A-6285
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RESEARCH ARTICLE Indian Journal of Agricultural Research

Evaluation on the Influence of Cropping Systems and Nutrient Management Practices in Pearl Millet (*Pennisetum glaucum*) Growth, Crop Nutrient Uptake and Soil Fertility Status

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10.18805/IJARe.A-6285

ABSTRACT

Background: At the present situations, sole croppingand generalized fertilization recommendations could not produce advantageous results for neither profitable crop production nor for a sustainable environment. Therefore, the study focuses on evaluating the response of pearl millet to various cropping systems and different nutrient management techniques for enhancing crop productivity and sustaining soil fertility.

Methods: The field trial took place at the instructional farm of Karunya Institute of Technology and Science in the Coimbatore district of western Tamil Nadu, India. The trial spanned over two growing seasons and followed a factorial randomized block design, with 2 factors: cropping systems and nutrient management, replicated three times. The design resulted in a total of 12 treatment combinations, comprising 3 levels of cropping system *viz.,* sole cropping of pearl millet, pearl millet with black gram and cowpea intercropping systems; and 4 levels of nutrient management comprising different doses of fertilizer levels in combination with biofertilizers such as *Azospirillum* and PSB and foliar sprays of 2% Urea and 3% *Panchagavya*.

Result: The experimental findings indicated that intercropping treatment, Pearl millet + Black gram at a 1:1 ratio, exhibited superior results in enhancing plant growth, improving the crop nutrient uptakeand enriching soil fertility. In the case of nutrient management treatments, application of 75% of recommended dose of fertilizers (RDF) + *Azospirillum* and phosphate solubilizing bacteria + foliar application of 2% urea at 15 and 35 days after transplanting (DAT) resulted in producing higher plant height, enhanced dry matter production, efficient crop nutrient uptake, improved soil fertility status for sustainable agriculture.

Key words: *Azospirillum,* Intercropping, *Panchagavya*, Pearl millet, PSB, Urea spray.

INTRODUCTION

Pearl millet (*Pennisetum glaucum* L.), an important crop of the Gramineae family, occupies a prominent role in global food production. It is India's fourth most vital cereal staple and the world's sixth most significant cereal crop. Pearl millet is cultivated worldwide for both food and fodder. Pearl millet stands out for its rich source of essential nutrients, serving as an abundant reservoir of energy, carbohydrates, fats (5-7%), dietary fiber (1.2 g/100 g) and protein (9-13%). It encompasses valuable antioxidants like coumaric acids, known for their improved digestibility (Gurjar *et al*., 2022). India is the world's top producer of millets which accounts for about 38.4 percent of total global cultivation. Pearl millet is the largest cultivated millet in India (62%) followed by sorghum (26%). Six states namely Rajasthan, Uttar Pradesh, Karnataka, Maharashtra, Madhya Pradeshand Haryana account for more than 79.6 per cent share in total millet production (APEDA, 2023)

In the present-day scenario, growing solely cereal crops in the field cannot compensate for the growing food demand and consumer needs, therefore it is high time for the incorporation of pulses among cereal crops (Sharmili *et al*., 2021). Pulse intercropping can aid in fixing atmospheric nitrogen to the soil through their root nodules by improving the overall nitrogen availability to the main crop. They also exhibit a weed-smothering effect that suppresses the growth of unwanted weeds in the crop fields. Legume intercropping systems strive to enhance land efficiency, overall productivityand time by optimizing the utilization of resources (Nasri *et al*., 2014). Assuming that in an intercropping system the two crops grown together can exploit the environment in a better way than as one sole crop and eventually producing higher yield (Yadav *et al*., 2015). Since pearl millet can withstand low-fertility conditions, farmers are reluctant to adopt proper nutrient management practices for its cultivation. Chemical

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How to cite this article: Iraiyanban A.A.A., Manuel R.I., Augustine, R. and Shiny, A.V.A. (2024). Evaluation on the Influence of Cropping Systems and Nutrient Management Practices in Pearl Millet (*Pennisetum glaucum*) Growth, Crop Nutrient Uptake and Soil Fertility Status. Indian Journal of Agricultural Research. 1-9. doi: 10.18805/IJARe.A-6285.

Submitted: 24-07-2024 **Accepted:** 06-10-2024 **Online:** 09-12-2024

fertilization is an effective means of improving the fertility of the soil but in recent years several researchers found that prolonged usage of chemical fertilizers can cause deteriorating effects on soil health. Biofertilizers such as *Azospirillum, Azotobacter*and PSB can increase nitrogen fixation and phosphorous solubilization in the soil. The microbes vary in their mode of action and act as a substitute for chemical fertilizers when applied solely or with other fertilizers (Brar *et al*., 2017).

Foliar application of fertilizers like urea and DAP promotes rapid absorption of nutrients through foliage and aids in improving the photosynthetic efficiency and delaying the leaf senescence in crops. On the other hand, foliar applications of bio-stimulants such as *Panchagavya* and *Jeevamurtha* improve the growth of crops and help to sustain the crop environment with better crop productivity as they hold major and minor plant nutrients along with growth hormones like IAA and GA (Patel *et al*., 2021). Therefore, a cumulative strategy of using organic, inorganicand biological sources of nutrients can be adopted to improve crop productivity and soil health. Keeping the above situations in mind a field experiment was carried out to increase the efficiency of pearl millet through intercropping and different nutrient management practices.

MATERIALS AND METHODS

Location description

The field trial was conducted at the instructional farm of Karunya Institute of Technology and Science, Coimbatore, Tamil Nadu, India. The trial was carried out in two consecutive seasons commenced from September to December of 2022 and January to April of 2023 on the same piece of land. The farm is geographically located at 10°56′N latitudes and 76°44′E longitudes at an altitude of 474 m above the mean sea level. The soil was of silty clay loam in texture, with high organic carbon content, medium availability of nitrogen, high levels of phosphorusand medium levels of potassium with a bulk density of 1.16 g cc^{-1}, pH of 5.36 and EC of 0.06 dS m^{-1}.

Crops and variety used

The main crop used for this experiment was Pearl millet hybrid CO 9 released from Tamil Nadu Agricultural University, having a duration of 75-80 days. The crop was raised in the nursery and transplanted to the main field with a spacing of 45 $\times$15 cm. Two different intercrops were taken for the intercropping system studies *viz.,* black gram of variety ‘VBN 8’ and cowpea of variety ‘VBN 3’. The intercrops were raised in accordance to the treatments details as elaborated below by adopting an additive series with a 1:1 row ratio.

Experimental setup

The field experiment was executed in a factorial randomized block design (FRBD) by incorporating two factors: cropping systems and nutrient management which resulted in a total of 12 treatment combinations. The treatments were replicated thrice to ensure reliable and robust results. The treatment comprises three intercropping treatments namely C_1 – Sole cropping of pearl millet, C_2 - intercropping of pearl millet + black gram (1:1), C_3 - intercropping of pearl millet + cowpea (1:1) along with four INM treatments *viz* N_1 - 100% RDF, N_2 – 75% RDF + Soil application of *Azospirillum* and PSB @ 2 kg/ha each, N_3 – 75% RDF + Soil application of *Azospirillum* and PSB @ 2 kg/ha each + Foliar spray of 2% urea at 15 and 35 DAT, N_4 – 75% RDF + Soil application of *Azospirillum* and PSB @ 2 kg/ha each + Foliar spray of 3% Panchagavya at 15 and 35 DAT. Recommended dose of fertilizers (RDF) was used @ 80:40:40 kg of N, P_2O_5 and K_2O per hectare. While applying the fertilizers the entire quantity of phosphorous and potassium and one-third of the nitrogen were applied as basal and the remaining nitrogen was top-dressed in two splits at 15 and 30 DAT. Farm Yard Manure @ 12.5 tonnes per hectare was applied basally for all treatment plots.

Plant and soil analysis

Plant samples were collected from every treatment plot at 45 DAT and at harvest to estimate the uptake of nitrogen, phosphorousand potassium content in the crop. The post-harvest soil samples were collected from all the treatment plots and were analyzed to determine the N, P_2O_5 and K_2O content in the soil. The soil microbial biomass carbon and soil microbial biomass nitrogen were determined by using the fumigation-incubation technique given by Jenkinson and Powlson (1976). In addition, the soil microbial population dynamics of bacteria, fungiand actinomycetes were also observed in at three different times namely, pre-sowing time of first trial, post-harvest time of first trial and post-harvest time of second trial, since both the trials were taken up consecutively in the same field itself.

Statistical analysis

The collected data were statistically analysed using a factorial randomized block design (FRBD). The significance of differences among treatments was determined using an “F” test at a significance level of 5 per cent (Gomez and Gomez, 1984). In cases where significant differences were observed among treatments, the critical difference was calculated. Treatment differences that were not found to be significant are denoted as non-significant (NS).

RESULTS AND DISCUSSION

Growth characters of pearl millet

The data on the influence of intercropping and nutrient management practices in pearl millet’s growth characteristics *viz.,* plant height and DMP were recorded at 15 DAT, 45 DAT and at the harvest stage of the crop are presented in Table 1. The results revealed that in the case of the intercropping treatments, there was no significant

Table 1: Influence of intercropping and nutrient management strategies on the growth characters of pearl millet.

Treatments	Plant height (cm)						Total dry matter production (Kg/ ha)					
	Trail I			Trail II			Trail I			Trail II		
	15 DAT	45 DAT	Harvest	15 DAT	45 DAT	Harvest	15 DAT	45 DAT	Harvest	15 DAT	45 DAT	Harvest
A. Intercropping systems												
C_1	67.31	136.05	156.18	68.72	140.80	157.08	415.33	3241.08	5253.25	414.80	3296.15	5316.44
C_2	71.79	142.05	164.27	74.70	145.30	165.10	454.83	3590.58	5690.83	450.76	3734.03	5760.78
C_3	70.72	141.61	163.63	72.47		144.70	164.46	450.16	3640.83	5675.33	444.77	3675.05
5707.23												
S.E.(d) +	2.92	3.49	4.21	1.85	2.48	3.81	6.07	75.94	84.78	21.54	173..92	162.14
CD at 5%	N S	NS	NS	3.87	NS	NS	13.99	158.51	176.96	NS	363.02	338.42
B. Integrated Nutrient management												
N_1	64.97	133.97	153.68	64.61	138.42	154.67	400.77	3107.44	5128.33	395.80	3202.33	5170.56
N_2	67.65	135.14	154.91	66.00	140.03	155.5	421.11	3314.56	5266.44	405.53	3334.55	5335.33
N_3	73.86	146.24	168.93	79.65	149.13	169.82	475.11	3787.66	5919.67	476.93	3899.60	6018.86
N_4	73.28	144.26	167.91	77.60	146.81	168.68	463.44	3753.67	5844.78	468.85	3837.15	5854.52
S.E.(d) +	3.38	4.04	4.86	2.14	2.87	4.40	7.74	87.69	97.89	24.87	200.83	187.22
CD at 5%	7.05	8.42	10.14	4.47	6.00	9.18	16.15	183.03	204.33	51.90	419.18	390.78
C. Interaction												
S.E.(d) +	5.85	6.99	8.15	3.71	4.98	6.82	13.4	151.88	169.56	43.07	347.85	324.28
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*Data represented are mean values of three replicates. C_1 – Sole cropping of pearl millet, C_2 – intercropping of pearl millet + black gram (1:1), C_3 – intercropping of pearl millet + cowpea (1:1), N_1 - 100% RDF @ -80:40:40 kg of N, P_2O_5 and K_2O per hectare, N_2 – 75% RDF + Soil application of *azospirillum* (2 kg/ha) and phosphate solubilizing bacteria (PSB) 2 kg/ha, N_3 – 75% RDF + Soil application of *azospirillum* and PSB + Foliar spray of 2% urea at 15 and 35 DAT, N_4 – 75% RDF + Soil application of *azospirillum* and PSB + Foliar spray of 3% Panchagavya at 15 and 35 DAT.

difference in the height of the plants, at all growth stages of the crop during both trials, though the intercropping treatments produced marginally taller plants. In the case of dry matter production at 15 DAT, the intercropping treatments have not shown any significant difference among themselves. This might be due to the fact that the intercropping of legumes may not have influenced the pearl millet crop through nitrogen fixation at this early stage of development. However, in terms of dry matter production at 45 DAT and harvest, the treatment of pearl millet intercropped with blackgram in a 1:1 row ratio recorded a significantly higher dry matter production, which was statistically similar to the pearl millet + cowpea (1:1) intercropping treatment. Specifically, the dry matter production under blackgram intercropping increased by 12.3 per cent and 11.4 per cent at 45 DAT in both the trials respectivelyand by 8 percent and 7.3 percent at harvest in both trials respectively, when compared to the sole cropping treatment of pearl millet. The increased dry matter production can be attributed to the legume effect of the intercrops, which might have provided additional nitrogen to the main crop of pearl millet, resulting in higher availability of nitrogen and thereby increasing the dry matter content. These findings are consistent with Islam *et al*. (2018) and Chaudhary *et al*. (2020). On the other hand, among the nutrient management treatments, the treatment N_3 - 75% RDF + soil application of *Azospirillum* and PSB + foliar application of 2% urea recorded taller plants and higher dry matter production during both the trials at all the stages of observation. There was an increase in plant height observed to a tune of 9.9 per cent and 9.7 per cent at harvest during both trials respectively and an increase in dry matter production to an extent of 15.4 per cent and 16.4 per cent during both trials respectively, when compared to the control treatment of 100% RDF. The treatment of 75% RDF + soil application of *Azospirillum* and PSB + foliar application of 3% *Panchagavya* was the next in order and was statistically on par. The improvement in height of the pearl millet crop might be owing to the balanced and better nutrient absorption, which could have increased the cell division and eventually amplified the plant height. Similar results were reported by Yadav and Sharma, (2022), Reddy *et al*. (2018) and Aravind *et al*. (2020). Whereas, the higher dry matter production observed with the integrated nutrient treatments might be due to the enhanced biological efficiency provided by the biofertilizers and growth-promoting foliar sprays as they might have increased the photosynthetic efficiency, resulting in greater carbohydrate accumulation and improved dry matter production during all the stages of crop growth. These findings align with those reported by Divya *et al*. (2017) and Rao *et al*. (2017).

Nutrient uptake by pearl millet

The data representing the influence of intercropping and nutrient management on nutrient uptake by pearl millet crop at 45 DAT and at harvest are given in Table 3. The analysis of data revealed that the intercropping treatment of C_2 - pearlmillet + blackgram (1:1) registered a higher nutrient uptake of nitrogen (N_2), phosphorous (P_2O_5) and potassium (K_2O) and was statistically on par with the treatment C_3 - pearl millet + cowpea (1:1). The peak nutrient uptake was observed during the crop's harvest stage, specifically in blackgram intercropping treatment the nitrogen uptake increased by 9.5 per cent and 13.3 per cent in first and second trial respectively, phosphorous uptake increased by 20.4 percent and 14.5 percent higher in first and second trial respectivelyand potassium uptake increased by 6.7 per cent and 12.4 per cent in first and second trial respectively, when compared to the sole cropping of pearl millet. This could be attributed to the increased nutrient availability due to nutrient fixation in the soil and the reduced competitive effect of intercrops in legume intercropping systems. Similar observations of higher NPK uptake in intercropping systems were also reported by Rawat *et al*. (2018) and Arif *et al*. (2022). On the other hand, the nutrient management practice of 75% RDF + *Azospirillum* and PSB + foliar application of 2% urea recorded that the maximum nitrogen, phosphorousand potassium uptake at 45 DAT and at harvest stages and was statistically comparable with the treatment 75% RDF + *Azospirillum* and PSB + foliar application of *Panchagavya* 3% during both the trials. Higher total uptake of nutrients was reported during the harvest stage of the crop when compared to 45 DAT. Specifically, the treatment of 75% RDF + *Azospirillum* and PSB + foliar application of 2% urea recorded 19.5 percent and 24.3 per cent higher uptake of nitrogen in the first and second trial respectively, 34 per cent and 31.2 per cent higher uptake of phosphorous in the first and second trial respectivelyand 13.5 percent and 18.4 per cent higher uptake of potassium in first and second trial respectively when compared to 100% RDF treatment (N_1). The higher NPK uptake under integrated nutrient management practices might be due to the effective nutrient mobilizationand better availability of essential nutrients through the integration of inorganic fertilizers, biofertilizersand foliar nutrients. These findings are in conformity with Choudhary *et al*. (2017) and Khadadiya *et al*. (2020). On the contrary, from the results it could be inferred that the interaction of cropping system treatments and nutrient management practices did hold any significance in the nutrient uptake of crop at 45 DAT and harvest during both trials.

Post-harvest soil fertility status

The data representing the effect of the cropping system and nutrient management strategies on the post-harvest soil fertility status are presented in Table 2. The data indicates that the intercropping treatment C_2, involving pearl millet with blackgram (1:1), achieved higher post-harvest soil nutrient levels and was statistically on par with the treatment C_3 - pearl millet + cowpea (1:1). Notably, the blackgram intercropping treatment (C_2) recorded of N, P_2O_5

Table 2: Influence of intercropping and nutrient management practices on nitrogen phosphorous, potassium uptakeand post-harvest soil nutrient status.

Treatments	N uptake (Kg/ ha)				P_2O_5 uptake (Kg/ ha)				K_2O uptake (Kg/ha)				Post-harvest soil nutrient status (Kg/ha)					
	Trail I		Trail II		Trail I		Trail II		Trail I		Trail II		Trail I			Trail II		
	45 DAT	Harvest	45 DAT	Harvest	45 DAT	Harvest	45 DAT	Harvest	45 DAT	Harvest	45 DAT	Harvest	N	P_2O_5	K_2O	N	P_2O_5	K_2O
A. Intercropping systems																		
C_1	42.3	52.55	42.65	52.26	10.6	14.32	11.87	17.55	45.97	58.88	47.29	58.01	172.64	13.83	424.21	177.64	17.42	420.96
C_2	46.92	57.59	48.71	59.26	12.7	17.25	14.28	20.1	50.45	62.88	54.38	65.21	194.5	15.77	478.24	201.25	19.92	479.99
C_3	46.35	56.69	48.18	58.73	12.17	16.68	13.81	19.66	49.59	62.04	53.62	64.85	192.31	15.36	472.76	198.05	19.57	474.85
S.E.(d) +	1.84	1.58	2.31	2.78	0.59	1.71	0.66	0.94	1.7	1.33	2.55	3.09	9.15	0.67	13.9	9.42	0.94	22.49
CD at 5%	3.85	3.31	4.81	5.83	1.24	0.82	1.37	1.96	3.56	2.78	5.33	6.45	19.09	1.4	29.02	19.66	1.97	46.94
B. Integrated Nutrient management																		
N_1	40.69	50.39	41.3	50.64	9.72	13.66	11.39	16.59	44.61	57.35	46.92	57.44	169.75	12.53	425.65	175.42	16.26	414.11
N_2	41.5	52.19	43.9	51.94	10.52	14.7	12.13	17.15	45.8	58.27	48.22	58.77	177.94	13.06	428.83	180.6	17.26	427.99
N_3	49.89	60.23	51.02	62.98	13.82	18.35	15.14	21.77	52.78	65.12	56.32	68.01	200.24	17.71	491.04	208.23	21.36	501.65
N_4	48.68	59.63	49.8	61.44	13.23	17.6	14.62	20.89	51.92	64.32	55.59	66.54	198	16.63	488.09	205	21.01	490.65
S.E.(d) +	2.13	3.82	2.66	3.22	0.68	0.95	0.76	1.09	1.97	1.54	2.95	3.57	10.56	0.77	16.05	10.87	1.09	25.97
CD at 5%	4.45	1.83	5.55	6.73	1.43	1.97	1.59	2.03	4.11	3.21	6.15	7.45	22.05	1.62	33.51	22.7	2.27	54.2
C. Interaction																		
S.E.(d) +	3.69	3.17	4.61	5.59	1.18	1.64	1.32	1.88	3.41	2.67	5.1	6.18	18.29	1.34	27.81	18.84	1.88	44.98
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*Data represented are mean values of three replicates. C_1 – Sole cropping of pearl millet, C_2 – intercropping of pearl millet + black gram (1:1), C_3 – intercropping of pearl millet + cowpea (1:1), N_1 - 100% RDF @ -80:40:40 kg of N, P_2O_5 and K_2O per hectare, N_2 – 75% RDF + Soil application of *azospirillum* (2 kg/ha) and phosphate solubilizing bacteria (PSB) 2 kg/ha, N_3 – 75% RDF + Soil application of *azospirillum* and PSB + Foliar spray of 2% urea at 15 and 35 DAT, N_4 – 75% RDF + Soil application of *azospirillum* and PSB + Foliar spray of 3% Panchagavya at 15 and 35 DAT.

and K_2O. Compared to C_1 - sole cropping of pearl millet C_2 showed a 12.6 per cent and 13.2 per cent higher soil nitrogen content in the first and second trial respectively, 14 per cent and 6.5 per cent higher soil phosphorous content in the first and second trial respectively and 12.7 per cent and a 14 per cent higher potassium content in first and second trial respectively, when compared to the sole cropping of pearl millet (C_1). The enhancement in post-harvest soil fertility observed with intercropping treatments could be attributed to the legume crop's ability to fix atmospheric nitrogen and enhance nutrient mobilization through improved soil biota. Similar results were reported by Patel *et al*. (2017) in maize intercropping systems. On the other hand, the nutrient management treatment of 75% RDF application + *Azospirillum* and PSB + foliar application of 2% urea (N_3) recorded a maximum post-harvest soil nutrient status of available N, P_2O_5 and K_2O but found to be statistically at par with the treatment 75% recommended dose of fertilizers + Soil application of *Azospirillum* and PSB + foliar application of 3% *Panchagavya* (N_4). When compared to the treatment of 100% RDF (N_1), the treatment 75% RDF application + *Azospirillum* and PSB + foliar application of 2% urea (N_3) recorded an increased post-harvest soil nitrogen content of 17.9 per cent and 18.7 percent in first and second trial respectively, increased post-harvest soil phosphorous content of 41.3 per cent and 31.3 percent in first and second trial respectivelyand increased post-harvest soil potassium content of 15.3 per cent and 21.1 per cent in first and second trial respectively. The improved post-harvest soil fertility observed with the combination of inorganic and organic amendments could be due to the enhanced availability of N, P_2O_5 and K_2O in the soil and the biofertilizers could have contributed to the biological nitrogen fixation and improved phosphorus mobilization. These results are consistent with the findings of Bhargavi *et al*. (2021) and Bharati and Thakare (2022). But then, the interaction between the cropping system and nutrient management practices on post-harvest soil fertility was found to be non-significant during both the trials.

Soil microbial biomass carbon and nitrogen

The data representing the effect of cropping systems and nutrient management strategies on soil microbial biomass carbon and nitrogen are presented in Table 3. The pearl millet cropping system treatments during both trials revealed that the soil microbial biomass carbon was non-significant in the later stages (45 DAT, at harvest) of the crop growth. In the case of soil microbial biomass nitrogen, the treatment C_2 - pearlmillet + blackgram intercropping (1:1) reported higher soil microbial biomass nitrogen but were statistically at par with the treatment C_3 – pearlmillet + cowpea intercropping (1:1). A maximum soil microbial biomass nitrogen was obtained at 45 DAT. The intercropping treatment of pearlmillet + blackgram (1:1) produced 18.1 per cent and 22.3 per cent higher soil microbial biomass nitrogen in first and second trial respectively, when compared to the sole cropping treatment (C_1). The intercropping treatment could have altered the soil microbial compositions and improved the microbial richness of the soil ecosystem. The interaction of legumes with the beneficial soil microbes could have been the reason for the significant increase in soil biomass nitrogen. Similar reports were observed by Wu *et al.,* (2024) and Xiao *et al.* (2023). On the other hand, the nutrient management treatments significantly influenced the soil microbial biomass carbon and nitrogen. The treatment N_3 -application of 75% RDF + soil application of *Azospirillum* and PSB + the foliar application of urea 2% spray recorded the highest microbial biomass carbon and nitrogen content and was on par with the treatment N_4 - 75% recommended dose of fertilizers + Soil application of *Azospirillum* and PSB + foliar application of *Panchagavya* 3% spray. Maximum soil microbial biomass carbon and nitrogen were recorded at 45 DAT. Specifically the nutrient management treatment N_3 - 75% RDF + soil application of *Azospirillum* and PSB + the foliar application of 2% urea reported an increase in soil microbial biomass carbon of 11.3 per cent and 29.3 per cent in the first and second trials respectively and an increase in soil microbial biomass nitrogen of 30.6 percent and 35.3 per cent in first and second trial respectively when compared to the 100% RDF treatment (N_1). The increase in the soil microbial biomass carbon and nitrogen might be due to the carbon and nitrogen added to the soil through organic sources and biofertilizers. Similar findings were reported by Bhargavi *et al*. (2021). Nevertheless, the interaction effect between the cropping system and nutrient management was found to be non-significant at all growth stages in the case of soil microbial biomass carbon and nitrogen.

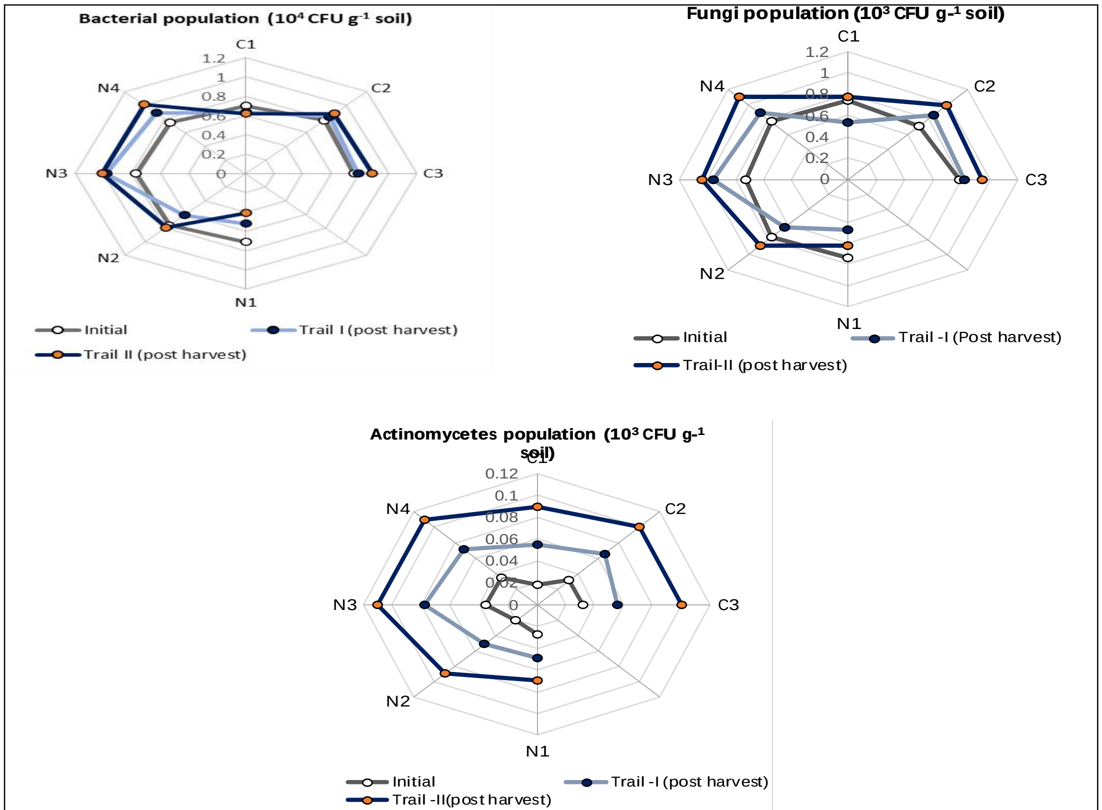
Soil microbial population

The data on the soil microbial levels of bacteria, fungiand actinomycetes in the soil are depicted in Fig 1. The soil microbial population recorded during the post-harvest time of first trial and post-harvest time of second trial shows that the cropping system treatment C_2, which involves intercropping of pearl millet and black gram in a 1:1 ratio, resulted in significantly higher microbial populations when compared to other treatments. However, it was statistically on par with the treatment C_3, intercropping of pearl millet and cowpea in a 1:1 ratio. When compared to the initial microbial populations, treatment C_2 led to an increase of up to 6.4 per cent and 12.8 per cent of bacterial population during first and second trials respectively, 19.7 pe rcent and 39.4 per cent of fungal population during the first and second trials respectively and 106 per cent and 212.5 per cent in actinomycetes populations during the first and second trials respectively. The increase in microbial population after the second trial indicates that soil microbial populations increase over a period of time if favourable condition exists. It could be inferred that the intercropping system could favoured an increase in soil microbial population leading to improved post-harvest soil nutrient levels. Similar findings were reported by Xiao *et al*. (2023).

Table 3: Influence of cropping system and nutrient management practices on soil microbial biomass carbon and nitrogen.

Treatments	Soil microbial biomass carbon (µg g^{-1} of soil)						Soil microbial biomass nitrogen (µg g^{-1} of soil)					
	Trail I			Trail II			Trail I			Trail II		
	15 DAT	45 DAT	Harvest	15 DAT	45 DAT	Harvest	15 DAT	45 DAT	Harvest	15 DAT	45 DAT	Harvest
A. Intercropping systems												
C_1	347.8	406.53	362.28	351.92	460.42	393.28	12.78	18.34	17.29	14.35	18.63	17.52
C_2	380.23	446.8	403.81	397.11	488.05	419.69	16.56	21.67	19.85	16.85	22.07	20.13
C_3	397.34	445.11	380.16	413.45	497.68	434.69	15.75	20.1	19.05	17.98	22.79	20.15
S.E.(d) +	18.85	21.42	19.06	19.39	24.09	20.93	0.78	0.99	0.94	0.87	1.06	0.98
CD at 5%	39.335	NS	NS	40.48	NS	NS	1.633	2.072	1.951	1.82	2.22	2.038
B. Integrated Nutrient management												
N_1	320.77	400.04	323.97	335.78	401.42	342.16	10.69	17.31	15.3	9.37	16.95	14.51
N_2	329.9	408.75	340.29	389.55	488.59	420.72	12.44	18.27	16.45	17.24	21.56	19.15
N_3	432.25	469.31	436.24	416.58	519.09	453.27	19.03	22.61	22.46	19.87	22.94	22.34
N_4	417.56	453.12	428.44	408.06	519.06	446.58	17.96	21.96	20.7	19.08	23.14	21.08
S.E.(D) +	21.76	24.73	22	22.39	27.82	24.17	0.9	1.15	1.08	1.01	1.23	1.13
CD at 5%	45.421	51.62	45.93	46.74	58.06	50.45	1.885	2.39	2.25	2.1	2.57	2.35
C. Interaction												
S.E.(d) +	37.69	42.84	38.11	38.786	48.18	41.86	1.564	1.99	1.87	1.743	2.13	1.95
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*Data represented are mean values of three replicates. C_1 – Sole cropping of pearl millet, C_2 - intercropping of pearl millet + black gram (1:1), C_3 - intercropping of pearl millet + cowpea (1:1), N_1 - 100% RDF @ -80:40:40 kg of N, P_2O_5 and K_2O per hectare, N_2 - 75% RDF + Soil application of *azospirillum* (2 kg/ha) and phosphate solubilizing bacteria (PSB) 2 kg/ha, N_3 – 75% RDF + Soil application of *azospirillum* and PSB + Foliar spray of 2% urea at 15 and 35 DAT, N_4 – 75% RDF + Soil application of *azospirillum* and PSB + Foliar spray of 3% Panchagavya at 15 and 35 DAT.



*Data represented are mean values of three replicates. C_1 – Sole cropping of pearl millet, C_2 – intercropping of pearl millet + black gram (1:1), C_3 – intercropping of pearl millet + cowpea (1:1), N_1 - 100% RDF @ -80:40:40 kg of N, P_2O_5 and K_2O per hectare, N_2 – 75% RDF + Soil application of azospirillum (2 kg/ha) and phosphate solubilizing bacteria (PSB) 2 kg/ha, N_3 – 75% RDF + Soil application of azospirillum and PSB + Foliar spray of 2% urea at 15 and 35 DAT, N_4 – 75% RDF + Soil

Fig 1: Effect of intercropping and nutrient management practices on bacteria, fungi and actinomycetes population.

On the other hand, the nutrient management treatment of N_3 - 75% RDF combined with Azospirillum and PSB and supplemented with a 2% urea foliar spray, resulted in higher populations of bacteria, fungiand actinomycetes. However, it was statistically similar to those of the treatment N_4, which used 75% RDF with Azospirillum and PSB, along with a 3% panchagavya foliar application. Compared to the initial microbial population, treatment N_3 showed an increase of 27.2 per cent and 31.1 per cent of bacterial population, 30 per cent and 42.4 per cent of fungal population and 120 per cent and 214.2 per cent of actinomycetes population during the first and second trials respectively. This demonstrates that the microbial population improved by the end of the trials due to effective nutrient management practices. The increase in bacteria, fungiand actinomycetes populations can be attributed to the combined use of inorganic sources of nutrients and biofertilizers. Similar findings were reported by Lal *et al*. (2012).

CONCLUSION

Based on the outcomes of the experiment, it is concluded that the pearl millet intercropping with pulses like black gram and cowpea, along with the nutrient management practice of 25% reduction in recommended dose of inorganic fertilizers, with the inclusion of biofertilizers like *Azospirillum* and phosphate solubilizing bacteria and foliar application of 2% urea has proven to be an environmentally sustainable crop production practice by increasing the growth characters and nutrient uptake of pearl millet, enhancing the soil microbial levels and eventually improving the soil fertility status.

ACKNOWLEDGEMENT

The authors are grateful to the Division of Agronomy, School of Agricultural Sciences (SAS), Karunya Institute of Technology and Sciences (KITS), Coimbatore, Tamil Nadu .

Conflict of interest

The authors have declared there is no competing interest.

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