium</i> inoculation (Consortia-I)	42.01	62.19	41.63	60.76	41.82	61.475
S ₃ - <i>Mesorhizobium</i> + <i>Pseudomonas</i> inoculation (Consortia-II)	46.92	72.86	45.85	71.04	46.385	71.95

<i>S</i> ₄ - <i>Mesorhizobium</i> + <i>Thiobacillusthiooxidant</i> inoculation (Consortia-III)	38.53	63.36	38.61	64.49	38.57	63.925
S.E.m \pm	0.73	0.90	0.30	1.63	0.51	1.26
C.D. at 5%	2.13	2.62	0.87	4.71	1.50	3.66
Chemical fertilizers (T)						
T ₁ - Control (without fertilizer)	36.81	56.58	36.40	53.00	36.605	54.79
T ₂ - 50% RDF	39.75	59.18	38.18	59.04	38.965	59.11
T ₃ - 75% RDF	41.98	61.88	40.91	62.12	41.445	62
T ₄ - 100% RDF	44.25	64.91	42.84	63.53	43.545	64.22
S.E.m \pm	0.73	0.90	0.30	1.63	0.51	1.26
C.D. at 5%	2.13	2.62	0.87	4.71	1.50	3.66
Interaction (S x T)						
S.E.m \pm	1.47	1.81	0.60	3.26	1.03	2.53
C.D. at 5%	NS	NS	NS	NS	NS	NS

Table 3. Effect of microbial consortia inoculation and chemical fertilizers on shoot weight (g plant⁻¹) of soybean

Treatments	2020-21		2021-22		Pooled	
	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS
Microbial consortia inoculation (S)						
S ₁ - Uninoculated control	29.28	38.36	30.71	43.83	30.00	41.10
S ₂ - <i>BradyRhizobium</i> + <i>Bacillus megaterium</i> inoculation (Consortia-I)	35.34	47.55	36.18	50.77	35.76	49.16
S ₃ - <i>BradyRhizobium</i> + <i>Pseudomonas triarii</i> inoculation (Consortia-II)	39.24	57.01	42.65	58.31	40.95	57.66
S ₄ - <i>BradyRhizobium</i> + <i>Thiobacillus thiooxidans</i> inoculation (Consortia-III)	32.60	43.03	33.84	59.78	33.22	51.41
S.E.m _±	0.46	0.73	0.72	0.56	0.60	0.65
C.D. at 5%	1.33	0.20	2.10	1.60	1.72	0.90
Chemical fertilizers (T)						
T ₁ - Control (without fertilizer)	32.07	44.20	33.10	49.01	32.59	46.61
T ₂ - 50% RDF	33.16	45.55	34.68	50.36	33.92	47.96
T ₃ - 75% RDF	34.86	46.88	37.09	51.31	35.98	49.10
T ₄ - 100% RDF	36.36	49.33	38.51	52.01	37.44	50.67
S.E.m _±	0.46	0.73	0.72	0.56	0.60	0.65
C.D. at 5%	1.33	0.20	2.10	1.60	1.72	0.90
Interaction (S x T)						
S.E.m _±	0.92	1.46	1.45	0.61	1.19	1.04
C.D. at 5%	NS	NS	NS	NS	NS	NS

Table 4. Effect of microbial consortia inoculation and chemical fertilizers on shoot weight (g plant⁻¹) of chickpea

Treatments	2020-21		2021-22		Pooled	
	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS
Microbial consortia inoculation (S)						
S ₁ - Uninoculated control	32.8 2	45.6 9	33.5 0	45.56	33.16	45.62 5
S ₂ - <i>Mesorhizobium</i> + <i>Bacillus megaterium</i> inoculation (Consortia-I)	49.7 3	64.2 3	50.8 3	89.58	50.28	76.90 5
S ₃ - <i>Mesorhizobium</i> + <i>Pseudomonas striata</i> inoculation (Consortia-II)	53.4 1	69.9 1	56.8 3	102.3 2	55.12	86.11 5
S ₄ - <i>Mesorhizobium</i> + <i>Thiobacillus thiooxidans</i> inoculation (Consortia-III)	45.2 3	58.4 6	47.1 7	62.64	46.2	60.55
S.E.m _±	0.89	0.56	0.62	9.93	0.75	5.24
C.D. at 5%	2.58	1.64	1.79	2.68	2.18	2.16
Chemical fertilizers (T)						
T ₁ - Control (without fertilizer)	39.3 8	56.3 3	40.6 7	72.60	40.02 5	64.46 5
T ₂ - 50% RDF	44.4 5	58.3 3	46.6 7	71.42	45.56	64.87 5
T ₃ - 75% RDF	48.0 5	60.3 3	49.5 8	74.96	48.81 5	67.64 5
T ₄ - 100% RDF	49.3 2	63.3 0	51.4 2	81.12	50.37	72.21
S.E.m _±	0.89	0.56	0.62	9.93	0.75	5.24
C.D. at 5%	2.58	1.64	1.79	2.68	2.18	2.16
Interaction (S x T)						
S.E.m _±	1.78	1.13	1.24	1.86	1.51	1.49
C.D. at 5%	NS	NS	NS	5.37	NS	NS

Table .5 Effect of microbial consortia inoculation and chemical fertilizers on root weight (g plant⁻¹) of soybean

Treatments	2020-21		2021-22		Pooled	
	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS
Microbial consortia inoculation (S)						
S ₁ - Uninoculated control	7.17	7.31	7.10	8.51	7.135	7.91
S ₂ - <i>BradyRhizobium</i> + <i>Bacillus megaterium</i> inoculation (Consortia-I)	9.00	9.66	9.54	10.5 7	9.27	10.11 5
S ₃ - <i>BradyRhizobium</i> + <i>Pseudomonas</i> inoculation (Consortia-II)	10.2 5	10.9 6	10.9 2	12.1 2	10.58 5	11.54
S ₄ - <i>BradyRhizobium</i> + <i>Thiobacillus thiooxidans</i> inoculation (Consortia-III)	7.78	9.44	9.00	10.1 4	8.39	9.79
S.E.m _±	0.18	0.11	0.09	0.36	0.14	0.23
C.D. at 5%	0.52	0.31	0.29	1.05	0.40	0.68
Chemical fertilizers (T)						
T ₁ - Control (without fertilizer)	7.58	9.10	8.43	9.00	8.005	9.05
T ₂ - 50% RDF	8.49	9.25	8.89	10.0 6	8.69	9.655
T ₃ - 75% RDF	9.01	9.44	9.35	10.9 4	9.18	10.19
T ₄ - 100% RDF	9.13	9.59	9.89	11.3 4	9.51	10.46 5
S.E.m _±	0.18	0.11	0.09	0.36	0.14	0.23
C.D. at 5%	0.52	0.31	0.29	1.05	0.40	0.68
Interaction (S x T)						
S.E.m _±	0.36	0.21	0.25	0.73	0.30	0.47
C.D. at 5%	NS	NS	NS	NS	NS	NS

Table 6. Effect of microbial consortia inoculation and chemical fertilizers on root weight (g plant⁻¹) of chickpea

Treatments	2020-21		2021-22		Pooled	
	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS
Microbial consortia inoculation (S)						
S ₁ - Uninoculated control	6.12	7.09	6.02	6.64	6.07	6.865
S ₂ - <i>Mesorhizobium</i> + <i>Bacillus megaterium</i> inoculation (Consortia-I)	7.25	8.85	7.55	8.99	7.4	8.92
S ₃ - <i>Mesorhizobium</i> + <i>Pseudomonas striata</i> inoculation (Consortia-II)	9.73	10.67	10.22	11.43	9.975	11.05
S ₄ - <i>Mesorhizobium</i> + <i>Thiobacillus thiooxidans</i> inoculation (Consortia-III)	7.11	7.91	7.49	8.57	7.3	8.24
S.E.m _±	0.11	0.12	0.10	0.18	0.10	0.15
C.D. at 5%	0.33	0.35	0.29	0.51	0.31	0.43
Chemical fertilizers (T)						
T ₁ - Control (without fertilizer)	7.28	7.75	7.49	7.91	7.385	7.83
T ₂ - 50% RDF	7.49	8.24	7.59	8.23	7.54	8.235
T ₃ - 75% RDF	7.66	8.95	7.95	9.57	7.805	9.26
T ₄ - 100% RDF	7.77	9.58	8.25	9.91	8.01	9.745
S.E.m _±	0.11	0.12	0.10	0.18	0.10	0.15
C.D. at 5%	0.33	0.35	0.29	0.51	0.31	0.43
Interaction (S x T)						
S.E.m _±	0.23	0.24	0.20	0.36	0.215	0.3
C.D. at 5%	NS	NS	NS	NS	NS	NS

Table 7. Effect of microbial consortia inoculation and chemical fertilizers on root length (cm) of soybean

Treatments	2020-21		2021-22		Pooled	
	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS
Microbial consortia inoculation (S)						
S ₁ - Uninoculated control	20.50	24.90	22.70	26.75	21.60	25.82
S ₂ - <i>BradyRhizobium</i> + <i>Bacillus megaterium</i> inoculation (Consortia-I)	24.98	29.44	26.07	34.17	25.52	31.80
S ₃ - <i>BradyRhizobium</i> + <i>Pseudomonas striata</i> inoculation (Consortia-II)	31.17	34.97	32.43	35.50	31.80	35.23
S ₄ - <i>BradyRhizobium</i> + <i>Thiobacillus thiooxidans</i> inoculation (Consortia-III)	22.33	26.21	23.24	32.08	22.78	29.14
S.E.m _±	0.33	0.74	0.48	0.29	0.40	0.51
C.D. at 5%	0.95	2.13	1.39	0.85	1.17	1.49
Chemical fertilizers (T)						
T ₁ - Control (without fertilizer)	22.83	26.54	23.90	29.17	23.36	27.85
T ₂ - 50% RDF	23.71	28.13	24.92	31.67	24.31	29.90
T ₃ - 75% RDF	25.15	29.75	27.21	33.17	26.18	31.46
T ₄ - 100% RDF	27.29	31.09	28.40	34.50	27.84	32.79
S.E.m _±	0.33	0.74	0.48	0.29	0.40	0.51
C.D. at 5%	0.95	2.13	1.39	0.85	1.17	1.49
Interaction (S x T)						
S.E.m _±	0.66	1.48	0.96	0.58	0.81	1.03
C.D. at 5%	0.91	NS	NS	NS	NS	NS

Table 8. Effect of microbial consortia inoculation and chemical fertilizers on root length (cm) of chickpea

Treatments	2020-21		2021-22		Pooled	
	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS
Microbial consortia inoculation (S)						
S ₁ - Uninoculated control	10.87	13.23	12.60	14.26	11.74	13.75
S ₂ - <i>Mesorhizobium</i> + <i>Bacillus megaterium</i> inoculation (Consortia-I)	14.11	17.76	17.43	18.31	15.77	18.04
S ₃ - <i>Mesorhizobium</i> + <i>Pseudomonas striata</i> inoculation (Consortia-II)	17.31	20.28	20.22	20.44	18.77	20.36
S ₄ - <i>Mesorhizobium</i> + <i>Thiobacillus thiooxidans</i> inoculation (Consortia-III)	13.22	16.30	16.73	17.53	14.98	16.92
S.E.m _±	0.52	0.37	0.31	0.21	0.42	0.29
C.D. at 5%	1.50	0.86	0.90	0.62	1.20	0.74
Chemical fertilizers (T)						
T ₁ - Control (without fertilizer)	12.31	16.31	15.38	17.08	13.85	16.70
T ₂ - 50% RDF	12.82	16.62	16.20	17.65	14.51	17.14
T ₃ - 75% RDF	14.19	17.38	17.33	17.83	15.76	17.61
T ₄ - 100% RDF	16.18	17.27	18.08	17.97	17.13	17.62
S.E.m _±	0.52	0.37	0.31	0.21	0.42	0.29
C.D. at 5%	1.50	0.86	0.90	0.62	1.20	0.74
Interaction (S x T)						
S.E.m _±	1.04	0.75	0.62	0.43	0.83	0.59
C.D. at 5%	NS	NS	NS	NS	NS	NS

Table 9. Effect of microbial consortia inoculation and chemical fertilizers on nodules of soybean

Treatments	2020-21			2021-22			Pooled		
	No. of nodules	Fresh wt (mg/pl)	Dry wt (mg/pl)	No. of nodules	Fresh wt (mg/pl)	Dry wt (mg/pl)	No. of nodules	Fresh wt (mg/pl)	Dry wt (mg/pl)
Microbial consortia inoculation (S)									
S ₁ - Uninoculated control	37.75	375.83	340.375	41.17	369.83	350.75	39.46	372.83	345.75
S ₂ - <i>BradyRhizobium</i> + <i>Bacillus megaterium</i> inoculation (Consortia-I)	73.42	795.08	468.58	80.67	816.50	541.67	77.04	805.79	505.12
S ₃ - <i>BradyRhizobium</i> + <i>Pseudomonas</i> riatainocul ation (Consortia-II)	95.92	889.42	563.67	104.68	906.25	578.08	100.30	897.84	570.87
S ₄ - <i>BradyRhizobium</i> + <i>Thiobacillusthiooxidans</i> † inoculation (Consortia-III)	70.08	763.25	407.08	75.92	773.00	495.92	73.00	768.13	451.5
S.E.m±	0.84	1.56	8.32	4.41	3.25	8.88	2.63	2.41	8.60
C.D. at 5%	4.90	4.50	24.02	12.74	9.40	25.63	8.82	6.95	24.82
Chemical fertilizers (T)									
T ₁ - Control (without fertilizer)	63.42	676.08	420.92	65.75	690.92	465.25	64.58	683.50	443.08
T ₂ - 50% RDF	66.42	700.08	442.83	75.25	702.67	486.00	70.84	701.38	464.41
T ₃ - 75% RDF	70.00	711.00	451.67	78.17	724.67	494.67	74.09	717.84	473.17
T ₄ - 100% RDF	77.33	736.42	464.67	83.25	747.33	520.50	80.29	741.88	492.58
S.E.m±	0.84	1.56	8.32	4.41	3.25	8.88	2.63	2.41	8.60
C.D. at 5%	4.90	4.50	24.02	12.74	9.40	25.63	8.82	6.95	24.82
Interaction(SxT)									
S.E.m±	1.69	1.56	16.63	4.41	3.25	17.25	3.05	2.41	17.19
C.D. at 5%	4.90	4.50	NS	12.74	9.40	NS	8.82	6.95	NS

Comment [IL28]: Font size of this table is not same as the other tables. Please ensure uniformity.

Table 10. Effect of microbial consortia inoculation and chemical fertilizers on nodules of chickpea

Treatments	2020-21			2021-22			Pooled		
	No. of nodules	Fresh wt (mg/pl)	Dry wt (mg/pl)	No. of nodules	Fresh wt (mg/pl)	Dry wt (mg/pl)	No. of nodules	Fresh wt (mg/pl)	Dry wt (mg/pl)
Microbial consortia inoculation (S)									
S ₁ - Uninoculated control	25.17	278.75	208.29	22.17	278.67	210.61	23.66	278.71	209.67
S ₂ - <i>Mesorhizobium</i> + <i>Bacillus megaterium</i> inoculation (Consortia-I)	33.17	439.17	281.36	33.17	451.50	299.53	33.17	445.34	290.29
S ₃ - <i>Mesorhizobium</i> + <i>Pseudomonas striata</i> inoculation (Consortia-II)	40.25	475.83	297.66	43.35	481.25	321.08	41.79	478.55	309.37
S ₄ - <i>Mesorhizobium</i> + <i>Thiobacillus thiooxidans</i> inoculation (Consortia-III)	31.50	389.17	233.66	33.42	452.08	273.34	32.46	420.63	253.28
S.E.m _±	0.42	0.98	5.20	0.25	2.29	4.67	0.34	1.64	4.93
C.D. at 5%	2.4	2.83	15.02	0.73	6.62	13.51	1.56	4.73	14.26
Chemical fertilizers (T)									
T ₁ - Control (without fertilizer)	28.25	384.25	232.34	30.33	401.33	249.62	29.29	392.79	240.57
T ₂ - 50% RDF	32.92	392.25	246.29	21.92	412.33	266.47	27.42	402.29	256.78
T ₃ - 75% RDF	33.83	400.17	263.65	33.83	421.92	283.32	33.83	411.05	273.78
T ₄ - 100% RDF	35.08	406.25	278.33	36.00	427.92	304.56	35.54	417.09	291.89
S.E.m _±	0.42	0.98	5.20	0.25	2.29	4.67	0.33	1.64	4.93
C.D. at 5%	2.4	2.83	15.02	0.73	6.62	13.51	1.56	4.73	14.26
Interaction(SxT)									
S.E.m _±	0.84	1.97	10.43	0.50	4.59	9.44	0.67	3.28	9.94
C.D. at 5%	2.42	5.68	NS	1.46	13.25	NS	1.94	9.47	NS

Comment [IL29]: See comment of table 9.

CONCLUSION

The growth parameter character viz., plant height, shoot weight, number of branches, root length, root weight and nodulation of both soybean and chickpea crop were improved with consortia of *Rhizobium* species + *Pseudomonas striata* (Consortia II) inoculation over other inoculation treatments along with 100 % RDF).

Comment [IL30]: Please remove. This parameter was not studied.

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Comment [IL32]: Ensure uniformity please. See reference below this.

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