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Impact of Nitrogen Amendments on Soil Enzyme Dynamics under Simulated Wetland Ecosystem

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Authors' contributions

This work is carried out in collaboration among all authors. Author DC did the investigation, writing original draft and preparation of manuscript. Author ST edited the manuscript. Authors RN and KK supervised the study. Author SU did the editing and fund acquisition. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To evaluate the influence of nitrogen amendments on soil enzyme dynamics in a long term incubation experiment.
Study Design: An *in vitro* simulated wetland ecosystem designed with rhizosphere soil was enriched with different N sources.
Place and Duration of Study: The study was conducted at Biocatalysts Laboratory, Tamil Nadu Agricultural University, Coimbatore, India. An incubation experiment ran for 150 days, to determine the temporal changes of soil enzyme activities.
Methodology: There were five treatments replicated thrice. The N enrichment included in the treatments were aerated except S1 as detailed below: rhizosphere soil (S1), rhizosphere soil without enrichment (S2), combined NH_4Cl and KNO_2 enriched rhizosphere soil (S3), KNO_2 enriched rhizosphere soil (S4) and NH_4Cl enriched rhizosphere soil (S5).

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Results: The soil enzymes such as dehydrogenase (24.59 µg TPF g^{-1} soil day^{-1}), urease (49.27 µg NH_3 g^{-1} soil) and acid phosphatase (38.57 µg PNP g^{-1} soil h^{-1}) were observed maximum in NH_4Cl enriched rhizosphere soil (S5) on 70 DAI (days after incubation). While, highest alkaline phosphatase (53.40 µg PNP g^{-1} soil h^{-1}) and fluorescein diacetate (7.57 µg fluorescein g^{-1} soil h^{-1}) were registered on 70 DAI in KNO_2 enriched soil (S4) and KNO_2 + NH_4Cl (S3) respectively. However, all the enzyme activities, irrespective of treatments, showed an increasing trend up to 70 DAI and thereafter, declined gradually.

Conclusion: Enzyme activities registered maximum in NH_4Cl enriched rhizosphere soil (S5) than other enrichments. Basal N application as ammoniacal form (NH_4^+) triggers efficient trade-offs between soil functions in the wetland ecosystem whereas, combined sources contribute to microbial biomass and redox status of soil.

Keywords: Simulated wetland ecosystem; nitrogen enrichment; incubation; soil enzymes; ammoniacal nitrogen.

1. INTRODUCTION

Wetlands are the unique, productive ecosystem that serves as carbon sinks, source, and transformers of nutrients [1]. Nitrogen is arguably a crucial nutrient in relating primary productivity and species diversity in the wetland ecosystem [2]. Imposing climate change ie., increased temperature and CO_2 in wetland, increase N mineralization, and microbial activities, respectively. Hence the function of wetland purely relies on the extensive interaction between water and wetland soil and there by enhances the function of soil enzymes [3].

Soil enzymes maintain soil health and pave the way for sustainable agricultural ecosystem. The enzymatic activity in the soil is contributed primarily from microbial resources, intracellular, extracellular and cell-associated enzymes, which are directly proportional to soil microbial biomass [4]. These soil enzyme activities may serve as biological indicators and actively change within the plant-soil system. Moreover, soil enzymes are closely linked to nutrient cycling and act as buffers in mediating the soil functions. Therefore, soil enzymes integrate information on both the microbial status and the physico-chemical conditions of soil, showing a rapid response to any changes in soil management practices [5]. Soil health was predicted based on the key activities of the extracellular enzymes such as dehydrogenase, phosphatase, urease and fluorescein diacetate in the soil profiles [6].

Soil dehydrogenase is an extracellular enzyme that occurs in all viable microbial cells and thereby reflects the total oxidative activity of microbial biomass. Dehydrogenase usually exists as an integral part of intact cells [7] and also sturdily related to soil organic matter and N cycle [8]. Similarly, Urease activity in soil is an important index to evaluate soil organic matter and N status of the soil. Application of NO_3^--N and NH_4^+-N steadily influence soil urease activities [9].

On the contrary, phosphatase is a critical player in P mineralization [10] that exists in two forms: Phosphodiesterases (PDE) and Phosphomonoesterases (PME). Soil generally contains large quantities of intracellular and extracellular phosphatases, and the addition of glucose and inorganic NH_4Cl to the soil stimulates PME at pH 6.5 and thereby makes it an available form to the plants. As the microbial biomass reaches its peak, phosphatase activities tend to increase rapidly. However, a prolonged period of incubation time has a negative impact on phosphatase activities [11]. Fluorescein diacetate (FDA) assay is a marker to assess the total microbial function in the soil. FDA undergoes hydrolysis by esterases, proteases and lipases, the enzymes responsible for microbial decomposition of organic matter in the soil [12].

The N amendments are considered as a strategy to hasten soil microbial process and stimulate associated wetland functions. Organic amendments such as compost, straw, and topsoil have been shown to increase soil C and N pools [13]. Furthermore, while organic amendments stimulate a balance in soil structure-functional relationships, it is unknown whether inorganic amendments also impact specific nutrient geo cycles with the highest lability. Hence the present investigation was aimed to study the temporal dynamics of soil enzymes pertaining to N cycle under *in vitro*

condition in a simulated wetland ecosystem for 150 d.

2. MATERIALS AND METHODS

2.1 Sample Collection for Simulated Wetland Ecosystem

Soil samples were collected from the rice field, Wetland, Tamil Nadu Agricultural University, Coimbatore (11.0160ºN and 76.9703ºE). Soil samples (0-20 cm) in triplicates collected from the rice rhizosphere region were placed in sterile plastic bags, sealed, and transported to the laboratory with ice. Plant residues, root samples, and stones were removed before each replicate of a sample was homogenized. A simulated wetland ecosystem was set up, to clearly envisage the influence of simulated environment on the nitrifiers at *In vitro* condition.

2.2 Experimental Design

Glass containers filled with 5 kg of homogenized soil sample were exposed to the flooded conditions as that of the rice field by saturating the soil with two litres of distilled water. Subsequently, the set up was aerated through an airlifting motor pump with constant pressure to favour the growth of both aerobic and facultative microorganisms in the soil. The rhizosphere soil in glass containers was amended with 0.5% inorganic N sources such as NH_4Cl and KNO_2. The treatment and enrichment details are as below:

Rhizosphere soil alone (S1)
Aerated rhizosphere soil (S2)
Aerated rhizosphere soil amended with NH_4Cl + KNO_2 (S3)
Aerated rhizosphere soil amended with KNO_2 (S4)
Aerated rhizosphere soil amended with NH_4Cl (S5)

The experimental set up of simulated wetland ecosystem was depicted in Fig. 1. The simulated wetland system was incubated for 150 d at room temperature to study the temporal changes in soil enzymatic activities. Sampling was done at different intervals *viz.,* 0, 35, 70 and 135 DAI (days after incubation). The reason behind the sampling days up to 135 days is to facilitate the microbial build-up in the soil. At each sampling intervals, the sample was collected at different points in the glass container, pooled and then analyzed by quadrant method of sample collection.

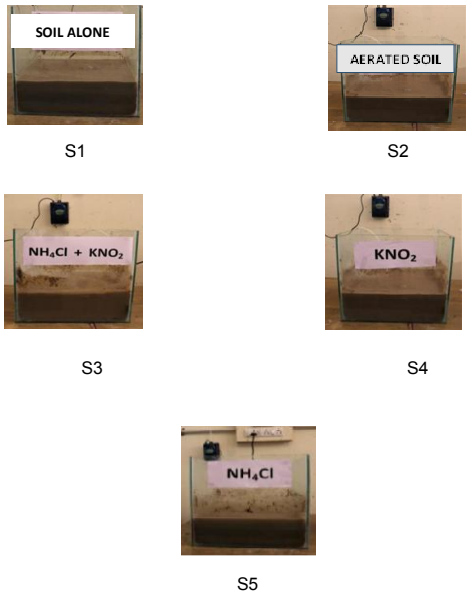

Fig. 1. Experimental Set up (Simulated Wetland Ecosystem)
S1 - Rhizosphere soil; S2 - Rhizosphere soil with aeration; S3 - combined NH_4Cl and KNO_2 enriched rhizosphere soil with aeration; S4 - KNO_2 enriched rhizosphere soil with aeration; S5 - NH_4Cl enriched rhizosphere soil with aeration

2.3 Temporal Dynamics of Soil Enzymes

2.3.1 Dehydrogenase (DHA)

The dehydrogenase activity was determined spectrophotometrically at 485 nm by measuring triphenyl tetrazolium formazan released from 5 g of soil after 24 h of incubation at 37ºC [14]. It is expressed as µg of TPF released g^{-1} soil hour $^{-1}$.

2.3.2 Urease (URE)

Urease activity was measured colorimetrically with 5 g of soil added with 0.2 mL of toluene and 9 mL of Tris-hydroxymethyl aminomethane (THAM) buffer (0.05 M, pH 9.0) and incubated for 2 h at 37ºC, according to the method of Bremner [15]. The urease activity was expressed in µg of NH_3 released g^{-1} soil h^{-1}.

2.3.3 Phosphatase

Acid phosphatase (ACP) was measured with the addition of 0.2 mL of toluene and 4 mL of modified universal buffer (pH 6.5) and followed by 1 mL of 0.05M *p*-nitrophenyl phosphate (pH 6.5) to 1 g of soil and kept for 1 h incubation. After 1 h, 1 mL of 0.5 M calcium chloride and 4 mL of 0.5 M NaOH was added. The enzyme activity was calculated and the activity expressed in µg of *p*-nitrophenol released g^{-1} soil h^{-1} (37). Alkaline phosphatase (ALP) was measured as that of acid phosphatase [16] with an exception of change in the pH of *p*-nitrophenyl phosphate as alkaline (pH 11.0).

2.3.4 Fluorescein diacetate (FDA)

FDA hydrolysis was carried out with 2 g of moist soil taken from the simulated wetland ecosystem and it's activity was measured by spectrophotometry at 490 nm after incubation for 20 min at 30ºC, according to the method described by Schnürer and Rosswall [17]. The FDA hydrolysis rate was expressed as µg fluorescein released g^{-1} soil h^{-1}.

2.4 Statistical Analysis

Statistically significant differences between the treatments were analyzed using analysis of variance (ANOVA) and Duncan's Multiple Range Test (DMRT) at 5% level of significance. The principal component analysis (PCA) and Eigenvalues are performed in XLSTAT version 2010.5.05 (XLSTAT).

3. RESULTS AND DISCUSSION

Soil enzyme, a crucial factor influencing ecosystem function was regarded as biological indicators for assessing the overall soil functions. In the process of nitrification, conversion of ammonia to nitrite and then to nitrate, are a classical two-step reaction. To hasten the process, several N amendments become an integral part of crop management practices. However, the augmentation of these N amendments, more specifically inorganic sources in sustaining soil health, is still a debate.

3.1 Dehydrogenase Activity

The addition of inorganic N amendments increased soil enzymes. Dehydrogenase (DHA) activity increased over time with N amendments up to 70 DAI and thereafter a steady decline was observed (Fig. 2). The dehydrogenase activity ranged between 2.73 and 24.59 µg TPF g^{-1} soil day^{-1} irrespective of the treatments and maximum activity was observed only on 70 DAI in S5 (aerated rhizosphere soil enriched with 0.5% NH_4Cl) compared to control (P = .05). The increase over time of DHA in NH_4Cl amended soil compared to non-amended and NO_2 amended soils indicate the availability of NH_4^+ ions in soil solutions. An increase in DHA activity in S4 showed active metabolic reactions catalyzed by soil microbiome producing adenosine triphosphate through oxidation of organic matter [18]. Furthermore, it signifies efficient N assimilation and increased microbial biomass in NH_4Cl amended soil.

Oxygen diffusion rate (ODR) is the proximal regulator of soil microbial activities [19]. Decrease in soil water content (> pF) causes an increase in ODR and redox potential [20]. The reduction of dehydrogenase (DHA) activity beyond 70 DAI might be attributed due to increased redox potential caused by loss of soil moisture. The response of DHA activity in the present study is in line with the findings of Zhao, et al. [21] that the activity of dehydrogenase in an inorganic fertilized soil at different stages of rice crop ranged between 12.75 µg TPF g^{-1} soil day^{-1} and 44.23 µg TPF g^{-1} soil day^{-1}. Thus, soil dehydrogenase activity in the treatments showed a decrease with an increase in incubation time.

3.2 Urease Activity

The soil urease activity differs with the soil type and organic matter content and also by the adsorption of the enzyme into the soil organic

carbon and mineral particles [22]. Maximum urease activity was seen on 70 DAI, thereafter decreased when the incubation time prolonged [23]. Here also, in comparison with other treatments, treatment S5 (NH_4Cl) showed maximum urease activity of 49.27 µg g^{-1} soil on 70th day (Fig. 3). However, statistical significance was not observed at P = .05, irrespective of the treatments, and DAI. The urease activity depends on the level of N fertilization [24] and releases NH_4-N through urea hydrolysis. It is also essential for the hydrolysis of amino compounds [25,26]. The non-significance in urease activity may be due to the application of urea in the previous season and have a profound influence on microbial biomass. These results were in concordance with the report of Mohammadi [27], who worked on the influence of the high quantity of ammonia on the activity of urease. An increase in the temperature increases the urease activity while the reduction in soil moisture by 10% leads to reduced urease activity.

3.3 Phosphatase Activity

Phosphorus dynamics in soil depend on pH, N, and organic matter [28,29]. Similar to DHA and urease, acid monophosphoesterase activity increased up to 70 DAI in all the treatments and after that started declining. The results also coincide with DHA and urease, where maximum acid monophosphoesterase activity was observed in S5 (NH_4Cl) registering 38.57 µg PNP released g^{-1} soil h^{-1} on the 70 DAI (Fig. 4).

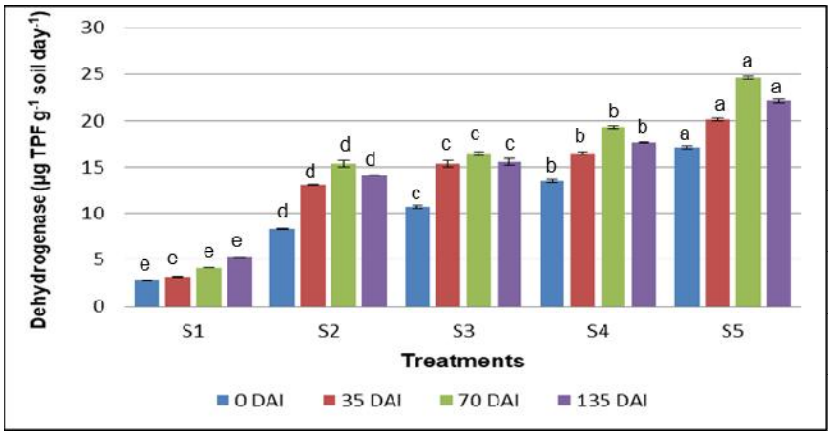

Fig. 2. Influence of nitrogen amendment on soil dehydrogenase

Values are mean (± standard error) (n=3) and within each column, values followed by same letters are not significantly different from each other as determined by DMRT (P≤.05). S1 - Rhizosphere soil; S2 - Rhizosphere soil with aeration; S3 - combined NH_4Cl and KNO_2 enriched rhizosphere soil with aeration; S4 - KNO_2 enriched rhizosphere soil with aeration; S5 - NH_4Cl enriched rhizosphere soil with aeration

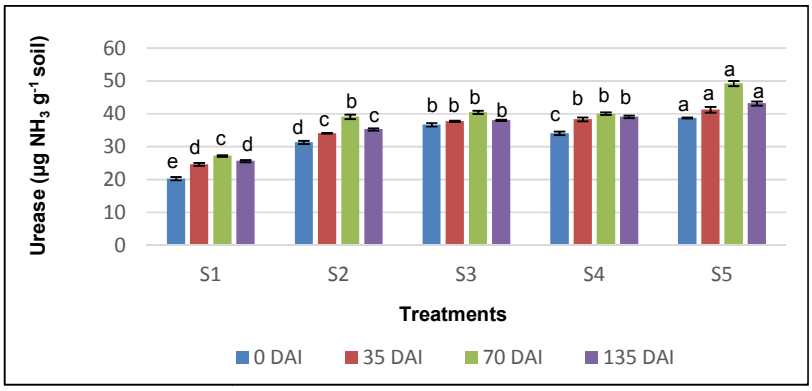

Fig. 3. Influence of nitrogen amendment on soil urease

Values are mean (± standard error) (n=3) and within each column, values followed by same letters are not significantly different from each other as determined by DMRT (P≤.05). S1 - Rhizosphere soil; S2 - Rhizosphere soil with aeration; S3 - combined NH_4Cl and KNO_2 enriched rhizosphere soil with aeration; S4 - KNO_2 enriched rhizosphere soil with aeration; S5 - NH_4Cl enriched rhizosphere soil with aeration

However, alkaline phosphatase is more in KNO_2 (S4) amended soils (53.40 µg PNP released g^{-1} soil h^{-1}) on 70 DAI (Fig. 5) and thereafter declined at a slow rate. The results suggest that N addition exerts a profound influence on soil P availability through changes in microbial metabolism. The result of present study stays in concordant with the findings of Tripathi, et al. [30] that acid and alkaline phosphatse activity ranged between 12.2-68.9 and 26 - 110.0 µg PNP released g^{-1} soil h^{-1} respectively in inorganic nutrient amended soil.

The increase in acid phosphatase activity in NH_4Cl amended soil might be attributed due to the acidification of soil by ammonium-N. The reduction in soil pH is due to H^+ ions from NH_4^+. More the NH_4^+ fraction in NH_4Cl amended soil, the release of H^+ ions also found to be higher and thus creates the acidic condition by reduction in soil pH [31]. Hence, the acid phosphatase activity is higher in S5. On the contrary, NO_2-N could not contribute to soil acidity due to the lack of H^+ ions [32]. Hence acid phosphatase activity is less in NO_2 amended treatments, whereas alkaline phosphatase activity is more in KNO_2 amended rhizosphere soil.

3.4 Fluorescein Diacetate Activity

Fluorescein diacetate hydrolysis, an indicator of microbial redox systems represents the detection of microbial oxidative activities in soil [17].

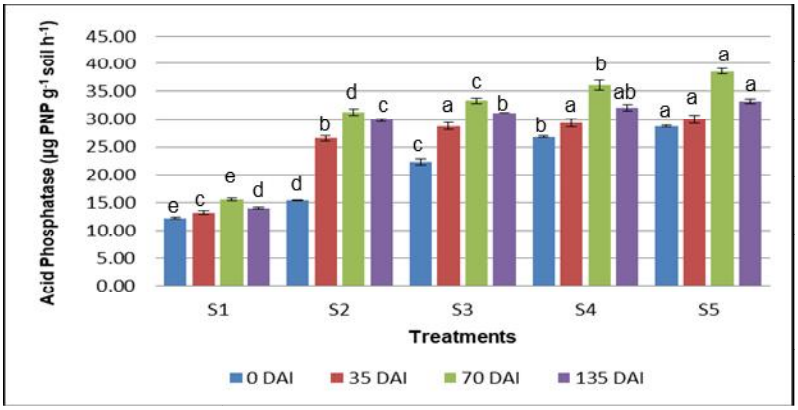

Fig. 4. Influence of nitrogen amendment on soil acid phosphatise

Values are mean (± standard error) (n=3) and within each column, values followed by same letters are not significantly different from each other as determined by DMRT (P≤.05). S1 - Rhizosphere soil; S2 - Rhizosphere soil with aeration; S3 - combined NH_4Cl and KNO_2 enriched rhizosphere soil with aeration; S4 - KNO_2 enriched rhizosphere soil with aeration; S5 - NH_4Cl enriched rhizosphere soil with aeration

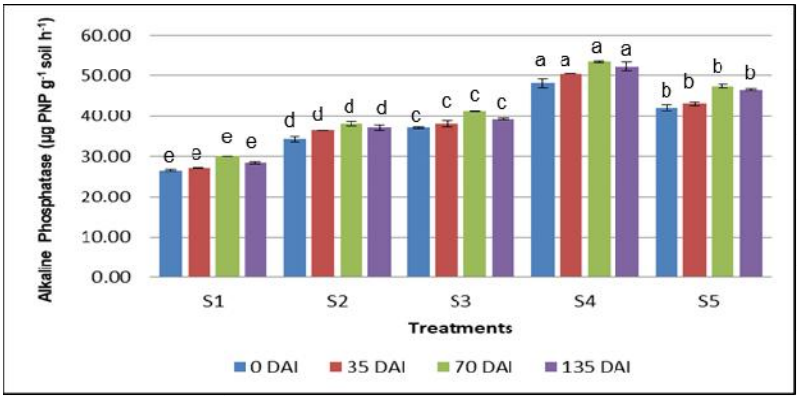

Fig. 5. Influence of nitrogen amendment on soil alkaline phosphatise

Values are mean (± standard error) (n=3) and within each column, values followed by same letters are not significantly different from each other as determined by DMRT (P≤.05). S1 - Rhizosphere soil; S2 - Rhizosphere soil with aeration; S3 - combined NH_4Cl and KNO_2 enriched rhizosphere soil with aeration; S4 - KNO_2 enriched rhizosphere soil with aeration; S5 - NH_4Cl enriched rhizosphere soil with aeration

The hydrolysis of the FDA was widespread among the bacteria, fungi, and decomposers. The FDA activity was observed maximum in S3 (7.57 µg fluorescein released g^{-1} soil h^{-1}) with a combined source of NH_4-N and NO_2-N amended rhizosphere soil when compared to individual compartments (Fig. 6). The results suggest that both the N sources synergistically contribute towards the soil redox reactions and indirectly to soil microbial biomass. Accelerated FDA indicates the contribution of several microbial reactions involved in decompositions of soil organic matter. This, in turn, indicates the soil fertility status [33]. Also, the results show concordant with the findings of Sofi, et al. [34] recorded a maximum of 19.16 µg fluorescein released g^{-1} soil h^{-1} in the N added soil.

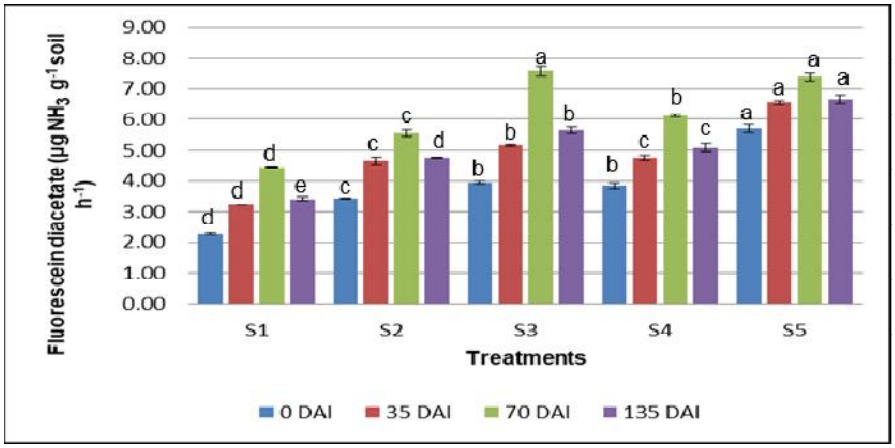

Fig. 6. Influence of nitrogen amendment on Fluorescein diacetate

Values are mean (± standard error) (n=3) and within each column, values followed by same letters are not significantly different from each other as determined by DMRT (P≤.05). S1 - Rhizosphere soil; S2 - Rhizosphere soil with aeration; S3 - combined NH_4Cl and KNO_2 enriched rhizosphere soil with aeration; S4 - KNO_2 enriched rhizosphere soil with aeration; S5 - NH_4Cl enriched rhizosphere soil with aeration

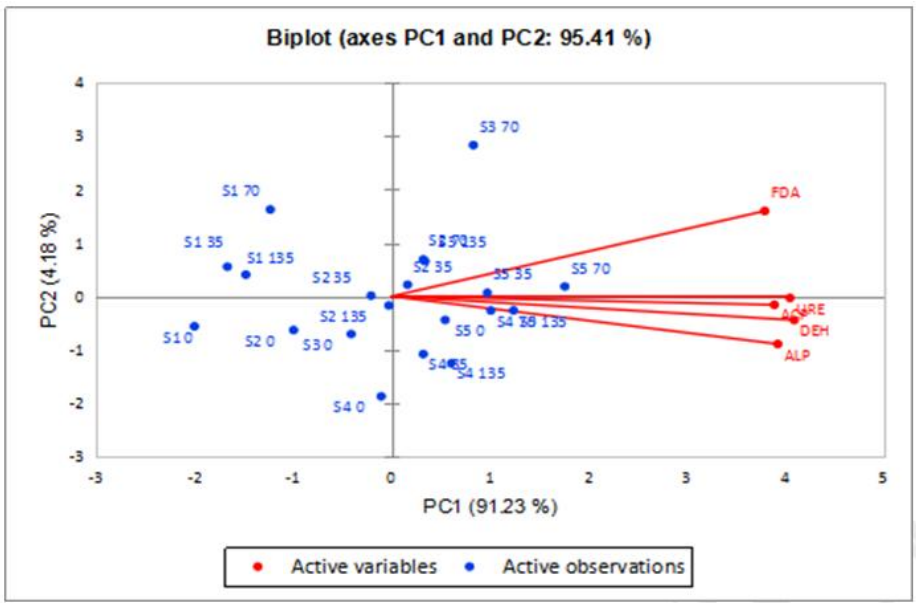

Fig. 7. Principal component analysis showing the relationship between soil enzymes in different N amended soil

DEH - Dehydrogenase, URE - Urease, ACP - Acid Phosphatase, ALP - Alkaline Phosphatase, FDA - Fluorescein diacetate

3.5 Principal Component Analysis

Principal component analysis (PCA) of changes in soil enzyme activities explained 91.23% and 4.18% variance for PC1 and PC2, respectively (Fig. 7). However, the cumulative variance was 95.41%. The PC with higher eigenvalues ≥1 and which explained at least 5% of variation in the data was considered. The variables which had positive factor loading were considered as the best representative of soil enzymes. In PC 1, S3 showed highest positive effect of FDA on 70 DAI and was regarded as best representative of soil enzyme influenced by N amendment. While the other variables like DHA, URE, ACP, and ALP showing correlation with one another were also considered as minimum dataset and retained in PC 1 for soil quality indexing [35].

4. CONCLUSION

The soil enzyme activities responded to different N amendments revealed that ammoniacal N (NH_4-N) contributed for efficient soil system functioning whereas, combined sources NH_4-N and NO_2-N facilitates soil redox reactions and indicates richness in microbial biomass. Also the study implies that addition of N amendments hastens the soil microbiological process and organic matter decompositions. Hence soil enzymes can be considered as biological indicators for assessing soil health.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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