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Research Paper

Microbial population and yield of rice–wheat system under variable irrigation and nutrient management

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ABSTRACT

A field experiment was conducted during rainy (*kharif*) season of 2018–19 and winter (*rabi*) season of 2019–20 at the Water Management Research Farm of CSK Himachal Pradesh Agricultural University, Palampur, Kangra, Himachal Pradesh to study the effect of moisture and nutrient management practices on different soil microbial entities and crop yields in rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) system. Experiment was laid out in a split-plot design with 3 replications. Treatments comprised of 3 irrigation levels, viz. Recommended critical stages regimes; Irrigation at 0.8 CPE (cumulative pan evaporation) (rice) and 0.6 CPE (wheat); Irrigation at 1.0 CPE (rice) and 1.0 CPE (wheat) assigned to main-plots and 4 nutrient management practices, viz. Inorganic; Organic; Natural farming; and Integrated management allotted to sub-plots. Irrigation at critical stages resulted in significantly higher rice yield, bacterial, azotobacter, phosphate solubilizing bacteria (PSB), actinomycetes population. However, fungi population increased under higher moisture regimes. In case of wheat crop, irrigation at 1.0 CPE resulted in a significantly higher yield (7.5% higher over irrigation at critical stages) in both the years of study. Organic and integrated nutrient management practices being statistically at par with each other recorded significantly higher microbial population. A significantly higher fungi population was, however, recorded with natural farming. The highest crop yields were obtained with integrated nutrient management (3.4 t/ha rice and 3.6 t/ha wheat in second year). The best combination for rice was irrigation at critical stages along with integrated nutrient management. Whereas, for wheat irrigation at 1.0 CPE with same nutrient management proved to be the best. Hence it is recommended to follow integrated nutrient management and irrigation at critical stages in rice and at 1.0 CPE in wheat for higher productivity as well as for improved biological properties of soil.

Key words: Integrated crop management, Irrigation, Microbial population, Natural farming, Nutrient management, Rice, Wheat

Soil microorganisms are sensitive to changes in soil moisture as it affects the physiological state of microorganisms and plants (Walker *et al.,* 2003; Dass *et al*., 2017; Rajanna *et al.,* 2022) which may lead to changes in their population in the soil. Although moist soils hold more functionally diverse microbial communities, excessive moisture in the soil may be detrimental to some type of microorganisms which may lead to lower biomass of microorganisms (Unger *et al.,* 2009). However, dry soils can also have negative effects on the homeostasis of soil (Kim *et al.,* 2008) reducing microbial population. Moreover, water is required for activation and maintenance of catalytically active state of soil enzymes (Jiang and Zhang 2002; Jinger *et al*., 2020). Hence too wet or too dry conditions may hamper the enzyme activities. Application of organic mulches on soil is known to provide various nutrients which is essential for plant nutrition, increase the soil organic matter content, improves the physical, chemical, and biological soil parameters (Chaudhary *et al*., 2003; Dass and Bhattacharyya, 2017). Moreover, organic amendments increase the size, biodiversity, and activity of microbial populations (Luo *et al*., 2018). The microbial and biochemical activity of soil is closely related to its physical and chemical properties, hence, soil's biological properties affect soil fertility and crop yielding potential (Wyszkowska *et al.,* 2007). For the aforementioned

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reasons, it is an extreme necessity to determine the correlations between the soil moisture content and nutrient management practices for soil microbial activity, their enzymatic activity and ultimately crop yield.

MATERIALS AND METHODS

A field experiment was conducted during rainy (*kharif*) season of 2018–19 and winter (*rabi*) season of 2019–20 at the Water Management Research Farm of CSK Himachal Pradesh Agricultural University, Palampur, Kangra (32° 06′ 05′′ N and 76° 33′ 02′′ E at an elevation of 1283 m amsl), Himachal Pradesh. Soil of the experimental site was silty clay loam and slightly acidic (pH 5.3) in nature. Soils were medium in available N (278.0 kg/ha), high in available phosphorus (29.8 kg/ha) and low in available K (182.44 kg/ha). Seeds of HPR-2795 variety of red rice and HPW-236 variety of wheat were used in this study. Rice was sown in first week of June and wheat was sown in first week of November. All package of practices other than irrigation and nutrient management were followed from sowing to harvesting. The experiment was conducted in a split-plot design with 3 irrigation regimes, viz. Recommended critical stages regimes (I_1); Irrigation at 0.8 CPE (cumulative pan evaporation) (rice) and 0.6 CPE (wheat) (I_2); Irrigation at 1.0 CPE (rice) and 1.0 CPE (wheat) (I_3) assigned to main-plots and 4 nutrient management practices, viz. Inorganic management (F_1); Organic management (F_2); Natural management (F_3); and Integrated management (F_4) in sub-plots, with total of 12 treatment combinations, replicated thrice.

Irrigation water requirement was calculated based on the daily evaporation data recorded from June to October for rice and November to May for wheat crop for the years 2018–19 and 2019–20. Irrigation requirement was determined by taking into account the difference of actual evaporation and effective rainfall (only positive values) and multiplying with CPE ratios. It was calculated as:

$$\text{Ratio} = \text{IW: CPE}$$

In critical stage irrigation regime, rice crop was irrigated at active tillering (2nd week of July) and grain filling stage (2nd week of September). The total amount of irrigation water applied for critical stage, I_1 was 100 mm in both the years; 94 and 133 mm for I_2 in 2018 and 2019, respectively and 118 mm and 167 mm for I_3 in 2018 and 2019 respectively. In wheat crop, irrigation was given at CRI (Crown root initiation) stage, tillering, late jointing, flowering and dough stage. The total amount of irrigation water applied for critical stage I_1 was 250 mm in both the years, 156 and mm 76 for I_2 in 2018 and 2019 respectively and 260 mm and 126 mm for I_3 in 2018 and 2019 respectively.

Under nutrient management practices in inorganic management (F_1) chemical fertilizers were applied at recommended dose of 60:30:30 N:P_2O_5:K_2O kg/ha (rice) and 120:60:30 N:P_2O_5:K_2O kg/ha (wheat) using urea, Single superphosphate (SSP) and Muriate of potash (MOP). In organic management (F_2), 15 tonnes FYM was applied and the seeds were treated using *Azospirillium/Azotobacter* and PSB. Vermiwash was given as foliar spray at 30-days interval (3 times in rice and 5 times in wheat). In natural management (F_3), powdered ghanjivamrit was applied and incorporated in the soil @395 kg/ha. Seeds were treated with bijamrit and dried under the shade for 30 min before sowing. Foliar application with jivamrit was done at 30-days interval (3 times in rice and 5 times in wheat). Mulch was applied in the inter-rows of crops for moisture conservation. In integrated management (F_4), 75% of the nutrient requirement was applied through Urea, SSP and MOP and the remaining through FYM, *Azospirillium/Azotobacter* and PSB as seed treatment.

After harvesting and threshing of crops, grain yield obtained from net-plot area was converted to kg/ha. Soil samples were collected from 0–15 cm depth after harvest of each crop. Samples were air-dried, processed, sieved (2 mm) and analyzed for microbial count (Bacteria, Fungi, *Azotobacter*, PSB and actinomycetes) using serial dilution and pour plate technique. The data recorded on various aspects in the present study were subjected to the statistical analysis using analysis of variance as per procedure suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Bacteria

Significantly higher bacterial count was recorded when irrigation was given at critical stages regimes in both the years as compared to other levels (Table 1). There was a gradual decrease of 9.2–14.8% (1st year) and 6.5–10.9% (2nd year) on bacterial population with increase in frequency of irrigation (irrigation at 1.0 CPE). This could be due to higher moisture content and antagonistic effect of fungi as fungal population was higher in higher moisture conditions. Antagonism between bacteria and fungi is connected to competition for substrate (Mille-Lindblom *et al.,* 2006). Organic management resulted in significantly higher bacterial population whereas lowest was recorded in inorganic management system. Comparing the initial population taken before treatments were imposed and the final population, an increment of about 13% in inorganic, 100% in integrated, 135% in organic and 27% natural management was observed. Energy for the microbial population is provided by the availability of carbonaceous materials and substrates to the soil from the decomposing organic materials (Mohammad *et al*., 2017).

Table 1. Effect of irrigation scheduling and nutrient management practices on the count of soil bacteria and fungi

Treatment	Bacteria (× 10^5 CFU/g soil)			Fungi (× 10^4 CFU/g soil)		
	2018	2019	2020	2018	2019	2020
Irrigation level						
I_1, Critical stage	8.13	10.87	14.94	3.83	4.56	6.92
I_2, CPE 0.8 (rice)/0.6 (wheat)	8.30	9.95	14.03	4.26	5.24	7.33
I_3, CPE 1.0	8.48	9.47	13.48	4.08	5.76	8.17
SEm±	0.13	0.20	0.21	0.16	0.10	0.17
CD (P=0.05)	NS	0.78	0.81	NS	0.38	0.66
Nutrient management						
F_1, Inorganic	8.15	7.78	9.17	3.77	4.15	4.17
F_2, Organic	8.49	12.61	19.98	4.23	5.32	8.72
F_3, Natural	7.90	9.06	10.05	3.98	6.33	9.89
F_4, Integrated	8.68	10.95	17.40	4.24	4.96	7.11
SEm±	0.30	0.49	0.32	0.13	0.12	0.17
CD (P=0.05)	NS	1.46	0.95	NS	0.37	0.49

Treatment details are given under Materials and Methods.

Fungi

In both the years of study, significantly higher fungi count was recorded when irrigation was given at 1.0 CPE followed by irrigation at 0.8/0.6 CPE (Table 1). Fungal population increased by 26% (1st year) and 18% (2nd year) when irrigation was given at 1.0 CPE over recommended critical stages. This may be because fungus thrives best in moist conditions, provided by the higher irrigation regimes which encouraged the growth and spread of their mycelia, resulting in a higher population. Borowik and Wyszkowska (2016) also reported similar results. Significantly higher fungal population was observed in natural management in both the years followed by organic management**.** This may be attributed to mulch application, which provides a congenial environment for fungus growth. FYM in organic and integrated nutrient management also plays a vital role in moisture-holding capacity. These findings are in line with Barakzai *et al.,* (2021).

Azotobacter

Significantly higher azotobacter count was recorded when irrigation was given at recommended critical stages regimes (Table 2). There was decrease of 11.74–14.36% (1st year) and 11.31–23.11% (2nd year) in azotobacter population with increase in irrigation levels. Although the moisture content in the soil affects the physiological state of microorganisms (Walker *et al.,* 2003), excessive soil moisture may lead to a lower biomass of microorganisms (Unger *et al.,* 2009). Organic and integrated nutrient management although at par with each other, were significantly higher than natural and inorganic management, in respect to azotobacter population. An increment of about 11% in inorganic, 232% in integrated, 280% in organic and 42% in natural management was noted in final population over

Table 2. Effect of irrigation scheduling and nutrient management practices on the count of soil azotobacter, PSB and actinomycetes

Treatment	Azotobacter (× 10^4 CFU/g soil)			PSB (× 10^4 CFU/g soil)			Actinomycetes (× 10^4 CFU/g soil)		
	2018	2019	2020	2018	2019	2020	2018	2019	2020
Irrigation level									
I_1, Critical stage	10.19	15.56	26.97	5.30	8.40	14.54	20.58	25.45	31.58
I_2, CPE 0.8 (rice)/0.6 (wheat)	9.95	13.74	23.92	5.34	6.94	12.75	21.44	25.93	29.37
I_3, CPE 1.0	9.34	13.33	20.74	5.06	6.54	11.02	20.77	24.80	26.88
SEm±	0.29	0.32	0.22	0.18	0.18	0.15	0.27	0.31	0.45
CD (P=0.05)	NS	1.26	0.87	NS	0.71	0.60	NS	NS	1.75
Nutrient management									
F_1, Inorganic	9.77	10.03	10.83	5.23	5.29	5.47	20.94	21.99	23.52
F_2, Organic	9.51	17.82	36.10	4.90	9.21	19.86	21.36	27.20	32.35
F_3, Natural	9.48	12.01	13.44	5.36	5.91	6.54	20.85	26.63	31.18
F_4, Integrated	10.56	16.97	35.11	5.44	8.76	19.20	20.57	25.77	30.05
SEm±	0.39	0.37	0.36	0.19	0.19	0.25	0.74	1.05	0.79
CD (P=0.05)	NS	1.09	1.06	NS	0.56	0.73	NS	3.13	2.34

Treatment details are given under Materials and Methods.

initial one. The higher azotobacter population in natural management may be owing to mulching which helps in slow release of nutrients for the microbes over the whole season.

Phosphate solubilizing bacteria (PSB)

A decreasing trend in PSB population was observed with increase in irrigation levels. The decrement was to the tune of 17.4–22.1% (1st year) and 12.3–24.2% (2nd year) on PSB population (Table 2). Prolonged moist conditions due to frequent irrigations may result in soil saturation resulting in anaerobic conditions, thereby decreasing decomposition and altering nutrient cycling which may have adverse effect on the growth of PSB. Either excessively dry or wet soil conditions may lead to decrease of microorganisms' biomass (Landesman and Dighton 2010; Rajanna *et al.,* 2022). Organic and integrated management resulted in significantly higher PSB population as compared to other management systems. An increment in final population over initial one was about 5% in inorganic, 253% in integrated, 305% in organic and 22% natural management. Mulch act as carbon source and provide congenial temperature, favourable moisture conditions for the microbes. It also also acts as a buffer for change in soil chemical properties which may be unfavourable for PSB.

Actinomycetes

Increased irrigation regimes decreased actinomycetes population (Table 2) which may be owing to excessive moisture which was not conducive for actinomycetes growth. Borowik and Wyszkowska (2016) reported optimum development of actinomycetes when the soil was neither too dry nor too wet (40% maximum water capacity). Inorganic nutrient management recorded significantly lower actinomycetes population, whereas other treatments were statistically at par with each other. Organic nutrient management resulted in highest actinomycetes count which is attributed to dead food material available from FYM for microbes (Mairan and Dhawan, 2016).

Yield

In both the years of study, significantly higher seed yield of rice was recorded when irrigation was given at critical stage which was at par with irrigation at 1.0 CPE. In wheat, significantly higher seed yield was recorded when irrigation was given at 1.0 CPE over other treatments. Significantly higher rice yield was noted in inorganic management in first season (Table 3). However, in second season of rice and in both seasons of wheat; integrated nutrient management resulted in highest seed yield. Irrigation at critical stages resulted in highest seed yield in rice whereas yield of wheat was highest with irrigation at 1.0 CPE. These results are in line with findings of Sarwar *et al.,* (2010). The high seed yield of rice in inorganic management in the first year may be owing to the fact that inorganic fertilizers release nutrients instantly and in readily available forms for the plants during its growth, development and reproductive phase when the nutrient demand is at its peak. However, in the second season, significantly higher yield was recorded in integrated management which may be due to cumulative built up of microbes and nutrients from FYM and external application of beneficial microbes. Wheat crop recorded significantly higher seed yield under integrated nutrient management in both the years of study which may be owing to increased availability of nutrients in soil because of balanced application of chemical fertilizers and manures (Fazily *et al.,* 2021). Similar results were reported by Meena *et al.,* (2023) and Verma *et al.,* (2023) where

Table 3. Effect of irrigation scheduling and nutrient management practices on rice and wheat yield

Treatment	Rice		Wheat	
	Grain yield (kg/ha) 2018–19	Grain yield (kg/ha) 2019–20	Grain yield (kg/ha) 2018–19	Grain yield (kg/ha) 2019–20
Irrigation level				
I_1, Critical stage	2557.2	2667.0	2470.8	2597.7
I_2, CPE 0.8 (rice)/0.6 (wheat)	2352.5	2434.4	2563.8	2672.7
I_3, CPE 1.0	2461.9	2572.4	2683.8	2792.1
SEm±	30.7	30.3	29.8	35.2
CD (P=0.05)	120.6	119.0	117.1	138.3
Nutrient management				
F_1, Inorganic	3125.1	2952.9	3114.9	3042.6
F_2, Organic	2036.5	2051.5	1960.8	2088.3
F_3, Natural	1780.3	1845.1	1905.4	1973.2
F_4, Integrated	2886.9	3382.2	3310.0	3646.0
SEm±	24.3	25.4	29.4	31.4
CD (P=0.05)	72.1	75.5	87.4	93.3

Treatment details are given under Materials and Methods.

Table 4. Interaction effect of irrigation levels and nutrient management on rice and wheat yield

Irrigation levels/ Nutrient management	Rice grain yield (kg/ha) (2019–20)			Wheat grain yield (kg/ha) (2018–19)			Wheat grain yield (kg/ha) (2019–20)		
	I_1 Critical stage	I_2 CPE 0.8	I_3 CPE 1.0	I_1 Critical stage	I_2 CPE 0.6	I_3 CPE 1.0	I_1 Critical stage	I_2 CPE 0.6	I_3 CPE 1.0
F_1, Inorganic	3,098	2,833	2,926	3,000	3,154	3,191	2,910	3,045	3,127
F_2, Organic	2,046	1,955	2,152	1,928	1,957	1,997	2,063	2,054	2,116
F_3, Natural	1,962	1,717	1,855	1,881	1,911	1,925	1,918	1,938	1,996
F_4, Integrated	3,560	3,231	3,355	3,074	3,233	3,623	3,381	3,497	3,948
	CD (P=0.05)			CD (P=0.05)			CD (P=0.05)		
Nutrient management practices at same irrigation levels	131			151			160		
Irrigation at same or different nutrient management practices	173			193			208		

Treatment details are given under Materials and Methods.

integrated nutrient management resulted in higher wheat and maize yield, respectively.

Interaction effect of irrigation levels and nutrient management on rice grain yield

Interaction effect between irrigation levels and nutrient management practices was found to be significant only during second year (2019–20). Results showed that a significantly higher grain yield was recorded when the crop was irrigated at critical stages and integrated management (I_1F_4) practice was used (Table 4). This was followed by treatments where irrigation was applied either at 1.0 CPE or 0.8 CPE but the same nutrient management practice was followed (I_2F_4 and I_3F_4). Pathak *et al.,* (2023) also reported higher rice yield with integrated nutrient management as compared to other nutrient management practices.

Interaction effect of irrigation levels and nutrient management on wheat grain yield

A critical evaluation of interaction between irrigation levels and nutrient management in both the years showed that a significantly higher grain yield was recorded when the crop was irrigated at 1.0 CPE and integrated management (I_3F_4) practice was used (Table 4). The lowest grain yield was recorded when the crop was irrigated at critical stages and natural farming management was practiced (I_1F_3).

From the experiment, it is evident that scheduling of irrigation had a significant impact on microbial population and yield of the crops. Higher soil moisture enhances the fungi population, however, bacteria, PSB, azotobacter and actinomycetes thrive better in lower moisture regimes as compared to fungi. Organic, integrated and natural management had a significantly higher microbial population as compared to inorganic nutrient management. There was a gradual build-up of soil microbes resulting in a gradual increase in yield of both rice and wheat which indicates the sustainability of organic, integrated and natural farming systems.

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