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INFLUENCE OF CARRIER-BASED MICROBIAL CONSORTIA ON THE GROWTH AND YIELD ATTRIBUTES OF SORGHUM [*Sorghum bicolor* (L.) Moench]

Y. Kavya*[1], N. Trimurtulu[2], A. Vijaya Gopal[3], P. Madhu Vani[4] and N.V.V.S.D. Prasad[5]

[1,3]*Department of Agriculture Microbiology, APGC,* [2]*Dean of Agriculture,* [4]*Department of Soil Science,* [5]*Department of Entomology, RARS, Acharya N.G. Ranga Agricultural University (ANGRAU), Lam, Guntur – 522 034, Andhra Pradesh (India)*
*e-mail: *kavyayerasi160@gmail.com*

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ABSTRACT

Pot experiments were conducted under greenhouse conditions at ARS, ANGRAU, Amaravathi (India) during *kharif* 2018-19 to assess the effect of carrier-based microbial consortia on the growth and yield of sorghum cv. 'CSV-27'. Two microbial consortia (MC_1 = *Azospirillium* + P-solubilizer + K-releaser + Zn-solubilizer + PGPR isolate; and MC_2 = *Azotobacter* + *Azospirillium* + P-solubilizer + K-releaser + Zn-solubilizer + PGPR isolate) were evaluated along with different doses of inorganic fertilizers. Crop growth attributes like plant height, shoot length, shoot weight, root weight, nutrient uptake, weight of ear head, grains ear head^{-1}, grain yield and stover yield were assessed. The treatment 75% recommended fertilizer dose + MC_2 + FYM proved superior over all other treatments tested and gave significantly higher yield than other treatments. The use of biofertilizer consortia along with reduced dose of inorganic fertilizer are advised for successful sorghum growth.

Keywords: Microbial consortia, sorghum, growth attributes, yield attributes, fertilizers.

INTRODUCTION

The microbial consortia are developed for sustainable soil health and for better plant growth promotion such as better root and shoot length elongation, higher seed germination, improvement in soil micro- and macro-nutrient status, higher yield, etc. These specifically-designed mixed microbial formulations also provide protection to plants against pathogens as well as lower the need for chemical fertilizers, solubilize minerals and render plant nutrients available to plants, thus lessen persistent pollution problem (Paikray, 2012).

Sorghum [*Sorghum bicolor* (L.) Moench] is one of the mandated crops grown worldwide in semiarid regions. It is a vital life sustaining crop ranking 5th after wheat, rice, maize and barley. India ranks 2nd after USA in sorghum production in grain producing countries (Paikray, 2012). In India, it is the 3rd important crop after rice and wheat. Sorghum is primarily used as food in different parts of India especially in Maharashtra, Karnataka, Andhra Pradesh and Madhya Pradesh. Nutritionally sorghum is superior to all other cereals (Prathibha and Siddalingeshwara, 2013). In general, only two to three beneficial microbes are used as a consortium upto date to influence the crop growth by their application. PGPR based consortia carrier containing *Acetobacter*, phosphate solubilizing bacteria and potassium solubilizing bacteria showed maximum accumulation of NPK in sweet corn leaves (Nadish *et al.*, 2018). In present study, microbial consortia comprising of six microbes having different role in nutrient and growth promotion activities were applied to know their impact on the growth, nutrient uptake and yield of sorghum.

MATERIALS AND METHODS

Experimental design and treatments

The pot culture experiments were carried out under greenhouse conditions at Agricultural Research Station, Amaravathi (India). Soil was first sterilized at 121°C for 15 min at 1.05 kg cm^2 pressure and then 7 kg sterilized soil (black loam) was filled into each pot. The microbial consortia were prepared using equal proportion of each microorganism and mixed with well the carrier material in 2:3 ratio (consortial broth: carrier material). The microbial consortium 1 (MC1) comprised of peat as carrier and *Azospirillium* + P-solubilizer + K-releaser + Zn-solubilizer and PGPR isolate; while microbial consortium 2 (MC2) had lignite as carrier and *Azotobacter* + *Azospirillium* + P-solubilizer + K-releaser + Zn-solubilizer and PGPR isolate. *Azospirillum* and *Azotobacter* were nitrogen fixing bacteria. The P solubilizer, K releaser and Zn solubilizer used in present study belonged to bacterial genus *Bacillus;* whereas PGPR isolate used was a *Pseudomonas* sp. The 12 treatments included in the study comprised of MC1, MC2, 50% recommended dose of fertilizers (RDF) + MC1, 50% RDF + MC2, 50% RDF + FYM + MC1, 50% RDF + FYM + MC2, 75% RDF + MC1, 75% RDF + MC2, 75% RDF + FYM + MC1, 75% RDF + FYM + MC2, 100% RDF and 100% RDF + FYM. The fertilizers were applied to the soil @ 200-100-100 kg ha^{-1} (100% RDF). The farm yard manure (FYM) was applied @ 4 t ha^{-1} as per treatment design. The carrier-based microbial consortia (in equal proportion) were added to the soil @ 5 kg ha^{-1} as per treatment just prior to seed sowing. Sorghum cv. 'CSV-27' was sown in pots @ 6-8 seeds pot^{-1}. After proper seed germination, only 2 plants pot^{-1} were maintained. The experiment was conducted in a completely randomized design with each treatment replicated three times. The experiment was conducted from September to the end of December, 2018. During crop growth, regular watering was done on alternate days and as and when required. The crop duration was 4 months and the crop was harvested on 31st December 2018.

Sorghum crop growth and yield attributes

The plant height was recorded at every 45 days interval from ground level to the tip of top most leaf of plant. Panicle length was measured in each treatment and expressed in cm. From each replication, the total number of seeds $panicle^{-1}$ were also counted. From seed yield of each pot, 100 seeds were randomly counted and their weight noted. Shoot and root dry weight was recorded at harvest. For this, plant samples were dried in an oven at 60^0C till constant weight and dry plant weight noted. The mature ear head in each pot was harvested, sun-dried, hand-threshed and winnowed. The dried grains from each treatment were weighed. The straw from pots after harvest was sun-dried and weighed.

Nutrient analysis

Nitrogen content in leaf was estimated by micro-Kjeldhal's method (Piper, 1960). For phosphorus estimation, the plant samples were digested in triacid mixture (HNO_3: H_2SO_4: $HClO_4$ in 9:4:1 ratio) and volume made up to 100 mL. The phosphorus content in triacid digest was determined by vanado-molybdo-phosphoric acid yellow colour method (Piper, 1960). The intensity of yellow colour was measured spectrophotometerically at 420 nm wave length. The potassium content in triacid digest was determined by using ELICO Flame photometer (Piper, 1960).

The nutrient uptake was calculated using the following formula:

$$\text{Nutrient uptake (g plant}^{-1}) = \frac{\text{Nutrient content (\%) x Dry matter production (g/plant)}}{100}$$

Zinc content in leaves of sorghum was estimated by using atomic absorption spectrophotometer.

The data was statistically analysis using SPSS and OPSTAT data analysis software and the values compared at 5% significance level.

RESULTS AND DISCUSSION

Effect on growth attributes

At 45 DAS the highest plant height (93.17 cm) was observed in treatment 75% RDF + MC_2 + FYM followed by treatment 75% RDF + MC_1 + FYM (91.07 cm). At 90 DAS highest plant height was recorded in treatment 75% RDF + MC_1 + FYM (96.67 cm) which was significantly higher than the second highest value obtained in treatment 75% RDF + MC_2 + FYM (95.83 cm). At 120 DAS highest plant height was found in treatment 75% RDF + MC_2 + FYM (185.16 cm), followed by treatment 75% RDF + MC_1 + FYM (183.00 cm) (Fig. 1). The increase in plant height may be attributed to the continuous supply of nutrients through all growth stages by beneficial association of microbial consortia (*Azospirillum*, *Azotobacter*, phosphobacteria, K-releasing and Zn-solubilizing bactria. In addition to high nitrogen fixation, *Azospirillum* and *Azotobacter* are known to produce plant growth substances such as IAA, auxins and vitamins B which might have helped in enhancing plant height. Govindan and Bagyaraj (1995) have reported that biofertilizers inoculation in rice enhanced shoots and root growth.

The treatments of microbial consortia along with chemical fertlilizer-use significantly affected panicle length of sorghum (Table 1). Panicle length was significantly high (20.5 cm) in 75% RDF + MC_1 treatment, followed by treatment 75% RDF + MC_2 (19.6 cm). The improvement in panicle length may be attributed to the continuous supply of nutrients during panicle emergence due to the beneficial association of microbial consortia. Lavakush *et al*. (2014) found the application of mixed

Table 1: Effect of microbial consortia on various plant growth and yield attributes of sorghum under greenhouse conditions

Treatments*	Panicle length (cm)	No. of grains ear head^{-1}	100-grain weight (g)	Plant dry matter (g)	Grain yield (g pot^{-1})	Stover yield (g pot^{-1})
MC_1	15.37	413.00	1.76	55.60	14.34	37.7
MC_2	15.63	406.00	1.64	60.47	13.62	36.3
50% RDF + MC_1	14.77	503.33	1.86	68.06	18.58	40.3
50% RDF + MC_2	15.73	564.00	1.93	73.44	21.32	34.3
50% RDF + MC_1 + FYM	15.63	712.33	2.72	78.49	38.56	34.3
50% RDF + MC_2 + FYM	17.13	724.00	2.82	82.05	39.43	42.3
75% RDF + MC_1	20.50	915.67	2.76	85.92	50.49	36.3
75% RDF + MC_2	19.60	936.00	2.77	89.52	50.67	43.3
75% RDF + MC_1+ FYM	17.63	1023.00	2.96	93.04	60.23	33.3
75% RDF + MC_2+ FYM	17.57	1128.00	3.10	96.42	68.53	46.3
100% RDF	16.63	805.00	2.22	82.89	35.63	40.3
100% RDF + FYM	16.53	753.67	2.88	86.00	43.41	40.7
SE(m)	0.125	1.851	0.004	0.899	0.146	0.037
$CD_{0.05}$	0.367	5.435	0.011	2.639	0.429	0.109
CV (%)	1.282	0.433	0.254	1.962	0.668	1.663

*MC_1: Microbial consortium 1 = *Azospirillium* + PSB + KRB + ZnSB + PGPR isolate;
MC_2: Microbial consortium 2 = *Azotobacter* + *Azospirillium*+ PSB + KRB + ZnSB + PGPR isolate;
RDF: Recommended dose of fertilizers; FYM: Farm yard manure

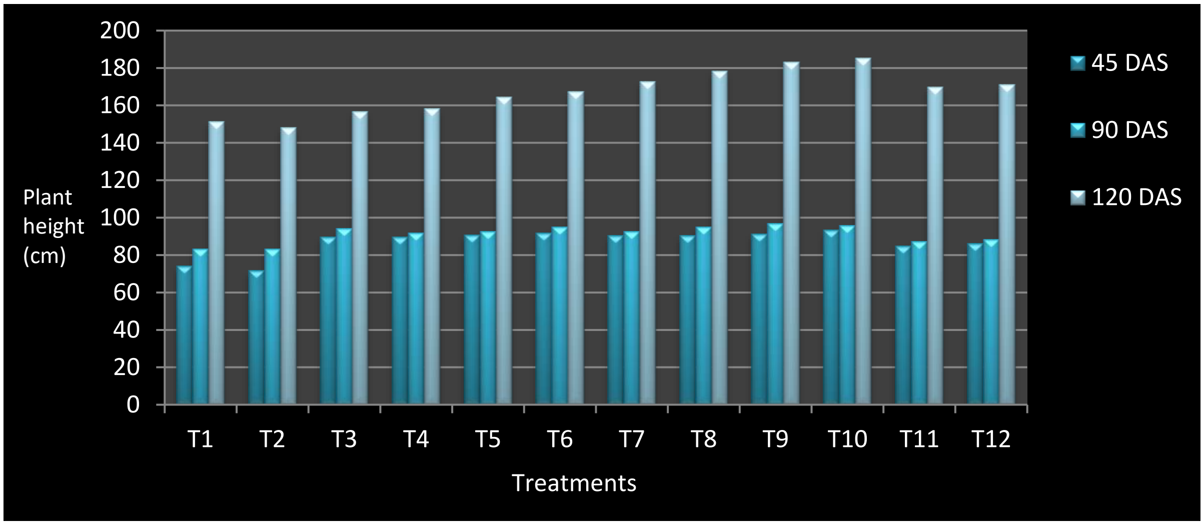

Fig. 1: Effect of microbial consortia on sorghum plant height (cm) at different intervals of crop growth; T1 = Microbial consortium 1 (MC1), T2 = Microbial consortium 2 (MC2), T3 = 50% recommended dose of fertilizers (RDF) + MC1, T4 = 50% RDF + MC2, T5 = 50% RDF + FYM + MC1, T6 = 50% RDF + FYM + MC2, T7 = 75% RDF + MC1, T8 = 75% RDF + MC2, T9 = 75% RDF + FYM + MC1, T10 = 75% RDF + FYM + MC2, T11 = 100% RDF, and T12 = 100% RDF + FYM

biofertilizers along with 60 kg ha^{-1} P_2O_5 significantly increased panicle length. In present study, the significantly high number of grains panicle^{-1} was found in treatment 75% RDF + MC_2 + FYM (1128 grains) which was significantly higher than treatment 75% RDF + MC_1 + FYM (1023 grains) [Table1]. Idris (2003) reported the positive effect of *Azotobacter* on 1000-seed weight. Yousefi and Barzegar (2014) reported that *Azotobacter* and *Pseudomonas* and their combination increased the number of grains spike^{-1} and 1000-seed weight compared to control treatment.

Effect on yield

Significantly high 100-grain weight of sorghum was obtained in treatment 75% RDF + MC_2 + FYM (3.05 g) which was significantly higher than the next best treatment 75% RDF + MC_1 + FYM (2.95 g) (Table 1). The number of grains ear-head^{-1} and test weight was enhanced due to the inoculation of microbial consortia and use of FYM along with reduced dose treatment of chemical fertilizers. A significant increase in 1000-grain weight in wheat due to *Azospirillum* inoculation was observed by Kapulink *et al*. (1985) and Millet *et al.* (1985). Similarly, a significant increase in grain cob^{-1} and 100- seed weight in maize has been reported due to *Azospirillum* inoculation (Mishra *et al*., 1998).

Significantly high plant dry matter was obtained in treatment 75% RDF + MC_2 + FYM (96.42 g pot^{-1}) which was significantly higher than treatment 75% RDF + MC_1 + FYM (93.04 g pot^{-1}) (Table 1). *Azospirillum* and PGPR appeared to have positively influenced the fresh and dry weight of plants. The results are in line with Murty and Ladha (1988), Gunarto *et al*. (1999) and Kannan and Ponmurugan (2010. Gopalswamy and Vidhyasekaran (1988) have reported that biofertilizer use improved the formation and development of root branching, root hairs and primary and secondary lateral roots which increased the nutrient uptake capacity of roots. The increased nitrogen uptake might have resulted in subsequent increase in biomass. Wu *et al*. (2005) reported that *Azotobacter* inoculation gave significantly high dry root biomass weight which might be attributed to its ability to effectively colonize roots of plant and enhance its production of organic material.

Highest straw yield was obtained in treatment 75% RDF + MC_2 + FYM (46.3 g pot^{-1}) followed by treatment 75% RDF + MC_2 (43.3 g pot^{-1}) [Table 1]. The increase in straw yield might be due to better availability of nutrients *viz*., N, P, K, S, etc. through microbial consortia activity. Nitrogen is known to promote improvement in length and width of leaves which, in turn, increases the dry matter and is responsible for increase in straw yield. Khanda and Dixit (1995) reported that N obtained at early growth stages resulted in the production of more straw than grain yield.

The treatment 75% RDF + MC_2 + FYM gave significantly high grain yield (68.53 g pot^{-1}), followed by treatment 75% RDF + MC_1 + FYM (60.23 g pot^{-1}) (Table1). Sharief *et al*. (1998) reported that the inoculation of wheat with combined use of *Azospirillium* and *Azotobacter* as biofertilizer increased weight and number of grains $spike^{=1}$, 1000-grain weight and grain and straw yields. The grain yield was high in treatments having microbial consortia + inorganic fertilizers. Our results are supported by Kumari *et al*. (2000) who reported that increased N level caused significant increase in grain yield. The grain yield of rice was also increased by microbial inoculants (Gopalswamy and Vidhyasekaran, 1988; Jayaraman, 1990). The increase in yield by microbial inoculants may not solely be due to N fixation or phosphate solubilization, but because of several other factors like release of growth promoting substances, control of plant pathogens and proliferation of beneficial organisms in root zone. These findings are in line with Datta *et al*. (1982), Kundu and Gaur (1984) and Mudenoor (2002) who reported that the response to mixed culture inoculation was more due to the synergistic action. The significant response appears due to the supply of two major nutrients N and P.

Nutrient uptake

At 45 DAS significantly high nitrogen content in shoot was found in treatment 75% RDF + MC_2 + FYM (2.27%), followed by treatment 75% RDF + MC_1 + FYM (2.12%) [Table 2]. At 90 DAS significantly high nitrogen in shoot was observed in treatment 75% RDF + MC_2 + FYM (3.09%), followed by treatment 75% RDF + MC_1 + FYM (2.88%). At 120 DAS significantly high nitrogen content in shoot was found in treatment 75% RDF + MC_2 + FYM (2.70%), followed by treatment 75% RDF + MC_1 + FYM (2.55%). The N content in grains increased in treatments wherein inoculation of *Azospirillum* and *Azotobacter* was done as compared to uninoculated control. Kar *et al*. (2005) reported enhanced nitrogen uptake in *Azospirillum* inoculated plants. The use of microbial consortia influenced the nutrient content in sorghum straw with highest nutrient content in treatments

Table 2: Effect of microbial consortia on nutrient contents in sorghum under greenhouse conditions

Treatments*	Nitrogen content (%)			Phosphorus content (%)			Potassium content (%)		
	45 DAS	90 DAS	120 DAS	45 DAS	90 DAS	120 DAS	45 DAS	90 DAS	120 DAS
MC_1	1.52	1.74	1.60	0.28	0.37	0.31	1.52	2.16	1.95
MC_2	1.58	1.80	1.64	0.30	0.40	0.34	1.55	2.35	2.07
50% RDF + MC_1	1.63	1.90	1.71	0.42	0.67	0.52	1.74	2.46	2.26
50% RDF + MC_2	1.67	1.96	1.77	0.45	0.72	0.61	1.84	2.75	2.46
50% RDF + MC_1 + FYM	1.73	2.05	1.84	0.57	0.78	0.65	2.03	3.17	2.94
50% RDF + MC_2 + FYM	1.79	2.12	1.90	0.61	0.82	0.70	2.09	3.36	3.16
75% RDF + MC_1	1.87	2.47	2.02	0.65	0.86	0.73	3.05	4.05	3.37
75% RDF + MC_2	1.99	2.53	2.05	0.69	0.90	0.76	3.16	4.24	3.45
75% RDF + MC_1 + FYM	2.12	2.88	2.55	0.75	0.95	0.79	3.28	4.55	3.76
75% RDF + MC_2 + FYM	2.27	3.09	2.70	0.78	0.99	0.82	3.45	4.75	4.06
100% RDF	1.72	2.39	2.06	0.54	0.75	0.65	2.19	3.67	3.24
100% RDF + FYM	1.75	2.43	2.09	0.60	0.78	0.70	2.28	3.77	3.32
SE(m)	0.010	0.018	0.020	0.011	0.010	0.009	0.019	0.019	0.020
$CD_{0.05}$	0.030	0.052	0.057	0.032	0.029	0.027	0.056	0.055	0.050
CV (%)	0.982	1.356	1.700	3.378	2.255	2.558	1.412	0.937	1.142

*MC_1: Microbial consortium 1 = *Azospirillium* + PSB + KRB + ZnSB + PGPR isolate;
MC_2: Microbial consortium 2 = *Azotobacter* + *Azospirillium*+ PSB + KRB + ZnSB + PGPR isolate;
RDF: Recommended dose of fertilizers; FYM: Farm yard manure

having microbial consortia + inorganic fertilizer. Similar observations have been reported by Raul *et al*. (2009) and Krishnaveni (2010). Combined use of NPK with strains of *Azospirillum* improved straw nitrogen content as compared to inorganic fertilization alone. Mahendran and Chandramani (1998) found increased N and P uptake with the application of phosphate solubilizing bacteria.

At 45 DAS significantly high nitrogen content in shoot was found in treatment 75% RDF + MC_2 + FYM (2.27%), followed by treatment 75% RDF + MC_1 + FYM (2.12%) [Table 2]. At 90 DAS At 45 DAS, significantly high phosphorus in sorghum shoots was found in treatment 75% RDF + MC_2 + FYM (0.78%), followed by treatment 75% RDF + MC_1 + FYM (0.75%) [Table 2]. At 90 DAS high phosphorus content in shoot was found in treatment 75% RDF + MC_2 + FYM (0.99%), followed by treatment 75% RDF + MC_1 + FYM (0.95%). At 120 DAS the highest phosphorus content of shoot was observed in treatment 75% RDF + MC_2 + FYM (0.82%), followed by treatment 75% RDF + MC_1 + FYM (0.79%). Neumann and George (2004) reported that the inoculation of phosphate-solubilizing microbes significantly enhanced phosphorus uptake as compared to the uninoculated plots, obviously due to the quantitative and qualitative changes in root exudate composition probably due to the degradation of exudates and release of microbial metabolites. Microbes solubilize and mobilize insoluble-phosphorus compounds through production of organic acids and thus increased P bioavailability (Krishnaveni 2010, Mishra and Dash, 2014).

Significantly high nitrogen in shoot was observed treatment 75% RDF + MC_2 + FYM (3.09%), followed by treatment 75% RDF + MC_1 + FYM (2.88%). At 120 DAS significantly high nitrogen content in shoot was obtained in treatment 75% RDF + MC_2 + FYM (2.70%), followed by treatment 75% RDF + MC_1 + FYM (2.55%). The N content in grains increased in treatments wherein inoculation of *Azospirillum* and *Azotobacter* was done as compared to uninoculated control. Kar *et al*. (2005) reported enhanced nitrogen uptake in *Azospirillum* inoculated treated plants. The microbial consortia application affected the nutrient content in sorghum straw. The highest nutrient content in straw was noticed in treatments having microbial consortia + inorganic fertilizer. Similar observations have been reported by Raul *et al*. (2009) and Krishnaveni (2010). Combined use of NPK with strains of *Azospirillum* improved straw nitrogen content as compared to inorganic fertilization alone. Mahendran and Chandramani (1998) found increased N and P uptake with the application of phosphate solubilizing bacteria.

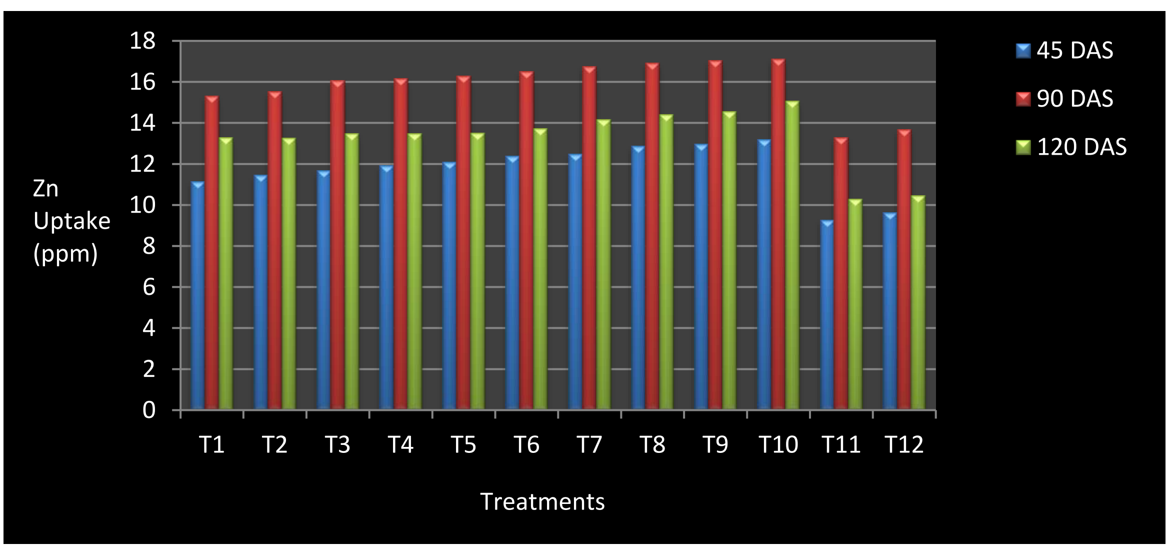

Fig. 2: Zn uptake in sorghum at different intervals of crop growth; T1 = Microbial consortium 1 (MC1), T2 = Microbial consortium 2 (MC2), T3 = 50% recommended dose of fertilizers (RDF) + MC1, T4 = 50% RDF + MC2, T5 = 50% RDF + FYM + MC1, T6 = 50% RDF + FYM + MC2, T7 = 75% RDF + MC1, T8 = 75% RDF + MC2, T9 = 75% RDF + FYM + MC1, T10 = 75% RDF + FYM + MC2, T11 = 100% RDF, and T12 = 100% RDF + FYM

At 45 DAS, significantly high phosphorus content in sorghum shoots was noticed in treatment 75% RDF + MC_2 + FYM (0.78%), followed by treatment 75% RDF + MC_1 + FYM (0.75%) [Table 2]. At 90 DAS high phosphorus content in shoot was found in treatment 75% RDF + MC_2 + FYM (0.99%), followed by treatment 75% RDF + MC_1 + FYM (0.95%). At 120 DAS the highest phosphorus content of shoot was observed in treatment 75% RDF + MC_2 + FYM (0.82%), followed by treatment 75% RDF + MC_1 + FYM (0.79%). Neumann and George (2004) reported that the inoculation of phosphate-solubilizing microbes significantly enhanced phosphorus uptake as compared to the uninoculated plots, obviously due to the quantitative and qualitative changes in root exudate composition due to the degradation of exudates and release of microbial metabolites. Microbes solubilize and mobilize insoluble-phosphorus compounds through production of organic acids and thus increased P bioavailability (Krishnaveni 2010, Mishra and Dash, 2014).

The highest potassium content in sorghum shoots at 45 DAS was observed in treatment 75% RDF + MC_2 + FYM (3.45%), followed by treatment 75% RDF + MC_1 + FYM (3.28%) [Table 2]. At 90 DAS significantly high K-content in shoot was found in treatment 75% RDF + MC_2 + FYM (4.75%), followed by treatment 75% RDF + MC_1+ FYM (4.55%). At 120 DAS significantly high potassium was found in treatment 75% RDF + MC_2 + FYM (4.06%), followed by treatment 75% RDF + MC_1 + FYM (3.76%). The enhanced uptake of K might have improved the potassium content in grain and straw. The inoculation with potassium releasing microbes also significantly increased the K uptake. Our results are supported by Singh *et al*. (2004). Increased potassium uptake by grain and straw might be due to the synergistic action ultimately enhancing the yield (Yadav *et al.*, 2010).

At 45 DAS significantly highest zinc content in shoot was in treatment 75% RDF + MC_2 + FYM (13.17 ppm), followed by treatment 75% RDF + MC_1 + FYM (12.95 ppm) [Table 2]. At 90 DAS significantly high zinc in shoots was observed in treatment 75% RDF + MC_2 + FYM (17.11 ppm), followed by treatment 75% RDF + MC_1 + FYM 17.04 ppm. At 120 DAS significantly high zinc content was in treatment 75% RDF + MC_2 + FYM (15.07 ppm), followed by treatment 75% RDF + MC_1 + FYM (14.55 ppm) (Fig. 2). Similar results were observed by Krishnaveni (2010). Microbial inoculants increased the uptake of both macro- and micro-nutrients. Bacterial strains used in microbial consortia seem capable of producing IAA which influenced root biomass and increased the root area available for nutrient uptake (Sahu and Jana 2000). Swarnalakshmi *et al*. (2013) reported that combined inoculation bio-inoculants (*Anabaena torulosa* + *Pseudomonas striata* and/or *Anabaena torulosa* + *Azotobacter chroococcum*) were superior over single inoculation and chemical fertilizer control in term of plant growth and nutrient uptake.

Conclusions: The higher plant growth and yield in treatments having 75% RDF or 50% RDF + MC_2/ MC_1 + FYM appears due to the continuous supply of nutrients by the synergistic action of bioincoulants in presence of chemical fertilizers. The biofertilizer consortia along with reduced dose of inorganic fertilizers are advisable for use in sorghum. This is expected to reduce the cost of cultivation and chemical fertilizer use thus minimizes ecosystem pollution.

REFERENCES

Datta, M., Banik, S and Guptha, R.K. 1982. Studies on efficiency of phytoharmone producing phosphate solubilizing *Bacillus firmis* in augmenting paddy yield in acid soils of Nagaland. *Plant and Soil*, **69:** 365-373.

Gopalswamy, G. and Vidhyasekaran, P. 1988. Effect of *Azospirillum brasilense* on rice yield. *International Rice Research Newsletter*, **12**: 56-57.

Govindan, N. and Bagyaraj, D.J. 1995. Field response of wetland rice to *Azospirillum* inoculation. *Journal of Soil Biology and Ecology*, **15**: 17-22.

Gunarto, L., Adachi, K. and Senboku, T. 1999. Isolation and selection of indigenous *Azospiriilum* spp. from a subtropical island, and effect of inoculation on growth of low land rice under several levels of N application. *Biology and Fertility of Soils*, **28**: 129-135.

Idris, M. 2003. Effects of integrated use of mineral, organic N and azotobacter on the yield, yield components and N-nutrition of wheat (*Triticum aestivum* L.). *Pakistan Journal of Biological Sciences.* **6**: 539-554.

Jayaraman, S. 1990. Studies on comparative performance of different biofertilizers with sub-optimal level of nitrogen on rice. *The Andhra Agriculture Journal,* **37:** 366-369.

Kannan, T. and Ponmurugan, P. 2010. Response of paddy (*Oryza sativa* L.) varieties to *Azospirillum brasilense* inoculation. *Journal Phytology,* **2**(6): 8-13.

Kapulnik, Y., Gafni, R. and Okon, Y. 1985. Effect of *Azospirillum* sp. inoculation on root development and NO_3 uptake in wheat (*Triticum aestivum* cv Miriam) in hydroponic systems. *Canadian Journal of Botany,* **63**: 627-631.

Khanda, C. and Dixit, L.A. 1995. Effect of zinc and nitrogen fertilization on summer rice (*Oryza sativa*). *Indian Journal of Agronomy,* **40**: 695-697.

Krishnaveni, M.S. 2010. Studies on phosphate solubilizing bacteria (PSB) in rhizosphere and non-rhizosphere soils in different varieties of foxtail millet (*Setaria italica*). *International Journal of Agriculture and Food Science Technology,* **1**: 23-29.

Kumari, M.B., Subbaiah, G., Veeraraghavaiah, R and Rao, C.V.H. 2000. Effect of plant density and nitrogen levels on growth and yield of rice. *The Andhra Agricultural Journal,* **47**(3&4): 188-190.

Kundu, B.S and Gaur, A.C. 1984. Rice response to inoculation with N_2-fixing and P-solubilizing microorganisms. *Plant and Soil,* **79**: 227-234.

Lavakush., Yadav, J., Verma, J. P., Jaiswal, D.K. and Kumar, A. 2014. Evaluation of PGPR and different concentration of phosphorus level on plant growth, yield and nutrient content of rice (*Oryza sativa*). *Ecological Engineering,* **62:** 123-128.

Mahendran, P.P. and Chandramani, P. 1998. NPK uptake, yield and starch content of potato cv. Kufri Jyoti as influenced by certain biofertilizers. *Journal of the Indian Potato Association,* **25**(1/2): 50-52.

Millet, E., Avivi, Y. and Feldman, M. 1985. Effects of rhizospheric bacteria on wheat yield under field conditions. *Plant and Soil,* **86**: 347-355.

Mishra, M., Patjoshi, A.K. and Jena, D. 1998. Effect of biofertilization on production of maize (*Zea mays* L.). *Indian Journal of Agronomy,* **43**: 307-310.

Mishra, P. and Dash, D. 2014. Rejuvenation of biofertilizer for sustainable agriculture and economic development. *The Journal of Sustainable Development,* **11**: 41-61.

Mudenoor, M.G. 2002. *Effect of Micronutrient Supplemented Azospirillum Biofertilizers on Maize (Zea mays L.)*. M.Sc. (Ag.) Thesis, University of Agricultural Sciences, Dharwad, Karnataka, India.

Murty, M.G. and Ladha, J.K. 1988. Influence of *Azospirillum* inoculation on the mineral uptake and growth of rice under hydroponic conditions. *Plant and Soil,* **108**: 281-285.

Nandish, M.S., Suchitha, Y., Madhuri, S., Latha, V. and Shilpa, H.C. 2018. Development and evaluation of native plant growth promoting rhizomicrobial consortia on growth parameters of sweet corn (*Zea mays* convar. *saccharata* var. *rugosa*). *International Journal of Current Microbiology and Applied Sciences* **7:** 1081-1094.

Neumann, E. and George, E. 2004. Colonization with the arbuscular mycorrhizal fungus *Glomus mosseae* (Nicol. & Gerd.) enhanced phosphorus uptake from dry soil in *Sorghum bicolor* (L.). *Plant and Soil,* **261**: 245-255.

Paikray, S.P. 2012. *Novel Formulation of Microbial Consortium Based Bioinoculant for Widespread Use in Agriculture Practices.* United States Patent Application Publication. Publication No.: US 2012/0015806 A1.

Piper, C.S. 1960. *Soil and Plant Analysis*. Academic Press, New York. USA.

Prathibha K.S. and Siddalingeshwara K.G. 2013. Effect of plant growth promoting *Bacillus subtilis* and *Pseudomonas fluorescence* as rhizobacteria on seed quality of sorghum. *International Journal of Current Microbiology and Applied Sciences*, **2**: 11-18.

Raúl, O.P., Carlos, H.B., Silvia, C.B., Paulo, M.F.B.S and Kátia, R.S.T. 2009. *Azospirillum* inoculation and nitrogen fertilization effect on grain yield and on the diversity of endophytic bacteria in the phyllosphere of rice rainfed crop. *European Journal of Soil Biology,* **45**: 36-43.

Sahu, S.N and Jana, B.B. 2000. Enhancement of the fertilizer value of rock phosphate engineered through phosphate-solubilizing bacteria. *Ecological Engineering*. **15**: 27-39.

Sharief, A.E., El-Kalla, S.E., Leilha, A.A. and Mostafa, H.E.M. 1998. Response of some wheat cultivars to nitrogen fertilizer levels and biological fertilization. *Mansoura Journal of Agricultural Science*, **23**: 5807-5816.

Singh, R., Behl, R.K., Singh, K.P., Jain, P. and Narula, N. 2004. Performance and gene effects for wheat yield under inoculation of arbuscular mycorrhiza fungi and *Azotobacter chroococcum. Plant, Soil and Environment,* **50**(9): 409-515.

Swarnalakshmi, K., Prasanna, R., Kumar, A., Pattnaik, S., Chakravarty, K., Shivay, Y.S., Singh, R. and Saxena, A.K. 2013. Evaluating the influence of novel cyanobacterial biofilmed biofertilizers on soil fertility and plant nutrition in wheat. *European Journal of Soil Biology*, **55**: 107-116.

Wu, S.C., Cao, Z.H., Li, Z.G., Cheung, K.C. and Wong, M.H. 2005. Effects of biofertilizer containing N-fixer, P and K solubilizers and AM fungi on maize growth: A greenhouse trial. *Geoderma*. **125**: 155-166.

Yadav, J., Verma, J.P. and Tiwari, K.N. 2010. Effect of plant growth promoting rhizobacteria on seed germination and plant growth chickpea (*Cicer arietinum* L.) under *in vitro* conditions. *Biological Forum - An International Journal,* **2**(2): 15-18.

Yousefi, A.A and Barzegar, A.R. 2014. Effect of *Azotobacte*r and *Pseudomonas* bacteria inoculation on wheat yield under field condition. *International Journal of Agriculture and Crop Sciences,* **7**: 616-619.