Impact of Fertilizer, Herbicide, Algicide and Fungicide on Soil Microbial and Enzyme Activities in Maize and Rice Ecosystem

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Impact of Fertilizer, Herbicide, Algicide and Fungicide on Soil Microbial and Enzyme Activities in Maize and Rice Ecosystem

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ABSTRACT

To increase crop productivity, modern agricultural practices comprise fertilisers, algaecides, herbicides and fungicides. Fertiliser application profoundly impacts soil microbes and enzymes, with organic fertilisers generally promoting beneficial microbial communities and enzyme activities like phosphatase and dehydrogenase, while high-dose inorganic fertilisers can lead to negative effects, such as reduced microbial richness and inhibition of certain enzyme activities, often altering soil nutrient availability and pH. Long-term studies show that organic amendments can enhance microbial biomass and functional diversity, supporting nutrient cycling, while mineral fertilisers, especially in excess, may negatively affect soil health and microbial respiration. Fungicide application negatively impacts soil health by reducing microbial biomass, decreasing fungal populations, altering microbial community structure, and inhibiting enzyme activities, such as phosphatases, dehydrogenases, and ureases. These effects disrupt soil fertility and ecological functions, although the specific impact depends on the fungicide's type, dose, persistence, and soil conditions. Algicide application can negatively impact soil microbes and enzyme activities, decreasing microbial populations and altering community structure due to

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toxicity, while simultaneously affecting key enzymes like urease, phosphatase, and catalase involved in nutrient cycling and organic matter breakdown. However, studies show a complex relationship, with algicides sometimes causing an initial increase in certain microbial populations before a decline, highlighting the importance of application rates and exposure time. The overall effect can lead to reduced soil fertility and long-term ecological consequences. Herbicide application generally alters soil microbial communities and enzyme activities, often with an initial inhibitory effect on microbial respiration and enzyme activity, though this can be temporary. The specific impact varies significantly based on the herbicide's type, dose, and soil conditions. Some herbicides can be particularly detrimental to beneficial microbes, slowing crucial processes like nitrogen cycling, while others may promote the growth of specific microbes involved in herbicide breakdown. Combined herbicide applications often intensify negative effects, and long-term exposure can shift microbial community composition and function, influencing soil health and fertility.

The purpose of this study was to evaluate the effects of soil microbial population and soil enzyme activity by the use of fertiliser in maize and inorganic input in the rice ecosystem.

A field experiment (2021 to 2023) was carried out using synthetic fertiliser doses with maize crops, followed by rice crops using inorganic inputs. Soil microbial population and enzyme activities were examined.

Maize field experiment revealed that the plots treated with 75 % Standardised Dose of Fertiliser (SDF) of NPK had the highest populations of diazotrophs (124 × 10^5cfu / g), Phosphobacteria (66.33 × 10^5cfu / g), and *Azospirillum* (0.409 × 10^5 MPN / g) than 100 % and 150 % SDF of NPK. The soil enzyme activity was higher in the unfertilized control plot than fertilised plot. These experimental results revealed that a low amount of fertiliser and no fertiliser favour the growth of soil microorganisms and soil enzyme activities, respectively. Followed by the rice field experiment, revealed that the soil microbial population was decreased by the application of inorganic inputs viz., fertiliser, algaecide, herbicide and fungicide. However, the maximum soil microbial population was found in algaecide application, followed by herbicide and fungicide.

The field experiment concluded that soil microbial population and enzyme activity were affected by inorganic amendments. Less inorganic fertilisers and no fertilisers improve soil microbial activities and soil enzyme activities.

Keywords: Fertiliser; algaecide; herbicide; fungicide; microbial population; soil enzyme activities.

ABBREVIATIONS

SDF : Standardized Dose of Fertilizers (N:P:K)
DAT : Days After Transplanting;
DAS : Days After Sowing.

1. INTRODUCTION

Soil microorganisms, which include bacteria, fungi, archaea, viruses, protozoa, and microscopic algae, play a critical role in maintaining soil health and fertility

(Chen et al., 2024). Fertilisers, derived from mineral, synthetic, and organic sources, have played a crucial role in modern agriculture by significantly increasing crop yields, thus ensuring essential human nutrition, global food security, crop quantity and quality, and sustainable soil management (Tagkas et al., 2024). However, the extended application of inorganic fertilisers produces a negative impact on the soil biota and reduces the variety of microorganism species, which facilitates the emergence of niches for the colonisation of pathogenic organisms. In addition to providing plants with a variety of available and necessary compounds, soil microorganisms are essential for the cycling of nitrogen. Nitrogen is a vital nutrient required for the synthesis of proteins, nucleic acids, and chlorophyll in plants (Fathi, 2022). Soil microbes also mineralise the essential plant nutrients in the soil to improve crop productivity, produce plant hormones that stimulate the plant's immune system, encourage growth, and activate stress responses (Ogidi & Akpan, 2023; Meena et al., 2020). The quantity and activity of microorganisms have dramatically decreased since the development of agricultural science and the spray of pesticides, fungicides, fertilisers, and herbicides, leading to subpar plants and crop yields. Therefore, research on the activity of soil microorganisms is concentrated as agricultural activities become more intense. The purpose of fertilisers, particularly synthetic ones, is to boost crop yield. Over-application of inorganic fertilisers can cause water contamination, soil acidification, ammonia volatilisation, denitrification, air pollution, and agricultural product quality degradation (Zhang et al., 2013).

Variability in soil microbial communities may result from improper farming methods such as overusing chemical fertilisers and pesticides and frequent land use changes, which can have a substantial impact on soil fertility and productivity (Onet et al., 2016). On the other hand, organic farming with the use of environmentally friendly organic fertilisers (such as compost, manure, and microbial fertilisers (Onet et al., 2019) can be a good substitute and help lessen the negative effects of synthetic fertiliser pollution on the environment. Wen et al. (2015) reported that the *Fusarium oxysporum f. sp. cubense population* was varied in the flooded and organic amendment soil. Luo et al. (2015) reported that monocultures maintained for extended periods without the addition of organic fertilisers or crop rotation, long-term mineral fertiliser applications cause a considerable loss in soil organic matter. It has also been discovered that mineral fertilisation reduces the porosity and nutrient availability of the soil (Song et al., 2015). Furthermore, the quantity of microorganisms and the qualitative selection of entire communities of soil microorganisms are both significantly impacted by mineral fertilisation (Bharathi et al., 2024). By reducing internal biological cycles and pest control, the use of synthetic fertilisers and herbicides alters interactions within and between below- and above-ground components of the soil microbial community, ultimately increasing the negative environmental impacts of agriculture (Dincă et al., 2022).

Applying herbicides to soil microorganisms can inhibit, activate, or have no effect at all. Bezuglova et al. (2019) showed that foliar application of sulfonylurea herbicide decreased the abundance of bacteria, especially for the quickly growing ones, on winter wheat soil. Chen et al. (2021) reported that sterane first

decreased soil bacterial diversity and abundance in maize fields 10 days after sowing, but increased them 60 days after application. Herbicides changed the population and diversity of the cultivatable soil bacteria, actinomycetes, and fungi, according to research done by Borowik et al. (2017) after applying a mixture of herbicides consisting of terbuthylazine, S-metolachlor, and mesotrione to pot culture maize soil (Bezug et al., 2017). According to Borowik (2017), the spray of sulfonylurea herbicide on winter wheat soil caused stress on the soil, which in turn affected the plants and soil bacteria. Herbicides may affect the soil microbial diversity by changing the plant root growth and root exudate secretion, since it is well known that plant root exudates regulate the soil microbial community.

The growth of microbial groups involved in the transformation or breakdown of the pesticide may change the structure of the microbial community, while the decline of sensitive groups may occur (Bharathi et al., 2024)**.** Pesticide introduction into the soil environment can initiate mechanisms that promote, inhibit, or suppress soil microbial activity. Certain pesticides can inhibit or even eradicate specific microbial populations, while other pesticides promote the growth of specific soil microorganism populations. The capacity of microorganisms to break down crop protection products or alter the microbial community composition is responsible for those alterations. The bioavailability of insecticides is one of the key factors that determines how they affect microbes that live in soil (Bharathi et al., 2024). According to Mehjin (2019), insecticides reduced the number of bacteria in all pesticide types and throughout all incubation times. According to Mehjin, the application of Glyset (Glyphosate 48 %) at 50 ppm, 100 ppm, and 200 ppm reduced the number of bacteria by 4 %, 11 %, and 13 %, respectively, during the first 7 days of incubation.

In contrast, the number of bacteria reduced by 6 %, 9 %, and 9 %, respectively, at the seventh week of incubation. Even at 100 and 200 ppm, this depression was noteworthy (Bharathi et al., 2024). These findings support the findings of (Newman et al., 2016), which found that glyphosate reduced the population of acid bacteria, microbial biomass, and the total number of bacteria. They thought that a protracted decline in the bacterial population might weaken some of the biogeochemical reactions that these microbes were able to carry out.

With this background, the research was focused on finding the impact of inorganic input sources on soil microbial and enzyme activities.

2. MATERIALS AND METHODS

2.1 Field Experiment with Maize and Rice

Maize and rice field experiments were carried out at the Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai. The maize field experiment's specifics were as follows: Blocks with Randomised Designs Create, Season: 2021 Kharif; Crop: Maize (COMH 1). Five treatments total; three replications; Seeding date: 10.08.2021; Harvest date: 20.11.2022. Dosage of

fertiliser: 150: 75:75 kg NPK/ha as Urea, Single Super Phosphate, and Muriate of potash. The following are the specifics of the treatment. T_1: Unfertilized and uninoculated control, T_2: 75 % of NPK SDF; T_3: 100 % of NPK SDF; T_4: 150 % of NPK SDF; and T_5: 100 % SDF of NPK (Water soluble fertilisers) (Bharathi et al., 2024).

The same field followed rice experiment specifics as follows: Blocks with Randomised Block design, Season: 2022–2023 Kharif; Crop: Rice (ADT 43); Ten treatments; three replications. DOT: 25.11.2022; Harvest date: 05.03.2023. The rate of fertiliser application was 150:50:50 kg NPK/ha. N was applied in two top dressings of 25 % each during the active tillering and panicle initiation stages, with 50 % acting as the basal dressing. The experimental plot was set up to be 3 × 4 m with 2 seedlings per hill. The following are the specifics of the treatment. T_1: Sodium bispyriphos, T_2: Almix, T_3: Pyrosulfuran T_4: Londox power, T_5: $CuSO_4$, T_6: CaO, T_7: $CuSO_4$ + CaO, T_8: Butachlor, T_9: Propiconaole, T_{10}: Hexaconazole and T_{11} – Control (Bharathi et al., 2024).

Rhizosphere soil samples (3 replications) were collected from the test crops (maize and rice) fields for analysing soil microbial diversity and enzyme activity. Collected soil samples were kept 5°C in a BOD incubator.

2.2 Specifics of the Microbial Diversity and Soil Enzyme Observations

Maize rhizosphere soil samples were collected and analysed to count Phosphobacteria (Srinivasan et al., 2012), diazotrophs (Islam et al., 2010), and *Azospirillum* (Bashan and Levanony, 1985). Four soil enzymes were measured for their activities: dehydrogenase (Mała-Chowska-Jutsz and Matyja, 2019), acid phosphatase (Margalef et al., 2017), alkaline phosphatase (Margalef et al., 2017), urease (Tabatabai and Bremner, 1972) and nitrogenase (Pay´a-Tormo et al., 2022).

A 50 g rhizosphere soil sample was taken from a rice field at 30, 60, and 90 days after transplanting (DAT) to count actinomycetes (Malcolm et al., 2018), fungi (Ameh and Kawo, 2017), and bacteria (Ameh and Kawo, 2017). The survival of *Azospirillum* (Bashan and Levanony, 1985) and Phosphobacteria (Srinivasan et al., 2012) in the rhizosphere of ADT 43 was estimated as per the reference cited. *Pseudomonas* population was estimated by following the procedure given by Deredjian et al. (2014).

3. RESULTS

3.1 Chemical Fertilisers on the Survival of Soil Microorganisms and the Soil Enzymes in a Maize Field

Utilising 75 %, 100 %, and 150 % recommended doses of NPK fertiliser, we examined the effects of synthetic fertiliser input sources on the populations of total diazotrophs, *Azospirillum*, and Phosphobacteria in the rhizosphere of maize (COMH 1) as well as soil enzymatic activities, including urease, dehydrogenase, acid phosphatase, and alkaline phosphatase (Bharathi et al., 2024).

3.1.1 Chemical fertilizers on the population of Phosphobacteria, Azospirillum, and total Diazotrophs in the Maize rhizosphere (COMH 1)

The experiment result revealed that compared with a higher dose of 150 % SDF of NPK-treated plot, 75 % SDF of NPK recorded, maximum rhizosphere microbial population, viz*.,* total diazotrophs (124.33 × 10^5cfu/g), *Azospirillum* (0.409 × 10^5 MPN/g), and Phosphobacteria (66.33 × 10^5cfu/g). Whereas, 150 % SDF of NPK-treated plot recorded, less microbial population *viz*., diazotrophs (31 × 10^5cfu/g), *Azospirillum* (0.299 × 10^5 MPN/g), and Phosphobacteria (39 × 10^5cfu/g) than 100 and 75 % SDF of NPK (Tables 1–3). To a certain extent, the usage of chemical pesticides and fertilisers serves a purpose because of their capacity to release nutrients quickly and promote faster and more effective plant growth (Sneha et al., 2018). However, frequent application of chemical fertilisers causes the soil's fertility to gradually decline and its quality to deteriorate. This can also result in the build-up of heavy metals in plant tissue, which can impact the yield's nutritional value and edibility (Farnia and Hasanpoor, 2015).

Due to a decrease in root growth and root exudations, the maximum microbial populations were observed during the vegetative growth stage, which subsequently declined from the flowering to the harvesting stage.

3.1.2 Chemical fertilizers on the rhizosphere soil's urease, dehydrogenase, acid, and alkaline phosphatase and nitrogenase enzyme activities in the maize rhizosphere (COMH 1)

Compared to the 75 %, 100 % and 150 % SDF of the NPK-treated plot, the control plot (without fertiliser) showed higher soil enzyme activities, *viz*., urease (79.6 µg of NH_4/g/24 h), dehydrogenase (110 µg of TPF/g/ 24 h), acid phosphatase (251 µg of p – nitrophenol/g/hr), and alkaline phosphatase (811 µg of p – nitrophenol/g/hr). The 150 % SDF of the NPK-treated plot showed the highest inhibition of soil enzyme activities, viz., urease (55 µg of NH_4/g/24 h), dehydrogenase (69 µg of TPF/g/24 h), acid phosphatase (151 µg of p – nitrophenol/g/hr), and alkaline phosphatase (585 µg of p – nitrophenol/g/hr) than 75 and 100 % SDF of NPK.

This might be due to the higher dose of fertiliser leading to more enzyme-substrate complexes, which suppress the normal enzymatic function in the soil. (Fig. 1) (Bharathi et al., 2024).

Compared to the fertilised plot, the unfertilized and uninoculated control plots showed the highest nitrogenase activity (1913.30 µmol of C_2H_4/g of soil/hr), followed by the 75 % SDF of NPK (1802.60 µmol of C_2H_4/g of soil/hr). There was a significant variation was observed between fertilised and unfertilised plots. Out of all the treatments, 150 % SDF of NPK showed a higher degree of nitrogenase activity inhibition (953.70 µmol of C_2H_4/ g of soil/hr) than the other treatments (Fig. 2) (Bharathi et al., 2024). This might be due to the increased amount of N fertilisers showing inhibitory role on nitrogenase activity. The results declared that the addition of fertiliser disturbs the soil enzyme activities, and the native soil ecosystems support the positive impact on soil enzyme activity than fertiliser application.

Table 1. Chemical fertilizer on the survival of *Azospirillum* in the rhizosphere of soil planted with maize (COMH 1)

***Azospirillum* population (×10^{5}MPN/g) Treatments**	**Vegetative growth stage**				**Flowering stage**				**Harvesting stage**			
	14 DAS	**21 DAS**	**28 DAS**	**Mean**	**42 DAS**	**49 DAS**	**56 DAS**	**Mean**	**70 DAS**	**77 DAS**	**85 DAS**	**Mean**
T1- uninoculated and unfertilized control	0.063	0.763	0.253	0.359	0.241	0.117	0.103	0.153	0.053	0.021	0.018	0.0306
T2 – 75 % SDF of NPK	0.323	0.466	0.479	0.409	0.439	0.357	0.264	0.353	0.156	0.133	0.042	0.110
T3-100 % SDF of NPK	0.303	0.479	0.425	0.402	0.187	0.097	0.061	0.115	0.049	0.042	0.025	0.038
T4-150 % SDF of NPK	0.173	0.363	0.363	0.299	0.175	0.073	0.039	0.095	0.033	0.028	0.019	0.260
T5-100 % SDF of NPK (water-soluble fertiliser)	0.281	0.358	0.295	0.311	0.284	0.274	0.163	0.240	0.067	0.029	0.022	0.039
SE_d	0.29	0.32	0.31	0.306	0.30	0.28	0.27	0.283	0.26	0.24	0.23	0.243

SEd: Standard Error deviation

Table 2. Chemical fertiliser on the survival of Phosphobacteria in the rhizosphere of soil planted with maize (COMH 1)

Phosphobacteria population (×105cfu/g) Treatments	**Vegetative growth stage**				**Flowering stage**				**Harvesting stage**			
	14 DAS	**21 DAS**	**28 DAS**	**Mean**	**42 DAS**	**49 DAS**	**56 DAS**	**Mean**	**70 DAS**	**77 DAS**	**85 DAS**	**Mean**
T1- uninoculated and unfertilized control	54	65	45	54.66	42	16	15	24.33	13	10	8	10.33
T2 – 75 % SDF of NPK	61	73	65	66.33	61	37	30	42.66	25	13	11	16.33
T3-100 % SDF of NPK	43	60	45	49.33	32	21	20	24.33	16	14	8	12.66
T4-150 % SDF of NPK	38	52	27	39.00	26	19	17	20.66	13	9	5	2.90
T5-100 % SDF of NPK (Water-soluble fertiliser)	58	69	53	60.00	51	23	26	33.33	21	11	10	14
SE_d	0.46	0.46	0.45	0.45	0.30	0.43	0.43	0.436	0.43	0.41	0.40	0.413

SEd: Standard error deviation

Table 3. Chemical fertiliser on the population of diazotrophs in the rhizosphere of soil planted with maize (COMH 1)

Diazotrophs population (×105cfu/g) Treatments	Vegetative growth stage				Flowering stage				Harvesting stage			
	14 DAS	21 DAS	28 DAS	Mean	42 DAS	49 DAS	56 DAS	Mean	70 DAS	77 DAS	85 DAS	Mean
T1- uninoculated and unfertilized control	33	38	50	40.33	45	39	16	33.33	14	13	12	13.00
T2 – 75 % SDF of NPK	111	129	133	124.33	62	46	21	43.00	19	17	15	17.00
T3-100 % SDF of NPK	85	116	126	109.00	38	33	13	28.00	12	11	9	10.66
T4-150 % SDF of NPK	35	45	55	45.00	31	30	16	25.66	11	10	8	9.66
T5-100 % SDF of NPK (water soluble fertilizer)	53	63	75	63.66	52	41	19	37.33	16	14	13	14.33
SE_d	0.46	0.46	0.47	0.463	0.45	0.45	0.42	0.44	0.42	0.41	0.41	0.413

SEd: Standard error deviation

Table 4. Wetland rice ecosystem: weedicides, fungicides, and algaecides application on microbial population in the rhizosphere of soil cropped with rice (ADT 43)

Treatments	Bacteria (×104cfu/g)				Fungi (×103cfu/g)				Actinomycetes (×102cfu/g)			
	30DAT	60DAT	90DAT	Mean	30DAT	60DAT	90DAT	Mean	30DAT	60DAT	90DAT	Mean
T_1 - Bispyriphossodium (H)	28	16	9	17.66	6	4	0	3.3	25	16	8	16.33
T_2–AlmixH)	35	29	21	28.33	21	13	6	13.3	19	13	6	12.66
T_3 -Pyrosulfuran (H)	31	25	13	23.0	13	9	4	8.66	14	10	5	9.66
T_4 - Londox power (H)	33	28	21	27.33	23	16	8	15.66	11	8	6	8.33
T_5 - ButachlorH)	35	27	16	26.00	26	17	10	17.66	24	15	12	17.00
T_6 -$CuSO_4$(A)	41	33	16	30.00	28	18	12	19.33	28	20	9	19.00
T_7-CaO(A)	33	26	18	25.66	26	16	9	17.00	26	16	7	16.33
T_8 -$CuSO_4$ + CaO(A)	36	29	23	29.33	19	13	5	12.33	28	19	13	20.00
T_9 –Propiconaole (F)	29	1 8	9	18.66	23	15	7	15.00	23	12	8	14.33
T_{10} -Hexaconazole (F)	33	24	12	23.00	21	13	8	14.00	20	9	7	12.00
T11 - Control	120	80	60	86.60	20	10	5	11.66	25	12	5	14.00
SEd	1.93	1.49	0.93	1.45	1.23	0.79	0.41	0.81	1.20	0.75	0.44	0.796

Note: SEd: Standard error deviation, H = herbicide, A = Algaecide, F = Fungicide

Table 5. Weedicides' effect on the wetland rice ecosystem on beneficial microbial population in the rhizosphere of soil

Treatments	Phosphobacteria (×104cfu/g)				*Azospirillum* (×10^5 MPN/g)				*Pseudomonas* (×10^{4}cfu/g)			
	30DAT	60DAT	90DAT	Mean	30DAT	60DAT	90DAT	Mean	30DAT	60DAT	90DAT	Mean
T_1 - Bispyriphossodium (H)	16	11	5	10.66	1.3	1.0	1.1	1.13	19	8.0	6	11.00
T_2–Almix (H)	26	19	11	18.66	1.5	0.9	0.2	0.86	26	21	19	22.00
T_3–Pyrosulfuran (H)	19	13	7	13.00	2.6	1.5	0.6	1.56	26	21	13	20.00
T_4 - Londoxpower (H)	27	21	11	19.66	2.6	1.9	0.7	1.73	24	19	12	18.33
T_5 – Butachlor (H)	21	15	8	14.66	2.6	1.7	0.7	1.66	36	29	16	27.00
T_6 -$CuSO_4$(A)	31	26	13	23.33	2.9	1.9	1.0	1.93	41	33	23	32.33
T_7–CaO (A)	29	21	13	21.00	2.3	1.6	0.2	1.36	31	26	17	24.66
T_8 -$CuSO_4$ + CaO (A)	28	21	13	20.60	1.5	0.9	0.2	0.86	37	31	23	30.33
T_9 –Propiconaole (F)	18	13	7	12.66	1.9	1.6	1.1	1.53	25	23	12	20.00
T_{10} -Hexaconazole (F)	13	7	3	7.66	1.5	0.9	0.6	1.00	21	16	9	15.33
T_{11} - Control	40	20	10	23.3	30	20	10	20	160	120	90	123.30
SEd	1.35	1.02	0.52	0.963	0.12	0.08	0.042	0.080	1.66	1.33	0.86	1.28

SEd: Standard error deviation; Note: H = herbicide, A = Algaecide, F = Fungicide.

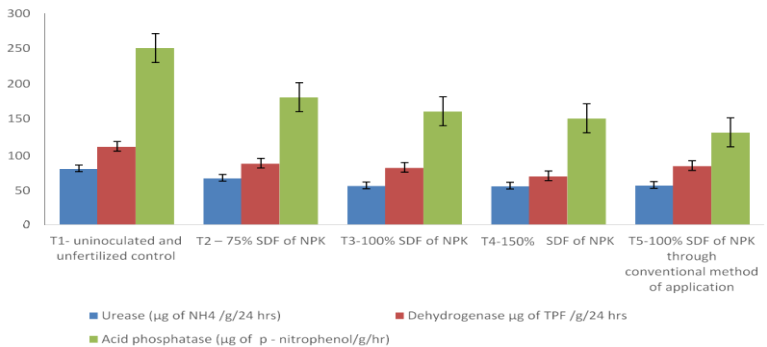

Fig. 1. Chemical fertilizer on urease, dehydrogenase and acid phosphatase activities in the soil planted with maize (COMH 1)

3.2 Inorganic Inputs on Soil Microbial Population's Survival in Rice Fields

Algaecide, herbicide, and fungicide were applied during the rice field experiment. It investigated how the inorganic input affected the population of soil microbes.

3.2.1 In rice fields, the recommendation of algaecide, herbicide and fungicide application on the microbial population

The current investigation reported that all the inorganic inputs drastically reduced the soil's beneficial microbial population. There was significant variation observed in the inorganic input sources treated plots and the control plots. Control treatment showed a higher bacterial population than inorganic input treatments. Among the inorganic amendments, algaecide has less inhibition than herbicide and fungicide application concerning soil bacteria, fungi, actinomycetes, *Azospirillum*, Phosphobacteria, and *Pseudomonas* population (Bharathi et al., 2024).

The influence of Algaecide on the soil microbial population is as follows. The algaecide application significantly decreased the microbial population than the control treatment. However, among the algaecides, maximum bacteria and *Pseudomonas* populations were recorded in the treatment $CuSo_4$ application (30.0, 32.33 × 10^4cfu/g), followed by $CuSo_4$ + Cao (29.33, 30.33 × 10^4cfu/g) and Cao (25.66, 24.66 × 10^4cfu/g), respectively (Bharathi et al., 2024). Maximum fungi and *Azospirillum* populations were observed in the treatment $CuSo_4$ (19.33 × 10^3cfu/g, 1.93 × 10^5MPN/g) followed by Cao (17.0 × 10^3cfu/g, 1.36 × 10^5 MPN/g) and $CuSo_4$ + Cao (12.33 × 10^3cfu/g, 0.86 × 10^5MPN/g) respectively. *Actinomycetes* population was abundant (less inhibition) in $CuSo_4$ + Cao (20.0 × 10^2cfu/g), followed by $CuSo_4$ (19.0 × 10^2cfu/g) and Cao (16.33 × 10^2cfu/g). Phosphobac- teria population was higher in the treatment $CuSo_4$ (23.3 × 10^4cfu/g), followed by Cao (21.0 × 10^4cfu/g) and $CuSo_4$ + Cao (20.66 × 10^4cfu/g). Herbicide application affects the soil microbial population more than the control and algaecide application. The influence of herbicide application on soil microbial population is as follows. Among the herbicide applications, Almix (28.33 × 10^4cfu/g) showed more bacteria population via less inhibition, followed by londox power (27.3310^{4}cfu/g) and butachlor (26 × 10^4cfu/g). The maximum fungal population was observed in the butachlor (17.66 × 10^3cfu/g), followed by londox power (15.66 × 10^3cfu/g) and Almix (13.3 × 10^3cfu/g) (Table 4). Maximum actino-mycetes population was observed in butachlor (17 × 10^2cfu/g), followed by bisphyriphos sodium (16.33 × 10^2cfu/g) and Almix (12.66 × 10^2cfu/g) application (Table 4) (Bharathi et al., 2024). Maximum phosphobacteria population was observed in the londox power (19.66 × 10^4cfu/g), followed by Almix (18.66 × 10^4cfu/g) and butachlor (14.66 × 10^4cfu/g). Maximum *Azo-spirillum* population was observed in the treatment londox power (1.73 × 10^5 MPN/g), followed by butachlor (1.66 × 10^5 MPN/g) and pyro-sulfuran 1.56 × 10^5 MPN/g) application. Maximum *Pseudomonas* population via less inhibition was observed in the treatment butachlor (27× 10^4cfu/g), followed by Almix (22 × 10^4cfu/g) and pyrosulfuron (20 ×10^4cfu/g) application.

The influence of fungicide application on soil microbial population is as follows. Maximum phosphobacteria and *Pseudomonas* populations via less inhibition were observed in the treatment with propiconazole (12.66, 20.0 × 10^4cfu/g), followed by Hexaconazole (7.66, 15.33 × 10^4cfu/g) (Table 5). Maximum Actinomycetes and *Azospirillum* were observed in the treatment with propiconazole (14.33 × 10^2cfu/g, 1.53 × 10^5 MPN/g), followed by Hexaconazole (12 × 10^2cfu/g, 1 × 10^5 MPN/g), respectively. Maximum abundance of bacteria and fungi population was observed in propiconazole (23 × 10^4cfu/g, 8 × 10^3cfu/g), followed by Hexaconazole (18 × 10^4cfu/g, 7 × 10^3 cfu/g), respectively (Table 5) (Bharathi et al., 2024).

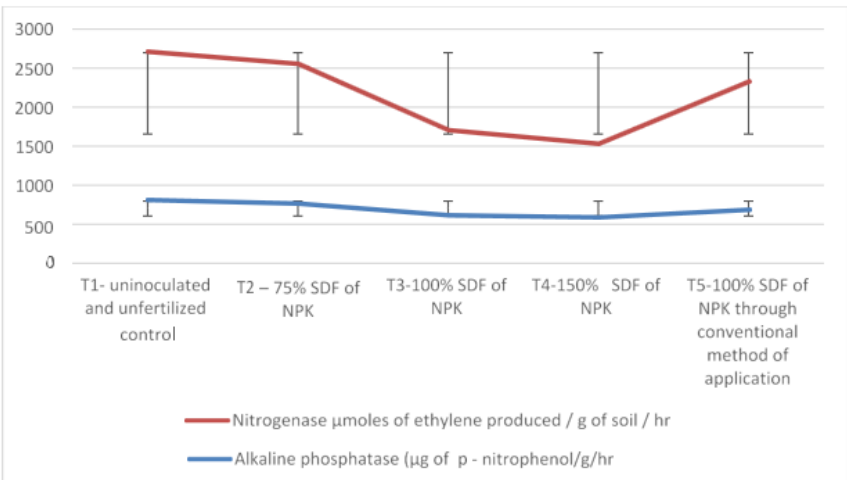

Fig. 2. Chemical fertilizer on nitrogenase activities in the soil planted with maize (COMH 1)

4. DISCUSSION

Microbial activity in soil is thought to act as a storehouse, contributing significantly to soil processes that ultimately determine plant productivity. The maize field experiment's findings revealed that higher fertiliser dosages reduced both the microbial population and soil microbial enzyme activity. Plots treated with 75 % SDF of NPK had the highest populations of *Azospirillum* (0.409 × 10^5 MPN/g), Phospho-bacteria (66.33 × 10^5cfu/g), and diazotrophs (124 × 10^5cfu/g), followed by 100 % and 150 % SDF of NPK. The soil enzyme activity, viz., urease (79.6 µg of NH_4/ g /24 h), dehydrogenase (110 µg of TPF /g/24 h), acid phosphatase (251 µg of p – nitrophenol/g/hr), alkaline phosphatase (811 µg of p – nitrophenol/g/hr) and nitrogenase (1913.30 µmoles of ethylene produced/g of soil/hr) were higher in the unfertilized control plot than the fertilised plot (Bharathi et al., 2024).

The data from the findings indicated that the survival of microorganisms is unaffected by the addition of a small amount of fertiliser to the soil. Higher amounts of inorganic nutrients build up in the soil as a result of increased fertiliser dosage, which reduces microbial survival and enzyme activity. Long-term fertiliser application significantly affects soil microbial communities throughout the soil profile. In fact, the relative abundance of ammonia-oxidising archaea at 0–40 cm depth was noticed (Li et al., 2014). In all tillage systems, chemical fertilisers decreased the enzyme activity (Bharathi et al., 2024). A possible reason might be that organic matter could increase microbial activity in the soil. Acid and alkaline phosphatase activity in the soil significantly depended on the type of organic manure and whether or not chemical fertilisers were employed. Higher acid and alkaline phosphatase activities of soil treated with organic manures could be related to microbial biomass production. The application of chemical fertiliser decreased urease activity (Heidari et al., 2016). To preserve the sustainability of the soil's biological ecosystem and soil organic carbon content, we must reduce the amount of chemical fertiliser that is available and replace it with organic amendments and biofertilizers.

Overuse of chemical fertilisers has detrimental effects on biodiversity, climate change, soil and water quality, and human health (Pirttila¨ et al., 2021). One method to address this issue that guarantees food safety, preserves soil biodiversity, and upholds ecological balance is organic agriculture (Du et al., 2022).

Fertilisation can indirectly impact soil microorganisms by changing soil properties or directly by input of nutrients (Pan et al., 2020; Yan et al., 2021). A study indicated that long-term application of chemical fertiliser resulted in a significant decline in soil bacterial diversity due to a decrease in soil pH value, while the addition of manure effectively alleviated this decline (Sun et al., 2015).

The results of the rice field experiment showed that the microbial population was decreased by the addition of fungicide, herbicide, and algaecide than the control treatment. Among the inorganic amendments added, algaecide recorded the highest microbial population via less inhibition than herbicide and fungicide applications (Bharathi et al., 2024). Among the algaecide applications, maximum bacteria and *Pseudomonas* population were recorded in the treatment $CuSo_4$ application (30.0, 32.33×10^4cfu/g), followed by $CuSo_4$ + Cao (29.33, 30.33×10^4cfu/g) and Cao (25.66, 24.66×10^4cfu/g), respectively. Maximum fungi and *Azospirillum* populations were found in the treatment $CuSo_4$ (19.33×10^3cfu/g, 1.93×10^5 MPN/g), followed by Cao (17.0×10^3cfu/g, 1.36×10^5 MPN/g) and $CuSo_4$ + Cao (12.33×10^3cfu/g, 0.86×10^5 MPN/g) application, respectively. *Actinomycetes* population was abundance in $CuSo_4$ + Cao (20.0×10^2cfu/g) followed by $CuSo_4$ (19×10^2cfu/g) and Cao (16.33×10^2cfu/g) application. Phosphobacteria population was higher in the treatment $CuSo_4$ (23.3×10^4cfu/g), followed by Cao (21×10^4cfu/g) and $CuSo_4$ + Cao (20.66×10^4cfu/g) application.

Prior research has mostly offered broad insights into the diversity, evenness, and abundance of the soil microbial community that was sensitive to various

fertilisation treatments (Li et al., 2017). When compared to the chemical fertiliser treatment, the organic fertiliser treatment improved potential ecosystem function by increasing the diversity of soil microorganisms, changing the network structure, and influencing key microbial organisms (Gu et al., 2019). The diversity of soil microbes responded differently to environmental disturbances (Cai et al., 2020). Additionally, it has been demonstrated that the emergence of soil-borne plant diseases was caused by a decline in soil microbial diversity, addressing the possibility that variations in the rhizosphere microbial community could influence variations in disease resistance.

5. CONCLUSION

Long-term accumulation of chemical fertilisers, herbicides, pesticides, and fungicides has altered the innate behaviour of the soil and altered the diversity of microbes growing there. Since microbes are present, the soil is referred to as a living ecosystem. The cycling of nutrients and the breakdown of soil depend on these processes (Bharathi et al., 2024). The soil microbial population was less affected by algaecide, followed by herbicide and fungicide application, based on the rice field study. Reduced use of chemical fertilisers increased soil microbial population, and without fertiliser, plots had higher soil enzyme activities than 100 % and 150 % standardised doses of NPK-treated plots, according to the maize field experimental study. Hence, to maintain soil health, organic amendment and less inorganic input supply is a more positive response to soil microbial diversity and soil enzyme activities of soil.

AUTHORS' CONTRIBUTIONS

Author MJB conducted research trial in maize and rice, enumeration of soil microorganism and analysis of soil enzyme activities. Author MA did the soil analysis and process of article. Author RR Technical writing and submission of article. Author ES Biometrics and analysis rice and maize field data.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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