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Performance of Nano- DAP under Rice-Wheat Cropping System in *Vertisol* of Chhattisgarh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was carried out in research farm, IGKV, Raipur, Chhattisgarh, India during *Rabi* 2020-2021 and *Kharif 2021-22* under rice- wheat cropping system at Research Farm, College of Agriculture, Raipur, (IGKV). The experiment was laid out with 12 treatments of rice and wheat in randomized block design. Treatments of rice in *Kharif* season includes (T1) Absolute Control (N0:P0:K0), (T2) 0% P (Control P0); (NPK @ 120:0:40), (T3) 100% P through DAP (NPK @ RDF 120:60:40), (T4) 75% P through DAP (NPK @120:45:40), (T5) 50% P through DAP (NPK

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@120:30:40), (T6) T4 + Root Dipping @ 5 ml /L + Foliar Spray @ 2 ml/ L at 30 DAT with Nano DAP, (T7) T4 + Root Dipping @ 5 ml /L + Foliar Spray @ 4 ml/ L at 30 DAT with Nano DAP, (T8) T5 + Root Dipping @ 5 ml /L + Foliar Spray @ 2 ml/ L at 30 DAT with Nano DAP, (T9) T5 + Root Dipping @ 5 ml /L + Foliar Spray @ 4 ml/ L at 30 DAT with Nano DAP, (T10) T5 + Root Dipping @ 5 ml / L + Foliar Spray @ 2 ml / L at 25 and 45 DAT with Nano DAP, (T11) T5 + Root Dipping @ 5 ml / L + Foliar Spray @ 4 ml / L at 25 and 45 DAT with Nano DAP and (T12) T5 + Seed Treatment @ 5 ml / kg seed + Foliar Spray @ 4 ml / L at 30 DAT with Nano DAP. In rice the results of soil microbial biomass carbon showed that higher values were recorded in treatments with 100 % P through DAP. Results of fungus reveals that 100 % and 75 % P through DAP obtained significantly higher soil fungus colony count. The results of total bacteria showed that 100 %, 75 % P through DAP and T4 + Root Dipping @ 5 ml /L + Foliar Spray @ 2 and 4 ml/ L at 30 DAT with Nano DAP obtained significantly higher soil total bacteria. The results of PSB reveals that 50% P through DAP and treatments in combination with 50% P through DAP and Nano-DAP obtained significantly higher phosphorus solubilizing bacteria.

Keywords: Nano DAP; DAP; rice; SMBC; PSB; bacteria; fungi; foliar application; root dipping; seed treatment.

1. INTRODUCTION

The application of nanotechnology in form of nanofertilizer provides an innovative, efficient, and eco-friendly alternative to synthetic fertilizers. The nano fertilizers allow a slow and sustained release of nutrients that not only supports plant growth but also conserve the diversity of the beneficial microbiome. Such attributes may help the Phyto microbiome to efficiently mitigate both biotic and abiotic stress conditions. Unfortunately, despite, exceptional efficiency and ease of applications, certain limitations are also associated with the nano fertilizers such as their complicated production process, tenuous transport and dosage-sensitive efficiency. These bottlenecks are causing a delay in the large-scale applications of nano fertilizers in agriculture [1].

Rice and wheat (*Triticum aestivum* L.) grown sequentially in an annual rotation constitute most widely adopted cropping system in India. The rice-wheat cropping system is one of the world's largest agricultural production systems, occupying 26 Mha of cultivated land in the Indo-Gangetic Plains and in China. The rice- wheat system comprises about 13 Mha in area in the Indo-Gangetic Plains, of which the Indian part of IGP comprises about 10 Mha [2]. In India, the production of rice and wheat grains during the year of 2020-21 was 121.46 million tons and 108.76 million tons, respectively (Ministry of Agriculture and Farmers Welfare 2020-21). Rice is the main cereal crop of Chhattisgarh; it covers an area of 4.33 Mha with a production and productivity of 9.24 MT and 21.3 q/ha. Wheat covers area of .315 Mha area with production and productivity of 0.259 MT and 8.22 q/ha. [3] Chhattisgarh Government). Nutrient management in the rice - wheat cropping system have a great importance for the maintenance of soil health. Both rice and wheat are exhaustive feeders, and this double cropping system is heavily depleting the soil of its nutrient content [4].

2. MATERIALS AND METHODS

The experiment was conducted at research farm of Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur, Chhattisgarh, India during *Kharif* and *Rabi* season of the year 2020-21 and continued to 2021-22 to investigate the response of nano DAP application on the growth and yield of rice and wheat. The soil of the experimental area was clayey in nature falling under the category of *Vertisol*, which is a fine, hyperthermic, montmorillonitic soil. The experimental soil was clayey in texture, slightly alkaline (7.33) and normal in nature (0.23 dS m^{-1}). Rice (variety – Rajeshwari) and wheat (variety- Wheat) was used as test crop in the experiment. The trial was laid down in a randomized block design (RBD) corresponding to 12 treatments and three replications.

All the treatments consisted of a common dose of 0%, 50%, 75% and 100% recommended dose of P through DAP in rice and wheat. Urea, DAP, Muriate of potash (MOP) and nano DAP were used as fertilizers. The urea, DAP and MOP were administered through soil application as basal and split dose whereas, nano DAP was given 2 times (at tillering and panicle initiation stage) through foliar application, as per the treatments.

Freshly wet soil samples from the rhizospheric area of each treatment were taken from random spots during 60 and 90 days after transplanting of rice crop. These soil samples are mixed thoroughly and made 50 gm so that it can be kept in different polythene bags followed by tagging each sample. Fresh samples are directly analysed for estimation of total bacteria count, PSB count, fungi count and MBC (cfu / gm soil). avoiding long storage and freezing of soil samples. Samples are also stored in freezer which are kept below ambient temperature in plastic pouch to prevent drying and incubate at room temperature for 24 hours before analysis.

3. RESULTS AND DISCUSSION

1. Soil microbial biomass carbon of rice crop (ug C/g soil)

The results of soil microbial biomass carbon 60 DAT and 90 DAT of rice in the year 2021 and 2022 (Table 1) showed that application of P @ 50% (T5) 75% (T4) and 100% (T3) through the conventional or granular DAP only, were significantly increased the soil microbial biomass carbon with increasing dose of phosphorous (50%-100% P) and respectively recorded the soil microbial biomass carbon at 60 DAT and 90 DAT 192.21, 196.01, 206.00 and 207.59, 212.56, 220.50 ug C/g soil in year 2021 while soil microbial biomass carbon at 60 DAT and 90 DAT was recorded 193.00, 197.36, 207.13 and 209.23, 214.31, 222.22 ug C/g soil in year 2022. These treatments were observed significantly superior over the control-T2 where 0% P (or no application) was applied.

The microbial activity and the soil health could be improved by the introduction of nano compounds such as nano clay, nano chitosan, and nano zeolite [5]. Nano zeolite, with a 99% purity, was able to support microbial population [6] and Basay et al. [7]. Increasing in the soil microbial biomass carbon due to increasing in the dose of P was also reported by many scientists. Nibin P. M. and Usha K. [8], Abdel-Aziz et al. (2019), Basay et al. [7], Rajesh et al. [9] and Meena et al. [10] also worked on effect of phosphorous on rice and reported that application of higher dose of P increased the soil microbial biomass carbon of rice.

2. Soil fungi of rice crop of rice during 2021 and 2022 (x 10^4 cfu g^{-1})

The results of soil fungi 60 DAT and 90 DAT of rice in the year 2021 and 2022 (Table 2) showed that application of P @ 50% (T5) 75% (T4) and 100% (T3) through the conventional or granular DAP only, were significantly increased the soil fungi with increasing dose of phosphorous (50%-100% P) and respectively recorded the soil fungi 11.75, 12.75, 12.83 and 5.95, 6.90, 7.08 (x 10^4 cfu g^{-1}) soil at 60 DAT and 90 DAT respectively in year 2021 while soil fungi was recorded 12.38, 13.37, 13.46 and 7.27, 7.94, 8.26 (x 10^4 cfu g^{-1}) soil at 60 DAT and 90 DAT respectively in year 2022. These treatments were observed significantly superior over the control-T2 where

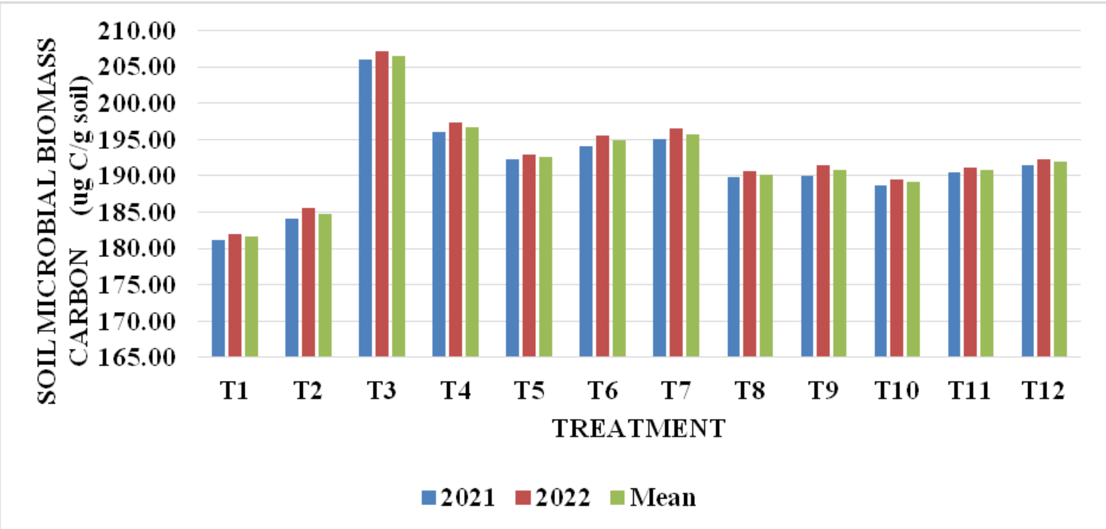

Fig. 1. Effect of application of Nano-DAP fertilizer on soil microbial biomass carbon 60 DAT of rice during 2021 and 2022 (ug C/g soil)

Table 1. Effect of application of Nano-DAP fertilizer on soil microbial biomass carbon of rice crop during 2021 and 2022 (ug C/g soil)

Treat	Treatment details	SMBC 60 DAT (ug C/g soil)			SMBC 90 DAT (ug C/g soil)		
		2021	2022	Mean	2021	2022	Mean
T_1	Absolute Control (N0:P0: K0)	181.21c	182.00c	181.61c	194.67c	196.36c	195.52c
T_2	0 % P (Control P0); (NPK 120:0:40 kg ha^{-1})	184.05c	185.51c	184.78c	196.50c	198.21c	197.36c
T_3	100 % P through DAP (NPK 120:60:40 kg ha^{-1})	206.00a	207.13a	206.57a	220.50a	222.22a	221.36a
T_4	75 % P through DAP (NPK 120:45:40 kg ha^{-1})	196.01b	197.36b	196.69b	212.60a	214.31a	213.46a
T_5	50% P through DAP (NPK 120:30:40 kg ha^{-1})	192.21b	193.00b	192.61b	207.53b	209.23b	208.38b
T_6	T4 + Root Dip. @ 5 ml /L + Foliar Spray @ 2 ml/ L at 30 DAT with Nano DAP	194.10b	195.56b	194.83b	211.00a	212.70ab	211.85a
T_7	T4 + Root Dip. @ 5 ml /L + FS @ 4 ml/ L at 30 DAT with Nano DAP	195.02b	196.48b	195.75b	212.03a	214.06a	213.05a
T_8	T5 + Root Dip. @ 5 ml /L + Foliar Spray @ 2 ml/ L at 30 DAT with Nano DAP	189.80b	190.60b	190.20b	209.47b	211.83b	210.65b
T_9	T5 + Root Dip. @ 5 ml /L + Foliar Spray @ 4 ml/ L at 30 DAT with Nano DAP	190.04b	191.50b	190.77b	210.00b	212.03b	211.02b
T_{10}	T5 + Root Dip. @ 5 ml / L + Foliar Spray @ 2 ml / L at 25 and 45 DAT with Nano DAP	188.75bc	189.54bc	189.15bc	209.70b	211.42b	210.56b
T_{11}	T5 + Root Dip. @ 5 ml / L + Foliar Spray @ 4 ml / L at 25 and 45 DAT with Nano DAP	190.42b	191.22b	190.82b	210.70ab	212.73a	211.72ab
T_{12}	T5 + Seed Treat. @ 5 ml / kg seed + Foliar Spray @ 4 ml / L at 30 DAT with Nano DAP	191.52b	192.32b	191.92b	206.70b	208.44b	207.57b
	SEm (±)	3.29	3.25	3.26	3.43	3.27	3.29
	C.D. (0.05)	9.64	9.52	9.56	10.06	9.59	9.64
	C.V. %	2.97	2.92	2.94	2.84	2.69	2.72

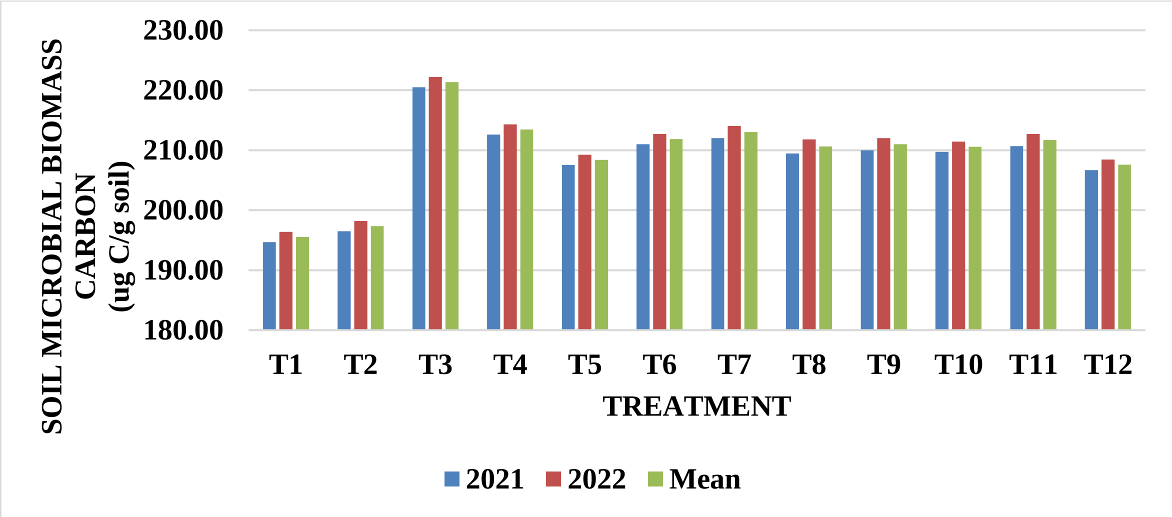

Fig. 2. Effect of application of Nano-DAP fertilizer on soil microbial biomass carbon 90 DAT of rice during 2021 and 2022 (ug C/g soil)

0% P (or no application) was applied. No variation in the soil fungi due to application @ 2 and 4 ml/l concentration of Nano-DAP were also observed. Treatments of roots and seeds treated through the Nano-DAP showed similar effect and recorded at par soil fungi.

Increasing in the soil fungi due to increasing in the dose of P was also reported by many scientists. Nibin P. M. and Usha K. [8], Abdel-Aziz et al. (2019), Basay et al*.* [7], Rajesh et al*.* [9] and Meena et al*.* [10] also worked on effect of phosphorous on rice and reported that application of higher dose of P increased the soil fungi of rice. N fertilization might have helped in increasing the root biomass, which in turn improved the soil microbial population *viz*., total bacteria, fungi *etc.* These results in agreement with the earlier work done by Khan et al*.,* (2019) and Rajonee et al*.* (2017). Foliar application of nanoparticles has been reported to be beneficial for the ectomycorrhiza [11].

3. Total bacteria 60 DAT and 90 DAT in rice during 2021 and 2022 (x 10^6 cfu g^{-1})

The results of total bacteria 60 DAT and 90DAT of rice in the year 2021 and 2022 (Table 3) showed that application of P @ 50% (T5) 75% (T4) and 100% (T3) through the conventional or granular DAP only, were significantly increased the total bacteria with increasing dose of phosphorous (50%-100% P) and respectively recorded the total bacteria 21.14, 22.91, 23.81 and 18.16, 18.55, 19.48 (x 10^6 cfu g^{-1}) in year 2021 while total bacteria was recorded 22.57, 24.34, 25.24 and 18.43, 18.75, 19.75 (x 10^6 cfu g^{-1}) in year 2022. These treatments were observed significantly superior over the control-T2 where 0% P (or no application) was applied.

The total bacteria 60 DAT of treatments of foliar spray of Nano-DAP at 30 DAT @ 2 ml (T6) and @ 5 ml / l (T7) with the common application of 75% P through granular DAP and root dipping of Nano-DAP (@ 5 ml/ l) were recorded highest total bacteria 22.88 and 22.90 (x 10^6 cfu g^{-1}) in year 2021 and 24.31 and 24.32 (x 10^6 cfu g^{-1}) in year 2022 among all the treatments of Nano-DAP and found at par with each other. Treatments with 50 % P in combination of Nano -DAP showed at par values with T6 and T7. Both the treatments were also observed statistically at par with 100% P application through granular DAP (T3) 23.81 (x 10^6 cfu g^{-1}) in 2021 and (T3) 25.24 (x 10^6 cfu g^{-1}) in 2022. Treatments T8 and T9 which were with 50% P in combination of Nano -DAP showed at par values with T6 and T7 in both the years.

The total bacteria of treatments at 90 DAT of foliar spray of Nano-DAP at 30 DAT @ 2 ml (T6) and @ 5 ml / l (T7) with the common application of 75% P through granular DAP and root dipping of Nano-DAP (@ 5 ml/ l) were recorded highest total bacteria19.10 and 19.12 (x 10^6 cfu g^{-1})soil in year 2021 and 19.33 and 19.31 (x 10^6 cfu g^{-1}) in year 2022 among all the treatments of Nano-DAP and found at par with each other. Both the treatments were also observed statistically at par with 100% P application through granular DAP

Table 2. Effect of application of Nano-DAP fertilizer on fungi of soil of rice crop during 2021 and 2022 (x 10^4 cfu g^{-1})

Treat	Treatment details	Fungi 60 DAT (x 10^4 cfu g^{-1})			Fungi 90 DAT (x 10^4 cfu g^{-1})		
		2021	**2022**	**Mean**	**2021**	**2022**	**Mean**
T_1	Absolute Control (N0:P0: K0)	10.22c	10.85c	10.53c	3.75g	4.27e	4.01e
T_2	0 % P (Control P0); (NPK 120:0:40 kg ha^{-1})	10.26c	10.89c	10.58c	4.04g	5.01d	4.52d
T_3	100 % P through DAP (NPK 120:60:40 kg ha^{-1})	12.83a	13.46a	13.14a	7.08a	8.26a	7.67a
T_4	75 % P through DAP (NPK 120:45:40 kg ha^{-1})	12.75a	13.37a	13.06a	6.90ab	7.94a	7.42a
T_5	50% P through DAP (NPK 120:30:40 kg ha^{-1})	11.75b	12.38b	12.06b	5.95d	7.27c	6.61c
T_6	T4 + Root Dip. @ 5 ml /L + Foliar Spray @ 2 ml/ L at 30 DAT with Nano DAP	12.18ab	13.09ab	12.64ab	6.38cd	7.03b	6.71b
T_7	T4 + Root Dip. @ 5 ml /L + FS @ 4 ml/ L at 30 DAT with Nano DAP	12.20a	13.11a	12.66a	6.46bc	7.08b	6.77b
T_8	T5 + Root Dip. @ 5 ml /L + Foliar Spray @ 2 ml/ L at 30 DAT with Nano DAP	11.74b	12.36b	12.05b	5.50ef	6.02c	5.76c
T_9	T5 + Root Dip. @ 5 ml /L + Foliar Spray @ 4 ml/ L at 30 DAT with Nano DAP	11.76b	12.39b	12.08b	5.66e	6.18c	5.92c
T_{10}	T5 + Root Dip. @ 5 ml / L + Foliar Spray @ 2 ml / L at 25 and 45 DAT with Nano DAP	11.75b	12.38b	12.06b	5.48f	6.00c	5.74c
T_{11}	T5 + Root Dip. @ 5 ml / L + Foliar Spray @ 4 ml / L at 25 and 45 DAT with Nano DAP	11.77b	12.40b	12.08b	5.65e	6.17c	5.91c
T_{12}	T5 + Seed Treat. @ 5 ml / kg seed + Foliar Spray @ 4 ml / L at 30 DAT with Nano DAP	11.72b	12.35b	12.03b	5.51e	6.04c	5.78c
	SEm (±)	0.23	0.27	0.25	0.15	0.2	0.11
	C.D. (0.05)	0.68	0.8	0.73	0.45	0.6	0.31
	C.V. %	3.42	3.8	3.58	4.67	5.57	3.04

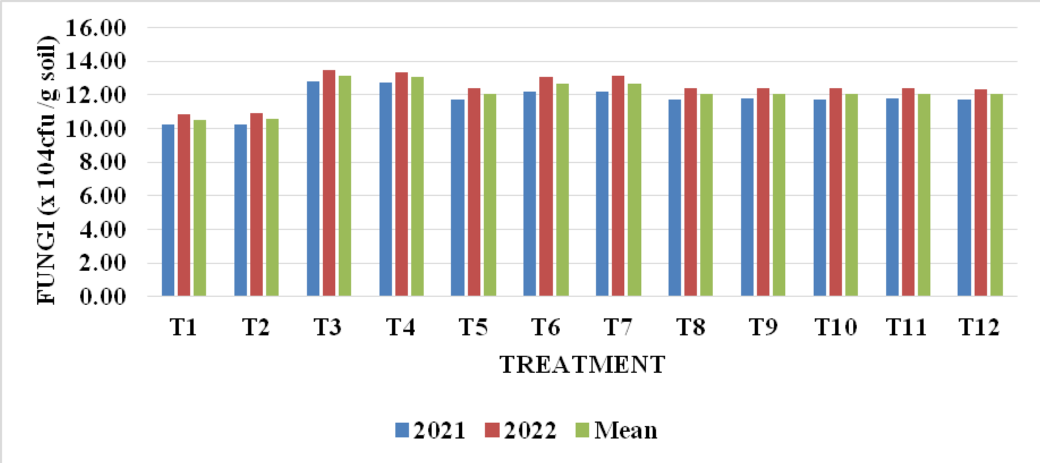

Fig. 3. Effect of application of Nano-DAP fertilizer on fungi of soil 60 DAT in rice during 2021 and 2022 (x 10^4 cfu g^{-1})

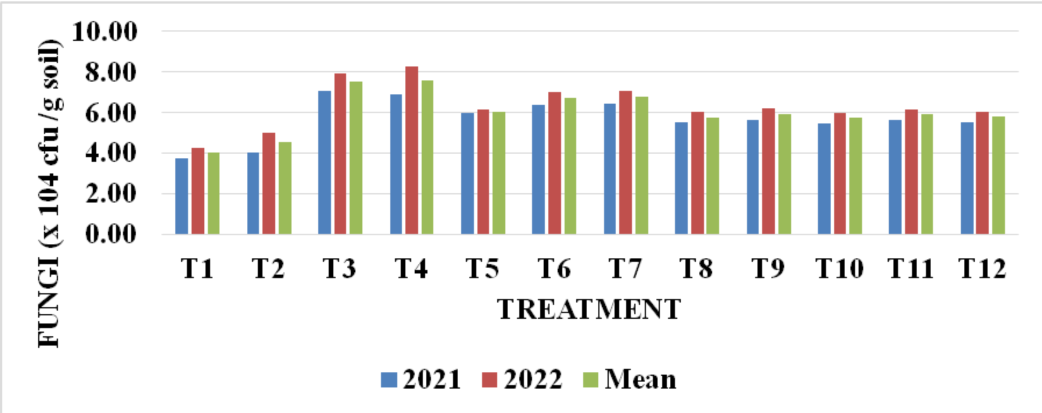

Fig. 4. Effect of application of Nano-DAP fertilizer on fungi of soil 90 DAT in rice during 2021 and 2022 (x 10^4 cfu g^{-1})

(T3) 19.48 (x 10^6 cfu g^{-1}) in year 2021 and (T3) 19.75 (x 10^6 cfu g^{-1}) in year 2022. These results showed that saving of 25% dose of P through the foliar application and root dipping with Nano-DAP. No variation in the total bacteria due to application @ 2 and 4 ml/l concentration of Nano-DAP were observed.

The microbial activity and the soil health could be improved by the introduction of nano compounds such as nano clay, nano chitosan, and nano zeolite [5]. Nano zeolite, with a 99% purity, was able to support microbial population [6] and Basay et al*.* [7].

4. Phosphorus solubilizing bacteria of rice crop (x 10^4 cfu g^{-1})

The results of phosphorus solubilizing bacteria 60 DAT and 90 DAT of rice in the year 2021 (Table 4) showed that application of P @ 100% (T3) 75% (T4) and 50% (T5) through the conventional or granular DAP only, were significantly increased the phosphorus solubilizing bacteria with decreasing dose of phosphorous (100%-50% P) and respectively recorded the phosphorus solubilizing bacteria 35.37, 39.40, 44.10 and 32.71, 36.52, 41.29 (x 10^4 cfu g^{-1}) in soil at 60 DAT and 90 DAT in year 2021 while phosphorus solubilizing bacteria was recorded 36.37, 41.07, 45.10 and 34.73, 38.80, 44.20 (x 10^4 cfu g^{-1}) soil at 60 DAT and 90 DAT in year 2022. Treatment T5- 50% P through DAP recorded highest PSB among all the treatments. These treatments were observed significantly superior over the control-T2 where 0% P (or no application) was applied.

Results at 60 DAT and 90 DAT among various treatments of 50% P application through the granular DAP with seed treatment with Nano-DAP at nursery (T12) and root treatment with Nano-DAP at transplanting (T8-T11) were given with foliar spray of different concentration of Nano-DAP (@ 2 or 4 ml/l) at 30 DAT (one time application) or at 25 and 45 DAT (two times application), were recorded at par phosphorus solubilizing bacteria (43.03 – 43.80 and 40.40 – 40.85 x 10^4 cfu g^{-1} 60 DAT and 90 DAT, respectively) in year 2021 and (44- 44.87 and 43.13- 43.80 x 10^4cfu g^{-1} 60 DAT and 90 DAT, respectively) in year 2022. These treatments (T8 - T12) were also found at par with T5 (50% P through granular DAP) observed statistical higher T3 (100% P through DAP). These results also showed saving of 25- 50% P through the application of Nano-DAP. No variation in the phosphorus solubilizing bacteria due to application @ 2 and 4 ml/l concentration of Nano-DAP were also observed. Treatments of roots and seeds treated through the Nano-DAP showed similar effect and recorded at phosphorus solubilizing bacteria.

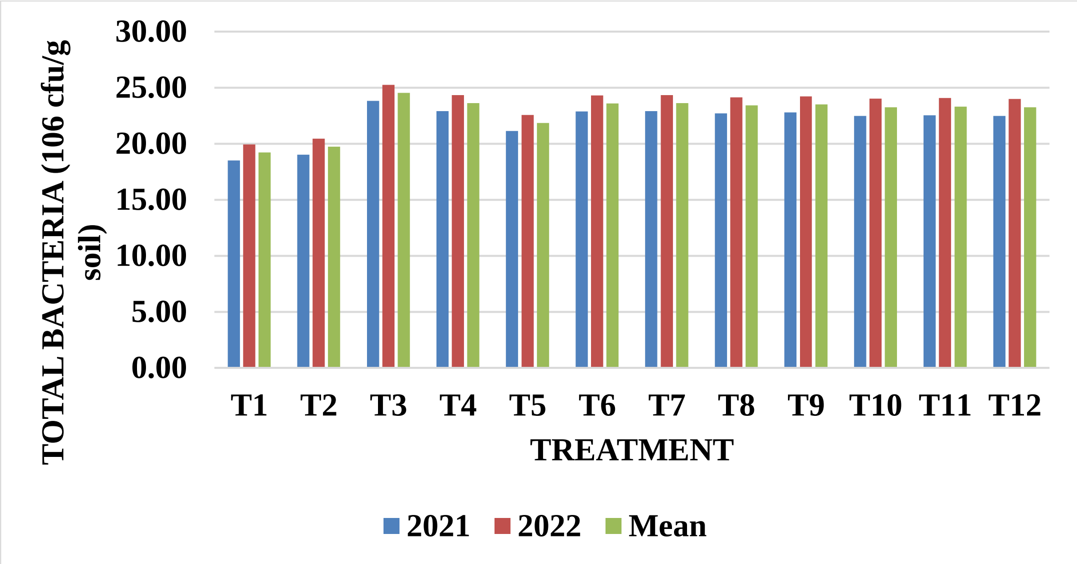

Fig. 5. Effect of application of Nano-DAP fertilizer on total bacteria in soil 60 DAT in rice during 2021 and 2022 (x 10^6 cfu g^{-1})

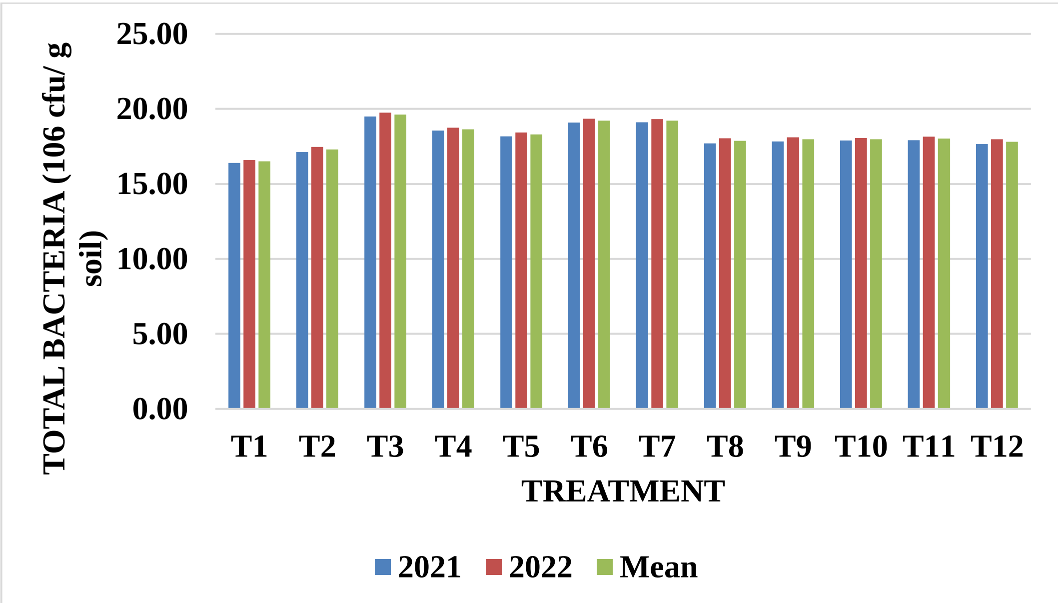

Fig. 6. Effect of application of Nano-DAP fertilizer on total bacteria in soil 90 DAT in rice during 2021 and 2022 (x 10^6 cfu g^{-1})

Table 3. Effect of application of Nano-DAP fertilizer on total bacteria of rice crop during 2021 and 2022 (x 10^6 cfu g^{-1})

Treat	Treatment details	Total bacteria 60 DAT (x 10^6 cfu g^{-1})			Total bacteria 90 DAT (x 10^6 cfu g^{-1})		
		2021	2022	Mean	2021	2022	Mean
T_1	Absolute Control (N0:P0: K0)	18.51d	19.94d	19.23d	16.40d	16.60d	16.50d
T_2	0 % P (Control P0); (NPK 120:0:40 kg ha^{-1})	19.01d	20.44d	19.72d	17.13c	17.47c	17.30c
T_3	100 % P through DAP (NPK 120:60:40 kg ha^{-1})	23.81a	25.24a	24.52a	19.48a	19.75a	19.62a
T_4	75 % P through DAP (NPK 120:45:40 kg ha^{-1})	22.91a	24.34a	23.62a	18.55ab	18.75ab	18.65ab
T_5	50% P through DAP (NPK 120:30:40 kg ha^{-1})	21.14c	22.57c	21.86c	18.16b	18.43b	18.30b
T_6	T4 + Root Dip. @ 5 ml /L + Foliar Spray @ 2 ml/ L at 30 DAT with Nano DAP	22.88a	24.31a	23.59a	19.10a	19.33a	19.22a
T_7	T4 + Root Dip. @ 5 ml /L + FS @ 4 ml/ L at 30 DAT with Nano DAP	22.90a	24.32a	23.61a	19.12a	19.32a	19.22a
T_8	T5 + Root Dip. @ 5 ml /L + Foliar Spray @ 2 ml/ L at 30 DAT with Nano DAP	22.71ab	24.14a	23.42ab	17.70b	18.04b	17.87b
T_9	T5 + Root Dip. @ 5 ml /L + Foliar Spray @ 4 ml/ L at 30 DAT with Nano DAP	22.78a	24.21a	23.49a	17.84b	18.11b	17.98b
T_{10}	T5 + Root Dip. @ 5 ml / L + Foliar Spray @ 2 ml / L at 25 and 45 DAT with Nano DAP	22.48b	24.03b	23.25b	17.90b	18.07b	17.98b
T_{11}	T5 + Root Dip. @ 5 ml / L + Foliar Spray @ 4 ml / L at 25 and 45 DAT with Nano DAP	22.54b	24.09ab	23.32b	17.91b	18.15b	18.03b
T_{12}	T5 + Seed Treat. @ 5 ml / kg seed + Foliar Spray @ 4 ml / L at 30 DAT with Nano DAP	22.47b	24.00b	23.24b	17.67bc	17.97bc	17.82bc
	SEm (±)	0.41	0.4	0.4	0.33	0.37	0.33
	C.D. (0.05)	1.19	1.17	1.17	0.96	1.09	0.97
	C.V. %	3.19	2.94	3.04	3.15	3.52	3.16

Table 4. Effect of application of Nano-DAP fertilizer on phosphorus solubilizing bacteria in soil of rice crop during 2021 and 2022 (x 10^4 CFU g^{-1})

Treat	Treatment details	Phosphorus solubilizing bacteria 60 DAT (x 10^4 cfu g^{-1})			Phosphorus solubilizing bacteria (x 10^4 cfu g^{-1}) 90 DAT		
		2021	**2022**	**Mean**	**2021**	**2022**	**Mean**
T_1	Absolute Control (N0:P0: K0)	19.73c	20.73c	20.23d	15.70e	16.87d	16.29d
T_2	0 % P (Control P0); (NPK 120:0:40 kg ha^{-1})	20.20c	21.17c	20.68d	18.76d	19.20d	18.98d
T_3	100 % P through DAP (NPK 120:60:40 kg ha^{-1})	35.37b	36.37b	35.87c	32.71c	34.73c	33.72c
T_4	75 % P through DAP (NPK 120:45:40 kg ha^{-1})	39.40ab	41.07a	40.23b	36.52b	38.80b	37.66b
T_5	50% P through DAP (NPK 120:30:40 kg ha^{-1})	44.10a	45.10a	44.60a	41.29a	44.20a	42.75a
T_6	T4 + Root Dip. @ 5 ml /L + Foliar Spray @ 2 ml/ L at 30 DAT with Nano DAP	39.77a	40.47ab	40.12b	35.28bc	37.67bc	36.47bc
T_7	T4 + Root Dip. @ 5 ml /L + FS @ 4 ml/ L at 30 DAT with Nano DAP	39.73a	40.80a	40.27b	32.57c	35.20c	33.89c
T_8	T5 + Root Dip. @ 5 ml /L + Foliar Spray @ 2 ml/ L at 30 DAT with Nano DAP	43.47a	44.47a	43.97a	40.40a	43.50a	41.95a
T_9	T5 + Root Dip. @ 5 ml /L + Foliar Spray @ 4 ml/ L at 30 DAT with Nano DAP	43.30a	44.00a	43.65a	40.75a	43.80a	42.28a
T_{10}	T5 + Root Dip. @ 5 ml / L + Foliar Spray @ 2 ml / L at 25 and 45 DAT with Nano DAP	43.03a	44.13a	43.58ab	40.82a	43.67a	42.24a
T_{11}	T5 + Root Dip. @ 5 ml / L + Foliar Spray @ 4 ml / L at 25 and 45 DAT with Nano DAP	43.80a	44.80a	44.30a	40.63a	43.33a	41.98a
T_{12}	T5 + Seed Treat. @ 5 ml / kg seed + Foliar Spray @ 4 ml / L at 30 DAT with Nano DAP	43.50a	44.60a	44.05a	40.85a	43.13a	41.99a
	SEm (±)	1.74	1.51	1.24	1.03	1.16	0.93
	C.D. (0.05)	5.11	4.42	3.64	3.02	3.41	2.72
	C.V. %	7.98	6.7	5.59	5.14	5.44	4.48

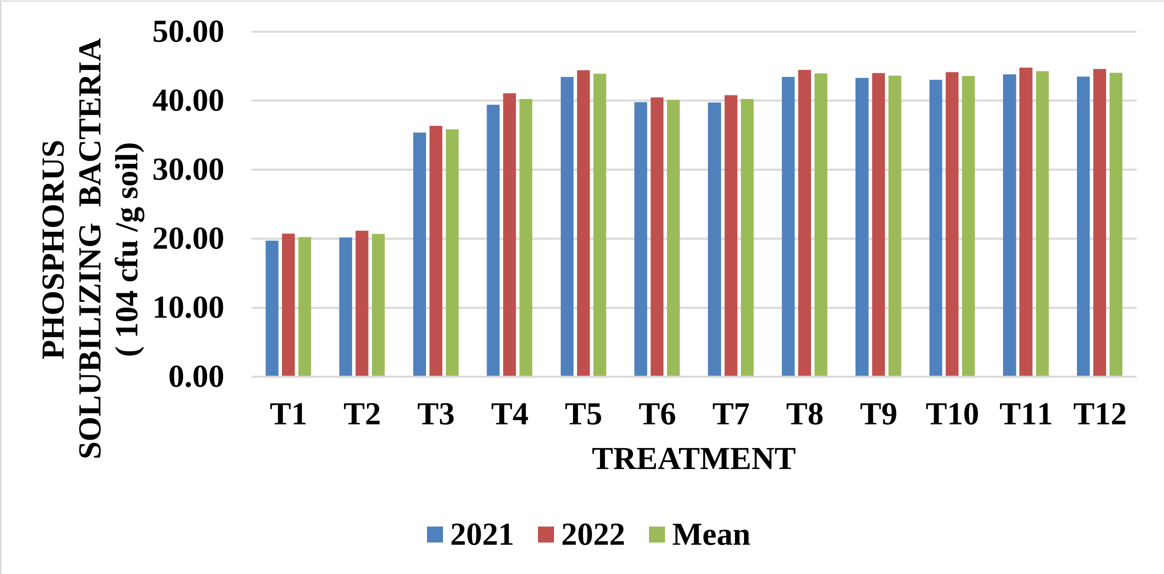

Fig. 7. Effect of application of Nano-DAP fertilizer on phosphorus solubilizing bacteria in soil 60 DAT in rice during 2021 and 2022 (x 10^4 cfu g^{-1})

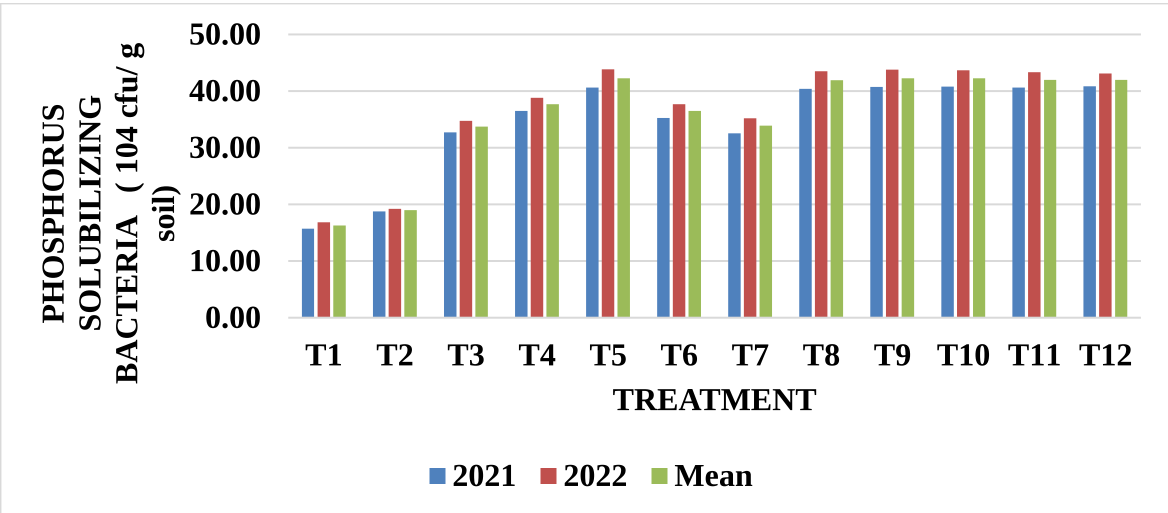

Fig. 8. Effect of application of Nano-DAP fertilizer on phosphorus solubilizing bacteria in soil 90 DAT in rice during 2021 and 2022 (x 10^4 cfu g^{-1})

Phosphorus solubilizing bacteria population, solubilizing index and phosphatase activity were directly proportional and were mediated by positive characteristics of nanomaterials [12-15].

4. CONCLUSION

The results showed that application of 75% P through DAP (T6 and T7) in combination with nano DAP and treatment with 100 % P through DAP gave at par result in soil microbial biomass carbon, fungus and total bacteria colony count in rice during both years. In phosphorus solubilizing bacteria treatment with 50 % P through DAP and combination of Nano- DAP with it gave at par results. The result soil microbial biomass carbon, fungus and total bacteria colony count reveals that 25% of DAP fertilizer can be saved by application through combination of nano DAP fertilizer with DAP and the result phosphorus solubilizing bacteria reveals that 50% of DAP fertilizer can be saved by application through combination of nano DAP fertilizer with DAP in rice.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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