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Root zone soil temperature and microflora population in QPM as influenced by irrigation regimes and nutrient levels in new alluvial zone of West Bengal

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Abstract
A field experiment was conducted on quality protein maize during *rabi* seasons of 2017-18 and 2018-19 at BCKV, West Bengal constituting three irrigation schedules *viz.* IW/CPE 0.5 (I_1), 0.75 (I_2) and 1.0 (I_3) in main plots and four nutrient management practices *viz.* control (N_1), 100% RDF (N_2), 75% RDF + 2 t/ha vermicompost (N_3) and 75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$ (N_4) in sub plots in split-plot design with three replications. Results suggested that I_3 recorded the lowest temperature at 15 and 20 cm soil depth at 60, 90 and 120 DAS (18.43^{0}C, 24.74^{0}C, 33.84^{0}C and 17.75^{0}C, 23.18^{0}C, 31.01^{0}C during 2017-18 and 18.76^{0}C, 23.94^{0}C, 29.41^{0}C and 18.03^{0}C, 22.12^{0}C, 27.48^{0}C during 2018-19 respectively). Nutrient application did not pose much influence on soil temperature but it affected microbial population significantly. Besides, I_3N_4 showed highest microflora population *i.e.* 248.00 and 247.00 CFU×10^6 total bacteria; 112.00 and 115.00 CFU×10^5 total actinomycetes and 8.67 and 12.67 CFU×10^4 total fungi during 2017-18 and 2018-19 at 60 and 90 DAS, respectively. The study shows that the pattern of microflora population was not affected significantly by soil temperature and I_3N_4 can be recommended for improving microbial communities in rhizosphere in new alluvial zone of West Bengal.

Keywords: Irrigation, microflora, nutrient, quality protein maize, soil temperature

Introduction
Maize is emerging as an important cereal crop in the world agricultural economy as food, feed and industrial raw material after wheat and rice, which is considered as 'Queen of Cereals'. In spite of several important uses, maize has an inbuilt drawback of being deficient in two essential amino acids, *viz*., lysine and tryptophan that leads to poor protein utilization and low biological value of traditional maize genotypes. To minimize the prevalence and persistence of malnutrition in developing countries, breeders have modified maize to produce a vitreous endosperm resembling that of conventional maize at Purdue University, USA, in 1963 and named as quality protein maize (QPM) by incorporating opaque-2 mutant gene, which is particularly responsible for enhancing lysine and tryptophan content of maize endosperm. Irrigated QPM grown in *rabi* season requires ample volume of irrigation water and availability of water is a limiting factor particularly in water scarce regions. Therefore, quantifying the crop response to irrigation schedules is an important invention for proper utilization of water resources and higher water use efficiency. Undoubtedly, being heavy feeder of nutrients and high productivity potential, maize also requires continuous and assured nutrient supply throughout the growing period from germination to grain filling stage. Thus, proper nutrient management for QPM hybrid is important to realize higher yields.
The present study exposed soil microbial communities to different irrigation regimes and nutrient levels and evaluated their response to a disturbance caused by them. Microbial communities in soil are affected by many anthropogenic inputs, including fertilization, organic carbon amendment, irrigation water quality, and the irrigation regime. The effects of these inputs on microbes are considered deterministic forces, which are also referred to as 'niche based' or 'habitat filters' in the literature (Ferrenberg *et al*., 2013) [3]. The addition of a substrate, such as in case of adequate irrigation water or nutrient sources, will encourage the proliferation or activity of organisms that utilize the given substrate, followed by a reduction in the availability of the resource. Therefore, understanding the effect of nutrient and water management as a force for structuring microbial community to natural events or disturbances

occurring as part of the management strategy is important for assessing the sustainability of a given management. Proper irrigation scheduling is a major soil management practice worldwide which was studied previously, and results showed that both the application of mineral fertilizer and the use of irrigation water at different treatment levels (Frenk *et al*., 2014) [4] drive microbial communities to a stable state.

Soil temperature is one of the most important environmental factors known to affect the growth of microorganisms and the biological activity of soils. Numerous studies have shown that microbial activities in soil are stimulated by increasing the temperature (Alexander, 1965) [1]. However, the natural environment for microorganisms in the soil is rarely constant as temperatures in the surface layer of cultivated soils undergo wide diurnal and seasonal fluctuations. Very little is known about the relative effect of cyclical as opposed to constant temperatures on biological systems. Studies with pure cultures of fungi (Jensen and Reynolds, 1971) [7] and bacteria (Howell *et al*., 1971) [5] have generally shown that the rate of microbial growth at constant temperature is considerably greater than at fluctuating temperature, particularly if the amplitude of fluctuation exceeds 10^0 C. However, some reports tend to contradict this relationship. Burgess and Griffin (1968) [2] claimed that temperature fluctuation per se does not affect the rate of fungal growth, and Powers *et al*. (1965) [9] reported that bacteria grew faster under cyclical 5-27^0 C than at the constant mean temperature of 16^0 C. However, no systematic study has been carried out on quality protein maize, which is one of the most important cereal crops in Eastern India. To address this lacuna, a comprehensive field experiment was conducted to determine the integrated effect of different irrigation schedule and nutrient management practices on root zone soil temperature at different soil depth as well as to address the soil microbial community at subsequent different temperature regime.

Materials and Methods

The field trial was carried out on quality protein maize (QPM) (Variety 'HQPM 1') during *rabi* seasons (November-March) of 2017-18 and 2018-19 at District Seed Farm, AB Block, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia encompassing the New Alluvial Zone of West Bengal, India. The experiment was laid out in split plot design with three irrigation treatments in main plots *viz.* IW/CPE 0.5 (I_1), IW/CPE 0.75 (I_2) and IW/CPE 1.0 (I_3) and four nutrient management treatments in sub plots *viz.* control (N_1), 100% RDF (120: 60: 60 N: P_2O_5: K_2O kg/ha) (N_2), 75% RDF+ 2 t/ha vermicompost (N_3) and 75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$ (N_4), replicated thrice.

Irrigations at IW/CPE 0.5, 0.75 and 1.0 were given when cumulative pan evaporation (CPE) from an USWB class A open pan evaporimeter reached 100, 67 and 50 mm respectively if no rain occurred between two irrigations. Fertilizer doses were calculated as per treatment and applied to each plot using urea, single super phosphate (SSP) and muriate of potash (MOP).

Entire dose of phosphorus and potassium and 50% recommended dose of nitrogen were applied as basal and remaining 25% N at knee high stage and 25% N at tasseling. $ZnSO_4$ @ 25 kg/ha and vermicompost @ 2 t/ha were given at the time of land preparation. Seed rate used in this experiment for QPM was 20 kg/ha to ensure desired plant population. Row to row spacing was maintained at 45 cm. and plant to plant spacing was adjusted to 20 cm.

Soil temperature measurement

Soil temperature was measured for all the treatments with the help of mercury in glass thermometer (soil thermometer) placed at 5, 15 and 20 cm depth at 13:35 hours. The observations were recorded from each plot at 30, 60, 90 and 120 DAS.

Estimation of microbial population

Composite soil samples from each plot (0-15 cm depth) were collected before sowing and at 30 days interval after sowing *i.e.* 30, 60 and 90 DAS and used for estimation of microbial population. For getting the initial values of microbial population, composite soil samples were collected from the field just after plot preparation. The enumeration of the microbial population was done by serial dilution plate technique (Pramer and Schmidt, 1965) [10]. Serial dilution of the samples was done and suitable aliquots were poured to the selective media. The plates were incubated at 28°C. The counts were taken at 3 days of incubation. The results were reported as number of cells colony forming unit (CFU) per gram of dry soil sample.

Total bacterial count

The total bacterial count was made on Thornton's agar medium (Thornton, 1922) [11]. The pH of the medium was adjusted at 7.4 and sterilised at 15 lbs pressure for 30 minutes.

Total actinomycetes count

Jensen's Agar medium (Jensen, 1930) [6] was used tor actinomycetes. The pH was adjusted to 6.5 to 6.6 and the medium was sterilised at 15 lbs pressure for 30 minutes.

Total fungal count

Martin's Rose Bengal Streptomycin Agar medium (Martin, 1950) [8] was used for counting total fungi. The pH was adjusted to 6.0 to 6.5 and streptomycin was added at the time of plating. A stock solution was prepared for dissolving 10 mg of streptomycin in 2.0 ml of distilled water. The medium was sterilised at 15 lbs pressure for 30 minutes.

Statistical analysis and interpretation of data

Data obtained on various variables were analyzed by 'Analysis of Variance' method developed by Panse and Sukhatme in the year 1967. The total variance (S^2) and d.f. (n-1) were partitioned into different possible sources. The variance due to replications, crops, irrigation regimes, nutrient levels and their interactions were compared with error variance for finding out 'F' values and ultimately for testing the significance at 5 per cent level (P = 0.05). The tested errors for the treatments based on error variance were calculated. Wherever, the results were found to be significant, critical difference (C.D.) was calculated.

Results and Discussion

1. Soil temperature

Soil temperatures were recorded at 5, 15 and 20 cm depth at 30, 60, 90 and 120 DAS during both the years of experimentation and presented in Table 1 and 2. Soil temperature measurement at different soil depths showed varied effect due to irrigation regimes. Generally, soil temperature values at all depths (5, 15 and 20 cm) became lower immediately after irrigation application irrespective of dates of observations in both the study years but the observed trend depicted that soil temperature values at all depths got

increased from 60 DAS towards 120 DAS as the harvesting was approaching. Maximum soil temperature (20.63, 24.69, 30.77 and 41.18^{0}C at 5 cm soil depth; 20.84, 20.94, 25.48 and 36.22^{0}C at 15 cm soil depth; 21.10, 20.32, 24.38 and 32.79^{0}C at 20 cm soil depth during 2017-18 and 21.70, 25.07, 29.49 and 36.01^{0}C at 5 cm soil depth; 21.49, 22.28, 25.63 and 31.83^{0}C at 15 cm soil depth; 21.91, 20.55, 23.44 and 29.40^{0}C at 20 cm soil depth during 2018-19 at 30, 60, 90 and 120 DAS respectively) were recorded in I_3 (IW/CPE 1.0). Nutrient management did not show significant impact on soil temperature variation measured at different soil depth irrespective of the dates of observations and study years. Soil temperature was more on the surface and at 20 cm soil depth the values were less. Interaction effect of irrigation regimes and nutrient levels showed differential effects on soil temperatures measured at various soil depths *i.e.* 5, 15 and 20 cm. It was clearly noted that, N_4 (75% RDF + 2 t vermicompost + 25 kg/ha $ZnSO_4$) showed coolest soil temperatures at all depths applied under each irrigation regime during all dates of observations of both the study years. On the contrary, N_0 (control) followed by N_1 (100% RDF) applied under each and every irrigation regime provided the hottest soil temperatures at all soil depths.

Table 1: Effect of irrigation and nutrient management on soil temperature (^{0}C) at different soil depth (2017-18)

Treatments	At 5 cm				At 15 cm				At 20 cm			
	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS
Irrigation (I)												
I_1	20.63	24.69	30.77	41.18	20.84	20.94	25.48	36.22	21.10	20.32	24.38	32.79
I_2	20.38	23.19	30.07	39.12	20.54	19.95	24.74	34.90	20.79	18.84	23.53	32.09
I_3	19.89	22.01	29.36	37.90	19.63	18.43	24.95	33.84	20.44	17.75	23.18	31.01
Nutrient management (N)												
N_1	20.40	23.56	30.29	39.54	20.52	20.18	25.28	35.21	20.97	19.28	23.87	32.10
N_2	20.42	23.34	30.11	39.43	20.37	19.84	25.18	35.02	20.77	19.09	23.74	32.06
N_3	20.28	23.22	29.98	39.29	20.31	19.66	24.93	34.93	20.72	18.90	23.62	31.94
N_4	20.11	23.07	29.88	39.32	20.14	19.41	24.84	34.78	20.66	18.61	23.54	31.76
Interaction												
I_1N_1	20.73	24.93	31.00	41.40	20.97	21.30	25.70	36.47	21.23	20.63	24.60	32.90
I_1N_2	20.70	24.73	30.80	41.27	20.83	20.93	25.63	36.10	21.10	20.40	24.40	32.90
I_1N_3	20.60	24.67	30.63	40.97	20.77	20.80	25.40	36.23	21.00	20.23	24.30	32.77
I_1N_4	20.50	24.43	30.63	41.07	20.80	20.73	25.20	36.07	21.07	20.00	24.23	32.60
I_2N_1	20.47	23.47	30.23	39.23	20.73	20.40	25.03	35.07	21.00	19.10	23.60	32.23
I_2N_2	20.53	23.23	30.10	39.20	20.60	20.07	24.87	34.93	20.73	18.93	23.60	32.10
I_2N_3	20.37	23.07	30.07	39.03	20.57	19.77	24.53	34.83	20.77	18.80	23.53	32.07
I_2N_4	20.17	23.00	29.87	39.00	20.27	19.57	24.53	34.77	20.67	18.53	23.37	31.97
I_3N_1	20.00	22.27	29.63	38.00	19.87	18.83	25.10	34.10	20.67	18.10	23.40	31.17
I_3N_2	20.03	22.07	29.43	37.83	19.67	18.53	25.03	34.03	20.47	17.93	23.23	31.17
I_3N_3	19.87	21.93	29.23	37.87	19.60	18.40	24.87	33.73	20.40	17.67	23.03	31.00
I_3N_4	19.67	21.77	29.13	37.90	19.37	17.93	24.80	33.50	20.23	17.30	23.03	30.70

Table 2: Effect of irrigation and nutrient management on soil temperature at different soil depth (2018-19)

Treatments	At 5 cm				At 15 cm				At 20 cm			
	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS
Irrigation (I)												
I_1	21.70	25.07	29.49	36.01	21.49	22.28	25.63	31.83	21.91	20.55	23.44	29.40
I_2	20.78	24.01	28.54	35.11	21.05	20.11	24.96	30.33	21.70	18.98	22.84	28.16
I_3	20.33	22.46	27.93	33.57	20.68	18.76	23.94	29.41	21.08	18.03	22.12	27.48
Nutrient management (N)												
N_1	21.21	24.06	28.78	35.03	21.36	20.61	25.01	30.74	21.71	19.41	22.98	28.57
N_2	21.18	23.91	28.71	34.97	21.12	20.49	24.91	30.59	21.60	19.22	22.84	28.43
N_3	20.86	23.76	28.62	34.82	20.98	20.31	24.78	30.47	21.54	19.10	22.80	28.24
N_4	20.51	23.66	28.50	34.76	20.83	20.11	24.67	30.30	21.40	19.00	22.58	28.13
Interaction												
I_1N_1	22.20	25.27	29.60	36.30	21.70	22.43	25.80	31.93	22.10	20.80	23.60	29.70
I_1N_2	22.07	25.10	29.57	36.10	21.50	22.43	25.63	31.90	21.93	20.60	23.43	29.47
I_1N_3	21.57	25.00	29.47	35.87	21.43	22.17	25.60	31.83	21.90	20.43	23.50	29.33
I_1N_4	20.97	24.90	29.33	35.77	21.33	22.07	25.47	31.67	21.70	20.37	23.23	29.10
I_2N_1	21.00	24.20	28.63	35.17	21.40	20.33	25.10	30.60	21.87	19.10	23.03	28.33
I_2N_2	20.90	24.10	28.57	35.13	21.10	20.20	25.03	30.43	21.70	19.00	22.93	28.23
I_2N_3	20.70	23.93	28.53	35.07	20.90	20.07	24.87	30.20	21.70	18.93	22.80	28.07
I_2N_4	20.53	23.80	28.43	35.07	20.80	19.83	24.83	30.10	21.53	18.87	22.60	28.00
I_3N_1	20.43	22.70	28.10	33.63	20.97	19.07	24.13	29.70	21.17	18.33	22.30	27.67
I_3N_2	20.57	22.53	28.00	33.67	20.77	18.83	24.07	29.43	21.17	18.07	22.17	27.60
I_3N_3	20.30	22.33	27.87	33.53	20.60	18.70	23.87	29.37	21.03	17.93	22.10	27.33
I_3N_4	20.03	22.27	27.73	33.43	20.37	18.43	23.70	29.13	20.97	17.77	21.90	27.30

2. Soil microflora

Under soil microflora, population of total bacteria, total actinomycetes and total fungi were recorded before sowing, at 30, 60 and 90 DAS and presented in Fig. 1 to 6. Significant variation in population of total bacteria, actinomycetes and fungi were seen irrespective of the dates of observations and study years except before sowing and 30 DAS. The results revealed that, I_3 (IW/CPE 1.0) recorded the maximum soil microflora population count (219.50 and 222.25 CFU×10^6 of total bacteria; 80.50 and 96.00 CFU×10^5 of total actinomycetes and 4.75 and 8.17 CFU×10^4 of total fungi during 2017-18 and 2018-19 at 60 and 90 DAS respectively) followed by I_2 (IW/CPE 0.75). Lowest population count (207.00 and 204.25 CFU×10^6 of total bacteria; 75.00 and 77.75 CFU×10^5 of total actinomycetes and 2.75 and 3.75 CFU×10^4 of total fungi during 2017-18 and 2018-19 at 60 and 90 DAS respectively) were observed in I_1 (IW/CPE 0.5). Nutrient management treatments also significantly influenced the population of total bacteria, actinomycetes and fungi at 60 DAS and 90 DAS in both the years of experimentation. The results showed that, N_4 (75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$) recorded the maximum soil microflora population count (255.33 and 249.33 CFU×10^6 of total bacteria; 104.00 and 105.33 CFU×10^5 of total actinomycetes and 6.67 and 10.22 CFU×10^4 of total fungi during 2017-18 and 2018-19 at 60 and 90 DAS respectively) followed by N_3 (75% RDF + 2 t vermicompost). However, the lowest microflora population counts (160.67 and 183.00 CFU×10^6 of total bacteria; 56.67 and 69.33 CFU×10^5 of total actinomycetes and 1.33 and 3.22 CFU×10^4 of total fungi during 2017-18 and 2018-19 at 60 and 90 DAS respectively) were observed in N_0 (control) which was significantly lower than N_1 (100% RDF). Interaction effect of different irrigation regimes and nutrient levels showed significant response on the population of total bacteria, total actinomycetes and total fungi at 60 DAS and 90 DAS during both the study years. The results depicted that, I_3N_4 (Irrigation at IW/CPE 1.0 with 75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$) showed highest soil microflora population count (248.00 and 247.00 CFU×10^6 of total bacteria; 112.00 and 115.00 CFU×10^5 of total actinomycetes and 8.67 and 12.67 CFU×10^4 of total fungi during 2017-18 and 2018-19 at 60 and 90 DAS respectively). Irrigation at IW/CPE 0.5 with no nutrient application (I_1N_1) showed lowest microflora population count (168.00 and 176.00 CFU×10^6 of total bacteria; 46.00 and 56.00 CFU×10^5 of total actinomycetes and 1.00 and 2.33 CFU×10^4 of total fungi during 2017-18 and 2018-19 at 60 and 90 DAS respectively). It is hypothesized that soil microflora communities under increasing mineral and organic matter input and sufficient water availability will have better population and communities receiving less input will have a large fraction of the population in an inactive or dormant state. Previous findings showed that soil microbes with a high diversity and richness utilize available resources more efficiently and cope better in fluctuating environments. The high organic and mineral load introduced to the irrigated soil enriched it with a high proportion of active populations.

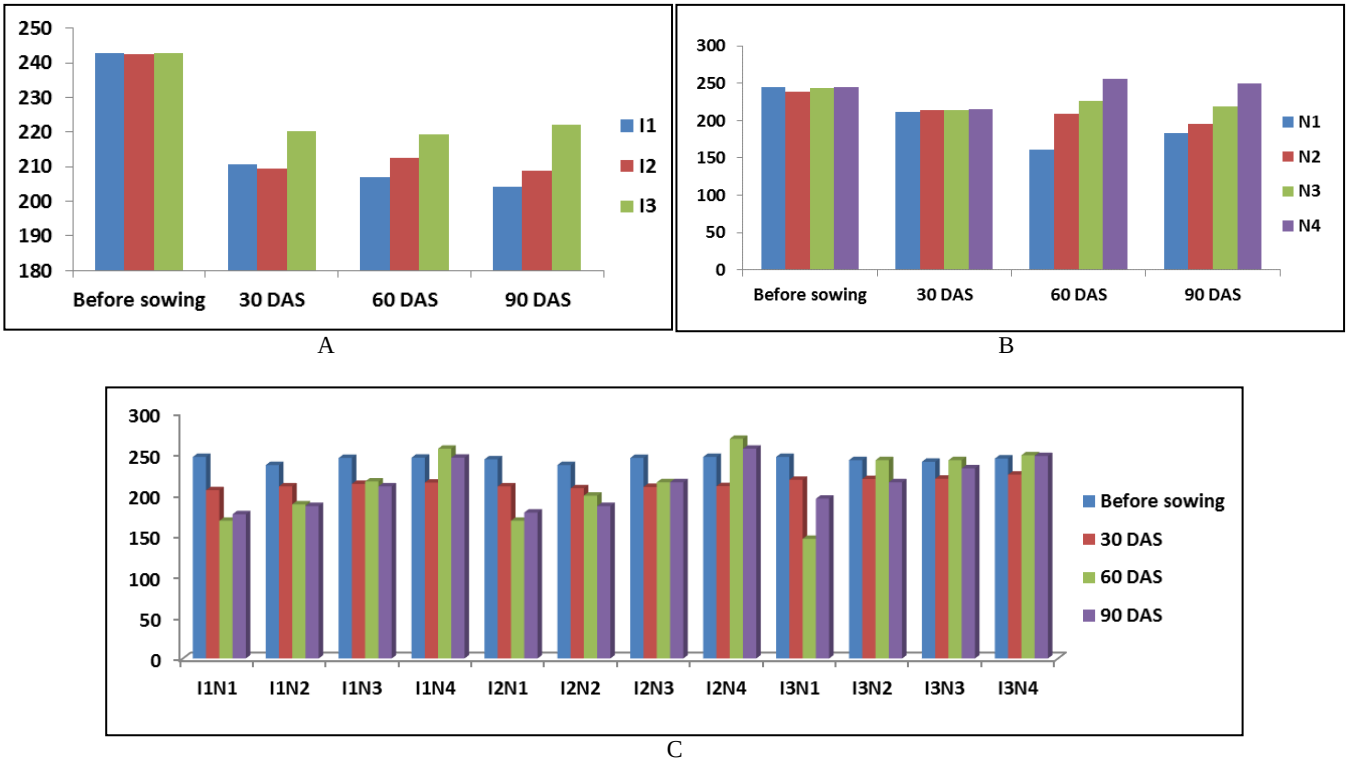
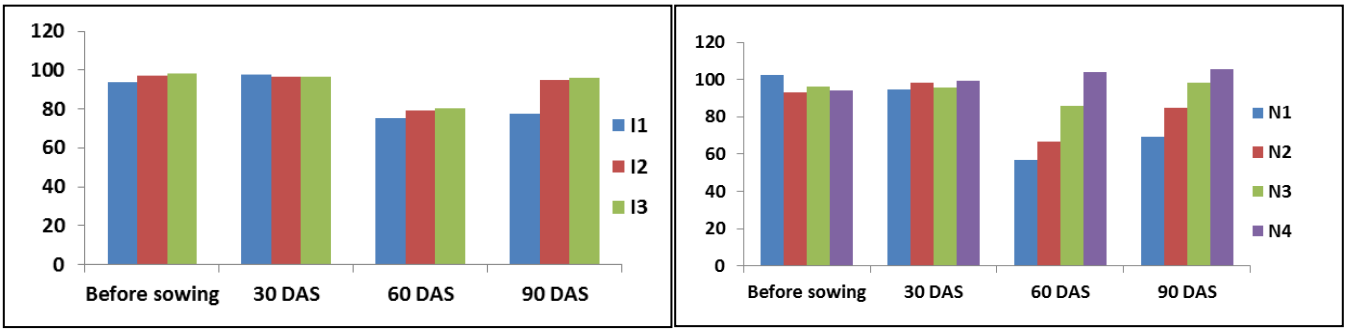


Fig 1: Effect of irrigation and nutrient management on total bacteria (2017-18)



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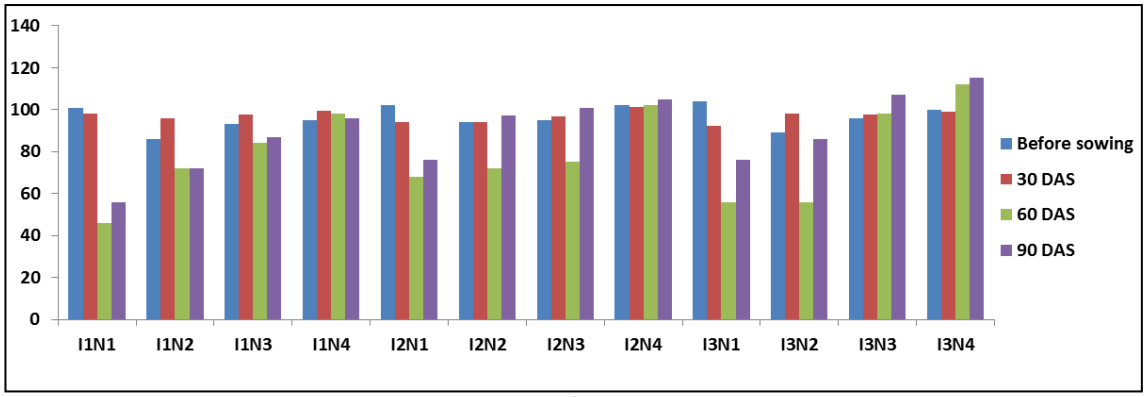

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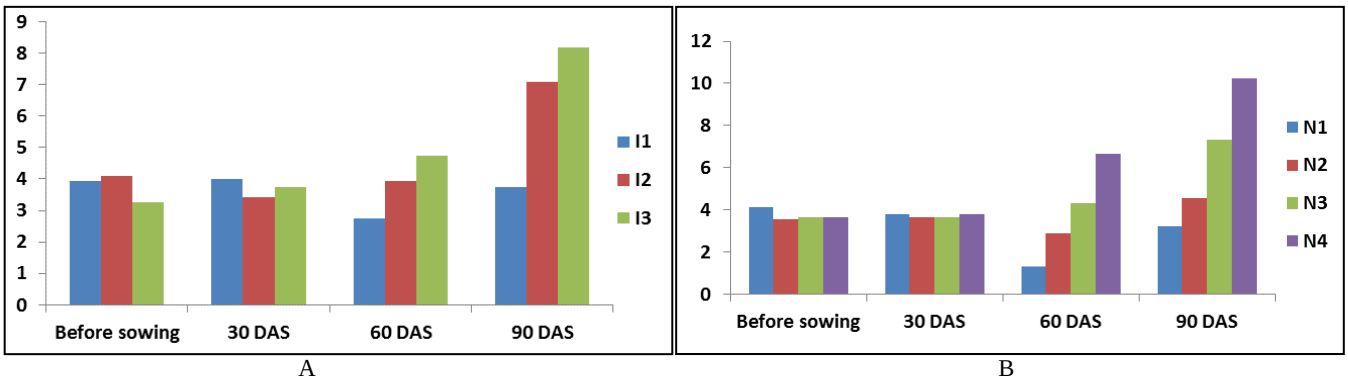
Fig 2: Effect of irrigation and nutrient management on total actinomycetes (2017-18)



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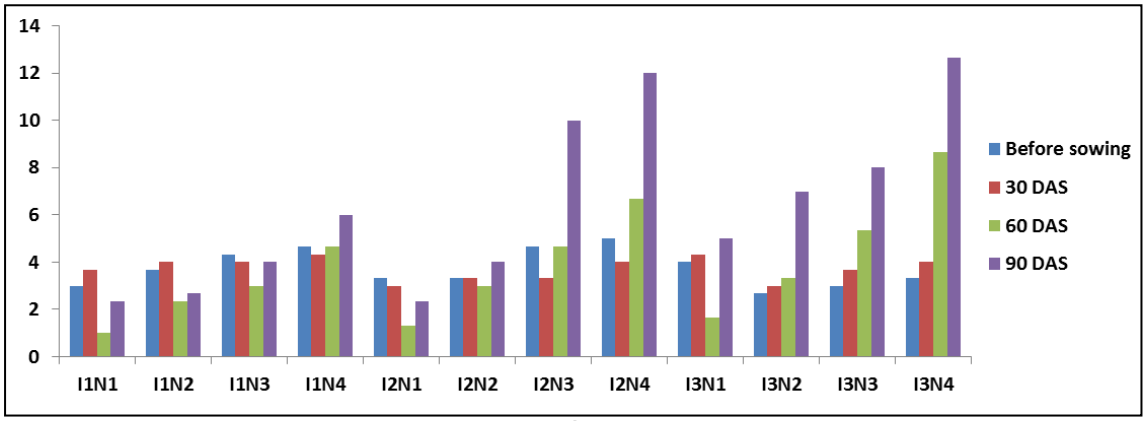

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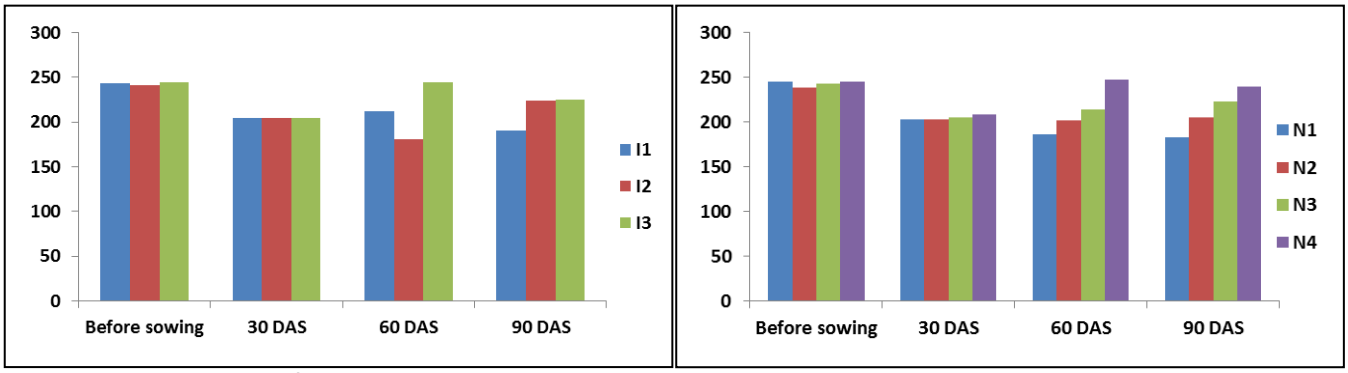
Fig 3: Effect of irrigation and nutrient management on total fungi (2017-18)



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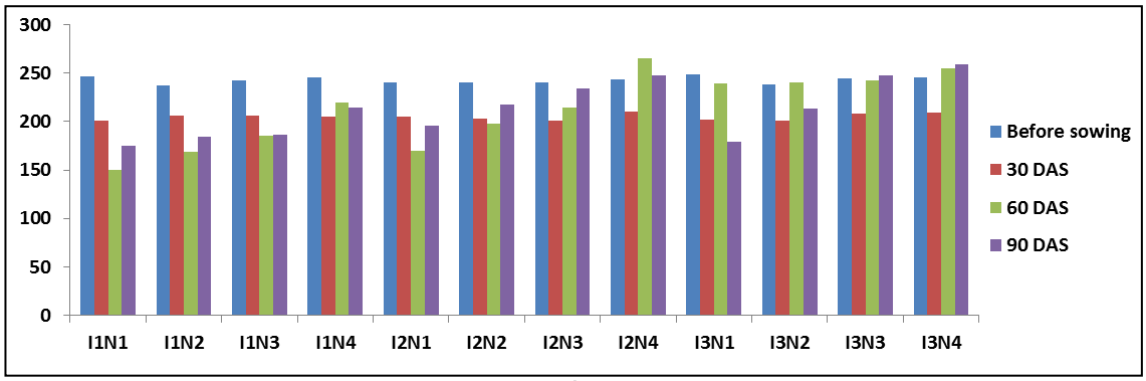

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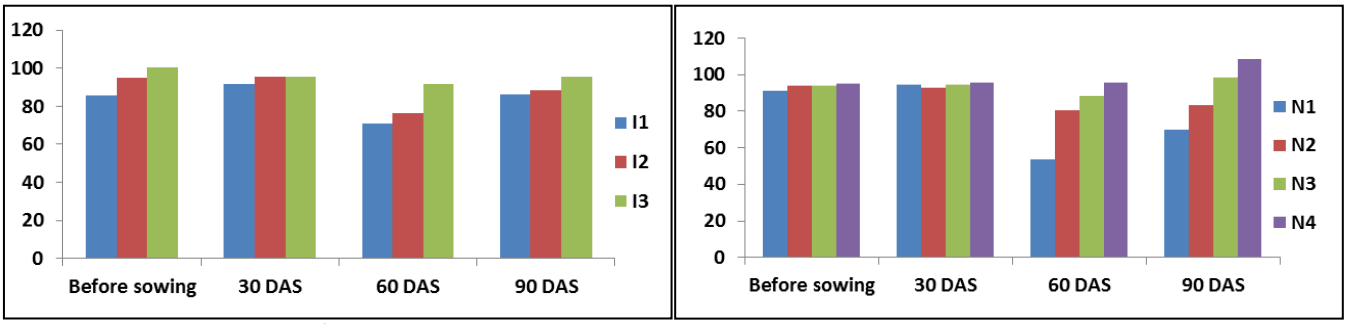
Fig 4: Effect of irrigation and nutrient management on total bacteria (2018-19)



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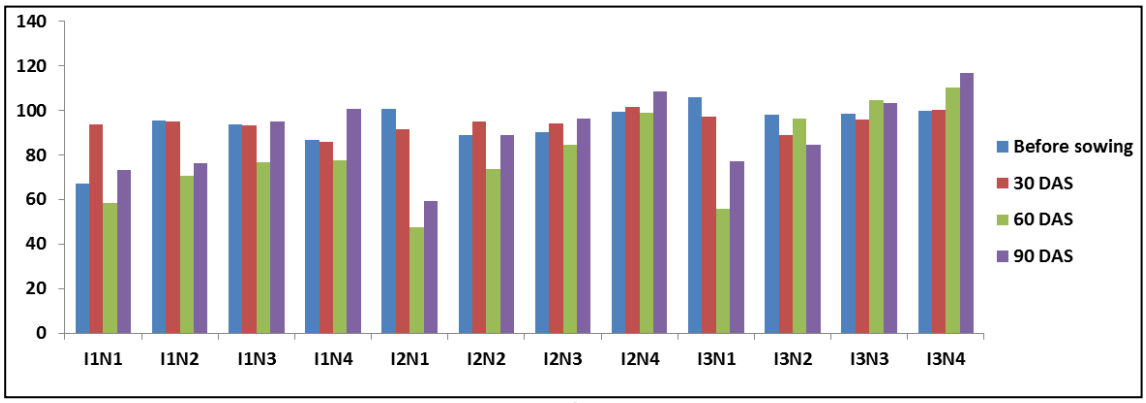

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Fig 5: Effect of irrigation and nutrient management on total actinomycetes (2018-19)

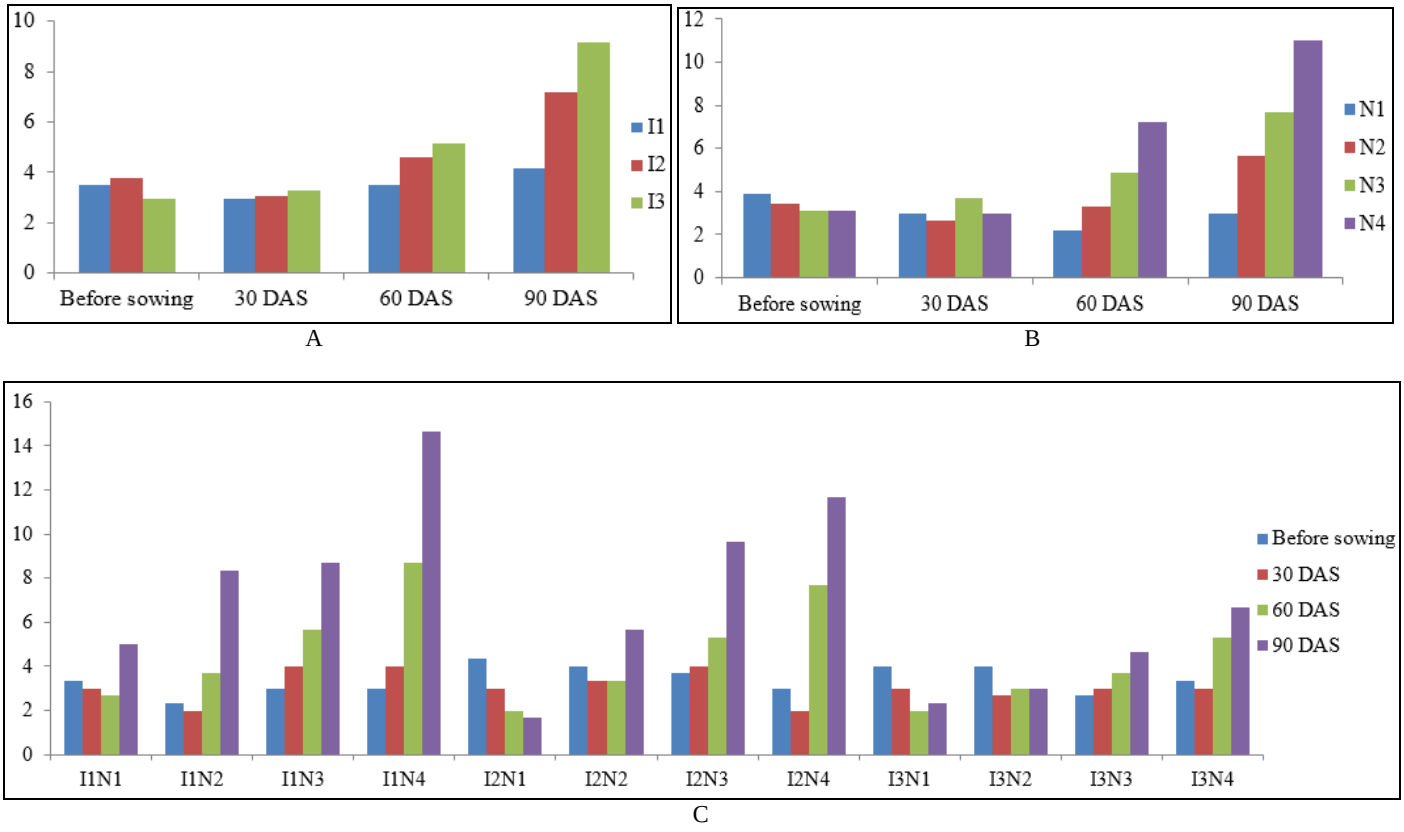
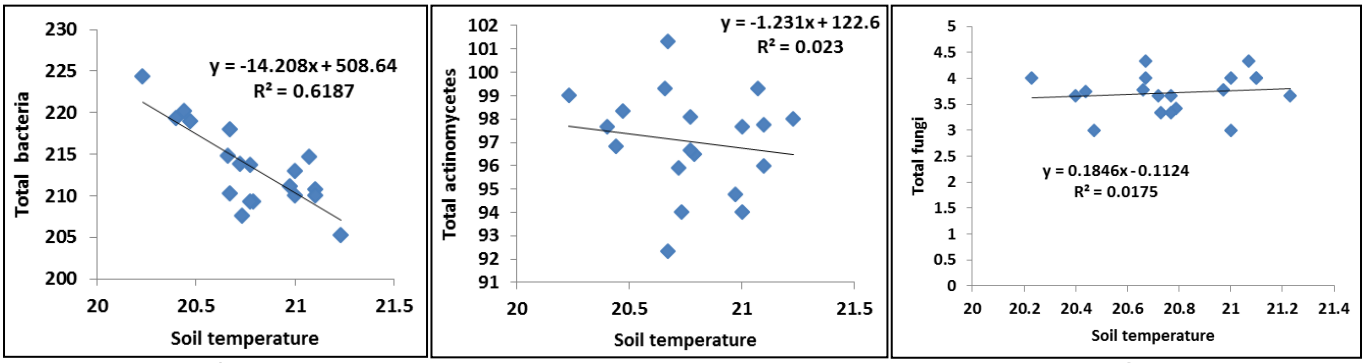


Fig 6: Effect of irrigation and nutrient management on total fungi (2018-19)

3. Effects of soil temperature on rhizosphere micro flora population

In order to study the variation in soil micro flora population in relation to soil temperature, relationships between microbial population and soil temperature were developed which showed that the population of soil microorganisms showed polynomial relationship with temperature at different times. The results at 30, 60 and 90 DAS (Fig. 7 to 12) during both the years of experimentation were not significant hence not considered. But it was observed that the positive response of the bacterial population to the change in soil temperature was considerably greater than the population of fungi and actinomycetes. The slower and weaker response of the actinomycetes and fungi was also reflected by the decline in their relative proportion of the total microflora during this period. The fungal population also changed very minimally in response to the different temperature treatments. As expected, the population did not increase sharply with an increase in fluctuating or constant temperatures. The pattern of population changes in response to different temperature treatments was generally the same for all three groups of soil organisms. During the first year of field trial, the coefficients of determination (R^2) for bacterial, actinomycetes and fungal populations were 0.62, 0.02 and 0.02 at 30 DAS; 0.11, 0.11 and 0.33 at 60 DAS as well as 0.21, 0.46 and 0.47 at 90 DAS respectively. During 2018-19, the coefficients of determination (R^2) for bacterial, actinomycetes and fungal populations were 0.07, 0.13 and 0.01 at 30 DAS; 0.47, 0.29 and 0.01 at 60 DAS as well as 0.45, 0.21 and 0.01 at 90 DAS respectively. Thus it was observed that the model was able to explain very little variation in soil micro flora population due to soil temperature through a polynomial function. The response of soil populations to temperature depends not only on moisture conditions but also on the relative availability of nutrients. It is reasonable to assume that this flush in nutrient availability rendered the substrate level non-limiting for microbial growth at any of the soil temperatures for the short duration of the experiment, because the increase in population observed at increased temperatures imply a direct positive relationship between temperature and population growth. The unusually small responses of the actinomycetes and fungal populations are probably a reflection of the particular conditions: (1) the relatively high soil moisture content was likely unfavourable for the vegetative as well as the sporogenous development of them and consequently created a competitive disadvantage in contrast to bacterial growth; (2) the temperature requirements of actinomycetes and fungi are generally higher than those of other mesophilic microorganisms and even the highest temperatures recorded in this study were still considerably below the optimum range for the growth of common soil actinomycetes and fungi.

Relationship between soil temperature and rhizosphere micro flora



A B C

Fig 7: Relationship between soil temperature and rhizosphere micro flora during 2017-18 at 30 DAS (a) Total bacteria (b) Total actinomycetes (c) Total fungi

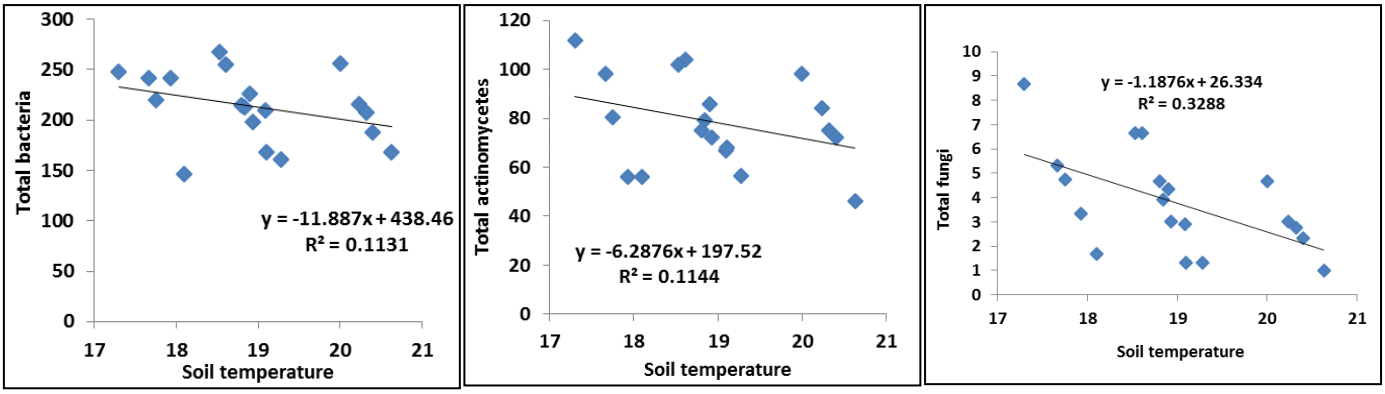
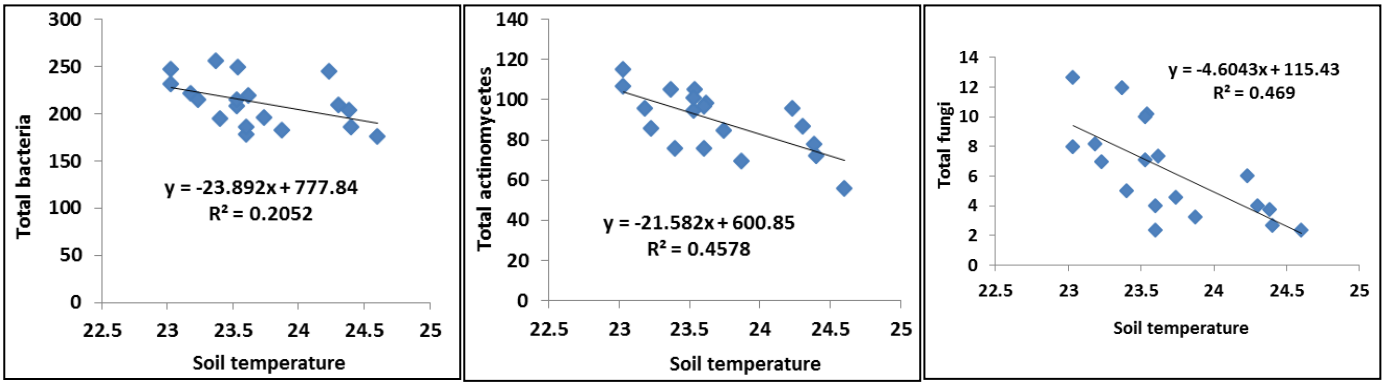


Fig 8: Relationship between soil temperature and rhizosphere micro flora during 2017-18 at 60 DAS (a) Total bacteria (b) Total actinomycetes (c) Total fungi



A B C

Fig 9: Relationship between soil temperature and rhizosphere micro flora during 2017-18 at 90 DAS (a) Total bacteria (b) Total actinomycetes (c) Total fungi

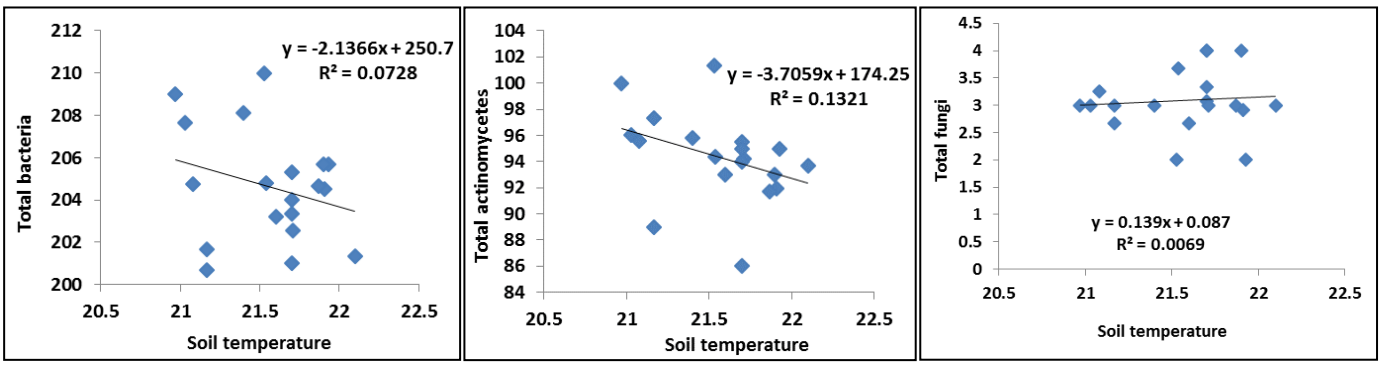


Fig 10: Relationship between soil temperature and rhizosphere micro flora during 2018-19 at 30 DAS (a) Total bacteria (b) Total actinomycetes (c) Total fungi

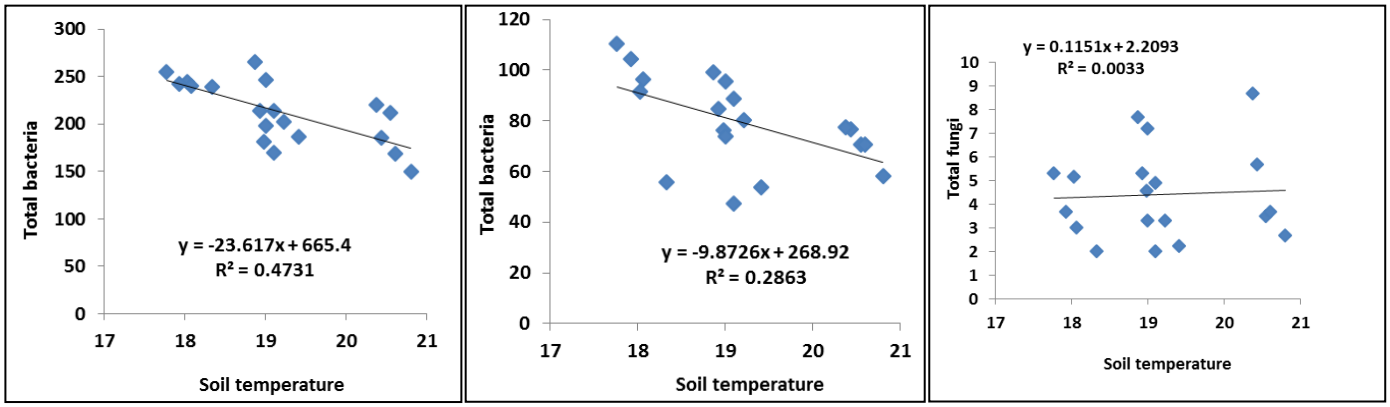


Fig 11: Relationship between soil temperature and rhizosphere micro flora during 2018-19 at 60 DAS (a) Total bacteria (b) Total actinomycetes (c) Total fungi

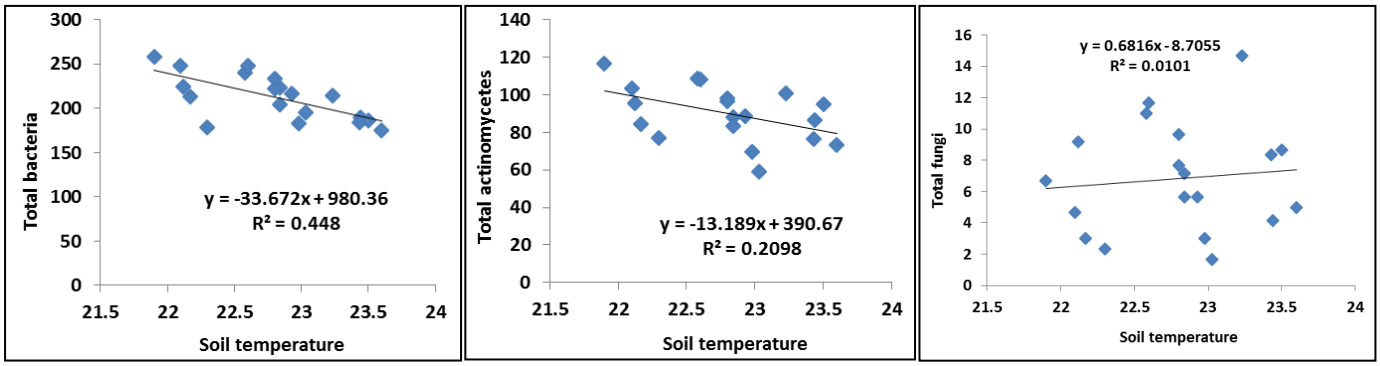


Fig 12: Relationship between soil temperature and rhizosphere micro flora during 2018-19 at 90 DAS (a) Total bacteria (b) Total actinomycetes (c) Total fungi

Conclusion

This study shows that the application of irrigation at IW/CPE 1.0 may help to reduce root zone soil temperature and improved soil micro flora population, which may translate into improved plant growth and yield in regions where high soil temperature can be a factor limiting plant growth and development. On the other hand, N_4 (75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$) exhibited the highest microbial populations due to periodic release of plant nutrients. It has implications for mitigating the negative impacts of warming trends to agriculture. However, additional and more comprehensive characterization of the biophysical processes, such as soil-plant system heat flux and balance, and plant physiological changes, such as carbon metabolism and balance, are needed in order to determine mechanisms leading to the observed plant growth benefits due to the adoption of alternative irrigation strategy.

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