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Long term impact of manuring, fertilization and liming on soil resilience, enzyme activities and productivity under maize-wheat system in an acidic Alfisol

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Abstract

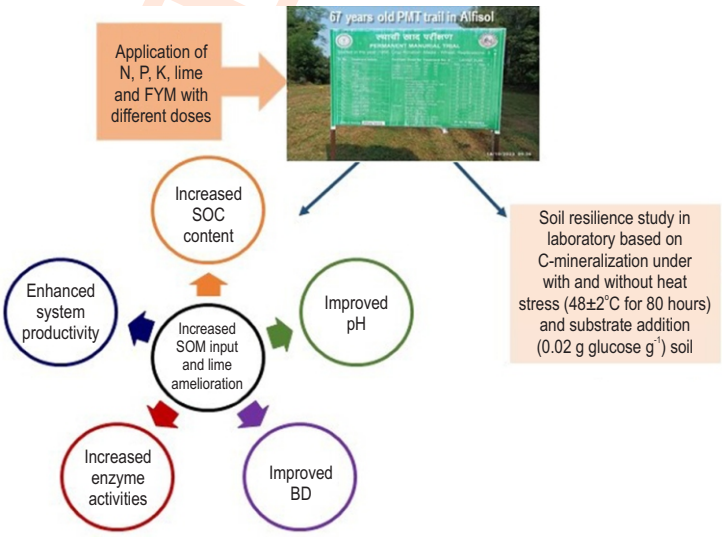
Aim: This study was carried out to evaluate the long-term impact of manuring, fertilization and liming on soil resilience, enzyme activities and system productivity under changing climate scenarios.

Methodology: The soil samples were collected from 67 year old long-term experiment going on, at Birsa Agricultural University, Jharkhand during 2022-23 under maize-wheat cropping system from seven treatments, viz. T_1: control, T_2: 100 % N, T_3: 100 % FYM, T_4: ½ (N+FYM) + $P_{X/2}$ + $K_{Y/2}$, T_5: 100 % NPK, T_6: Lime + NPK, T_7: Lime + FYM +$P_{(A-X)}$ + $K_{(B-Y)}$. To assess soil resistance and resilience, surface samples were subjected to with and without heat stress (48±2°C for 80 hrs) and substrate addition (0.02 g glucose g^{-1} soil).

Results: Application of FYM/lime with NPK significantly improved bulk density, pH, SOC and system productivity. The highest enzyme activities and cumulative respiration were observed in lime + FYM + $P_{(A-X)}$ + $K_{(B-Y)}$ treatment. It exhibited the highest resistance index (0.92) and resilience index (0.34).

Interpretation: The integrated use of inorganic, organic along with liming proved to be a useful management strategy for maintaining soil quality, resistance and resilience, and crop productivity in acid soil of Jharkhand.

Key words: Enzyme, Heat stress, Maize-wheat system, Soil acidification, Substrate induced respiration, Wheat-maize



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Introduction

Soil acidification is a natural process that significantly affects the soil properties and plant growth, particularly in tropical regions where it hampers agricultural crop production. The alleviated acidity in soil pose is challenges by reducing nutrient availability and microbial activity, thereby impeding plant growth (Chakraborty *et al.,* 2023). Effective management of soil acidity and application of appropriate fertilizers are crucial for improving crop yields and revolutionizing agriculture in these regions. However, the nutrient demands of intensive agriculture cannot be solely met by chemical fertilizers or organic manures. Therefore, a recommended approach involves combining chemical fertilizers and organic manures to optimize nutrient supply to crops, ultimately aiming to enhance soil quality and sustain crop production (Laxinarayana, 2021; Thakur *et al.,* 2023). Liming is commonly practised to ameliorate soil acidity, but liming may affect other soil properties also (Thakur *et al.,* 2023). Over the past few decades, extensive research has delved into understanding the extended consequences of fertilization, manuring, and liming on acidic soil dynamics in agricultural ecosystems (Vishwanath *et al.,* 2022; Laxinarayana, 2021).

The abundance and stability of microbial populations in soil play crucial roles in nutrient cycling, including carbon, nitrogen, phosphorus, and sulfur cycle enzymes. For instance, the activity of β-glucosidase is closely associated with carbon dynamics in soil. Additionally, phosphatase activity serves as a sensitive indicator of soil response to factors like liming and organic matter addition, particularly in acidic soils (Ekenler and Tabatabai, 2003). In numerous long-term fertilizer trials conducted in India, the application of organic matter has been identified as a key factor contributing to the continual production of crops. This is because organic matter enhances soil fertility by modifying various soil properties, thereby bolstering the soil's resistance and resilience to stress (Tripathy *et al.,* 2023; Vishwanath *et al.,* 2022; Kumar *et al.,* 2014). The physiological efficiency of organisms in soil can be assessed through parameters like their respiration rate, making substrate-induced respiration a useful index of soil biological activity (Tripathy *et al.,* 2023).

Temperature plays a significant role in determining the soil respiration rates, with long-term field monitoring and laboratory incubations demonstrating a considerable temperature dependency (Hartley *et al.,* 2007). The ability of microbial community to resist and recuperate from environmental disturbances profoundly influence the soil processes and hence, the soil sustainability. It is widely acknowledged that organic manures positively impact the soil properties, activities and crop yields. Long-term fertilizer trials provide valuable insights into how manuring, fertilization, and liming affect the physic-chemical properties, enzyme activities, and overall productivity of agricultural systems. The full extent of how long-term fertilization, manuring, and amendments positively influence soil's ability to recover from abiotic stressors, such as high temperatures common in Indian ecosystems and potentially exacerbated by climate change, remains incompletely understood. Tripathy *et al.* (2023) studied resilience of soil to abiotic stress in rice- rice system. No such attempt was carried out in wheat based cropping system in Alfisol. In lieu of the above, the present study was conducted to assess the soil physico-chemical properties, enzyme activities and system productivity in soil as affected by 67 years of long-term fertilization, to assess the effect of substrate induced respiration under heat stress and substrate addition on carbon mineralization, and to develop soil resistance, resilience indices. The novelty of the investigation lies in the identification of best management practices for maintaining soil quality, resilience and crop productivity in an acidic Alfisol under sub-tropical conditions.

Materials and Methods

Site description and treatment details: The study was conducted at Birsa Agricultural University, Kanke, Ranchi, India on a permanent manurial trial (PMT) with a maize-wheat cropping system on *Paleustalf.* The experimental site has a subtropical climate with annual precipitation of 1400 mm. The crop cultivars "Suwan" for maize and "K 9107" for wheat were sown. Thirteen treatments were laid out in a randomized block design (RBD), with individual plot sizes of 10 m^2 in the experiment. Out of thirteen treatments, seven treatments were selected. The seven selected treatments were T1: Control, T2: 100 % N, T3: 100 % FYM, T4-: ½ (N+FYM) + $P_{X/2}$ + $K_{Y/2}$, T5: 100 % NPK, T6: Lime + NPK, T7- Lime + FYM +$P_{(A-X)}$ + $K_{(B-Y)}$.

The dosage of fertilizer recommended for maize and wheat was 110: 90: 70 kg ha^{-1} N: P_2O_5: K_2O supplied through urea, single superphosphate and muriate of potash, respectively. Lime was administered once in every four years in T6 and T7 treatments based on the requirements for lime. Fifteen days before sowing of each crop, farm yard manure (FYM) was administered based on nitrogen (N) content in accordance with lime treatments. A and B denoted the complete doses of phosphorus (P) and potassium (K) in treatment T7, which was 90 kg P_2O_5 and 70 kg K_2O ha^{-1}, respectively. The amount of phosphorus and potassium in the whole dosage of FYM was administered on nitrogen basis to achieve 110 kg N ha^{-1}, represented by X and Y. When applied in combination with fertilizers, the amount of N, P, and K in FYM was taken into account to modify the final dosage.

Collection and analysis of soil samples: Following the maize harvest in October 2023, representative field wet soil samples (0 to 15 cm) were collected from each plot (7 treatments × 3 replications). After collection, the composite samples were loaded into plastic bags and brought to the laboratory of Division of Soil Science and Agricultural Chemistry, ICAR-IARI, New Delhi, and divided into two parts. One part was stored in a refrigerator at 4 °C for the analysis of biological parameters and other part was dried, ground and sieved using a 2 mm sieve and stored in a plastic container for analyzing the chemical properties. For the estimation of bulk density, the soil sample was collected with a core sampler separately. Subsequently, the bulk density (Veihmeyer and Hendrickson, 1948), pH (Page *et al.,* 1982), soil

organic carbon (Walkley and Black, 1934) was estimated following the standard laboratory procedures. Enzymatic activities like β-glucosidase and amidase (Dick *et al.,* 1996), arylsulphatase (Tabatabai and Bremner, 1970), alkaline phosphatase (Tabatabai and Bremner, 1969) were also estimated following the standard protocols.

Computation of system productivity: The grain yield of maize was translated into wheat equivalent yield (WEY t ha^{-1}) and computed as a sum of wheat yield and WEYs of maize to analyse the system productivity (SY).

WEY of maize = [(maize grain yield x MSP of maize) / (MSP of wheat)]

SY (kg ha^{-1}) = Grain yield of wheat (t ha^{-1}) + wheat equivalent yield (t ha^{-1})

Where, MSP- Minimum support price of Govt. of India

Substrate induced respiration study: Four sets of soil were extracted, and two of the sets were subjected to heat stress (48 °C ± 2) for 80 hrs in an incubator after covering it with a parafilm to prevent moisture loss. Glucose was supplied @ 0.02 g g^{-1} of soil in one set of heat-stressed soil and one set of normal soil (Tripathy *et al.,* 2023).

Four sets of soil were prepared : Soil + without heat stress and glucose ©; Soil + heat stress without glucose (H); Soil + glucose (G) and Soil + heat stress + glucose (H+G).

Following substrate addition and stress, soils were maintained at a field capacity and incubated at 25 °C. The impact of this process on biological function, or substrate induced respiration (SIR), was assessed by alkali trap method for 60 days, with a focus on C-mineralization (Franzluebbers and Arshad, 1996). The readings were taken on the first, third, sixth, thirteenth, twenty- third and sixtieth-days following stress (DAS).

Development of soil resistance and resilience index: With a continuation of substrate induced respiration study, the soil resistance and resilience index were computed by the following formulas given by Mandal *et al*. (2017).

Statistical analysis: Analysis of Variance (ANOVA) was used to analyse the experimental data. R software version 4.3.0 was used to conduct mean comparisons based on Duncan's Multiple Range Test (DMRT) at a 5% probability level to differentiate treatment means.

Results and Discussion

In the present study, soil pH varied significantly, ranging from 4.1 to 6.3 (Table 1). The application of lime along with NPK (T_6 and T_7) resulted in higher soil pH (6.3) compared to other treatments, attributed to lime's soil acidity ameliorating effect, consistent with previous findings (Laxminarayana, 2021). A slight improvement in pH observed with the combined use of FYM and fertilizers may be due to FYM's moderating effect, curtailing exchangeable Al^{+3} ions activity in soil solution through organic molecule chelation (Dhiman *et al.,* 2019). Conversely, continuous urea application 100% N (T_2) treatment markedly decreased the soil pH (4.1) due to liberation of H^+ ions through urea hydrolysis and nitrification processes (Vishwanath *et al.,* 2022). The prolonged use of fertilizer along with FYM/lime significantly influenced the soil bulk density (Table 1), with the highest reduction accounted to increased the organic matter content, improved aggregation, subsequent enhancement in micropore volume and root growth (Thakur *et al.,* 2023). Conversely, the control and only N-fertilizer-treated plots exhibited greater bulk density 1.61 and 1.56 gm^{-3}, respectively, likely due to lower organic matter and compaction in soil (Dutta *et al.,* 2015). After 67 years, the soil organic carbon (SOC) varied from 4.73 in the control (T_1) to 7.98 in 100% FYM (T_3) treated plots (Table 1), with the highest increase recorded with FYM application compared to the control. The augmented SOC in FYM-treated plots is

Table 1: Effect of long-term fertilization, manuring and liming on soil pH, bulk density, organic carbon and system productivity

Treatments	pH	Bulk density (g m^3)	Soil organic carbon (g kg^{-1})	System productivity (t ha^{-1})	
				2021-22	2022-23
T_1	5.66^c	1.61^a	4.73^e	1.58^c	1.08^e
T_2	4.1^e	1.59^a	5.32^d	1.96^c	0.99^e
T_3	6.1^b	1.31^c	7.98^a	4.90^b	4.77^d
T_4	5.7^c	1.33^c	5.91^c	8.83^a	7.04^b
T_5	4.7^d	1.5^{ab}	5.40^d	5.05^b	5.86^c
T_6	6.3^a	1.49^{ab}	5.44^d	8.56^a	8.36^a
T_7	6.3^a	1.43^{bc}	7.02^b	4.79^b	4.66^d
Mean	5.5	1.47	5.97	5.10	4.68
SD	0.78	0.11	1.05	2.63	2.59

T_1: Control, T_2: 100 % N, T_3: 100 % FYM, T_4: ½ (N+FYM) + P X/2 + K Y/2, T_5: 100 % NPK, T_6: Lime + NPK, T_7: Lime + FYM +P(A-X) + K(B-Y). Mean values within a column followed by different letters differ significantly ($p < 0.05$) by Duncan's Multiple Range Test (DMRT).

Table 2: Effect of long-term fertilization, manuring and liming on soil enzymatic activities

Treatments	BGA (μg PNP g^{-1} soil hr^{-1})	Amidase (μg NH_4-N g^{-1} hr^{-2})	ALKP (μg PNP g^{-1} soil hr^{-1})	ASP (μg PNP g^{-1} soil hr^{-1})
T_1	25.36^{c}	99^{f}	9.6^{e}	8.5^{f}
T_2	26.25^{c}	129^{de}	30.4^{d}	11.7^{ef}
T_3	28.82^{c}	126^{e}	70.2^{b}	32.3^{b}
T_4	50.82^{a}	141^{d}	43.2^{c}	20.5^{d}
T_5	44.91^{b}	189^{b}	34.9^{cd}	14.2^{e}
T_6	40.90^{b}	162^{c}	66.5^{b}	27.5^{c}
T_7	45.06^{b}	214^{a}	95.6^{a}	42.4^{a}
Mean	37.44	152	50.1	22.4
SD	9.64	36.73	26.86	11.36

BGA: β-Glucosidase activity, ALKP: Alkaline phosphatase activity, ASP: Arylsulphatase activity. Mean values within a column followed by different letters differ significantly ($p < 0.05$) by Duncan's multiple range test (DMRT). T_1: Control, T_2: 100 % N, T_3:100 % FYM, T_4: ½ (N+FYM) + P X/2 + K Y/2, T_5: 100 % NPK, T_6: Lime + NPK, T_7: Lime + FYM +P(A-X) + K(B-Y).

speculated to result from increased organic material input and higher crop production, leading to additional crop residues (Verma *et al.,* 2022; Thakur *et al.,* 2023). Organic manure application is known to enhance SOC, and combined fertilizer and lime application further increased SOC concentration over control. The application of lime in Alfisols aims to improve the development and crop yield by alleviating Al^{3+} and/or Ca^{2+} deficiency. Liming significantly increase root and aboveground biomass, leading to increased carbon return to soils through root and crop residue decomposition (Dhiman *et al.,* 2019). The system productivity (t ha^{-1}) in the 2021-22 and 2022-23 cycles followed specific patterns (Table 1), with increased productivity indicating the system's economic viability (Mondal *et al.,* 2020). System productivity was highest in T4 (8.83 t ha^{-1}) and T6 (8.36 t ha^{-1}) in year 2021-22 and 2022-23, respectively. SY follows trend $T_4 > T_6 > T_5 > T_3 > T_7 > T_2 > T_1$.

Continuous FYM application over 67 years resulted in substantial organic matter deposition, potentially providing necessary macro- and micronutrients (Alam *et al.,* 2024), while lime application reduced soil acidity, enhancing nutrient availability and optimizing soil ecological conditions (Dhiman *et al.,* 2019). FYM was found to be effective in boosting system productivity when added along with inorganic fertilizers due to its indirect effect of reduced loss of organically supplied nutrients (Mohapatra *et al.,* 2024). The System productivity severely declined in treatment receiving 100% N (0.99 t ha^{-1}). Depletion of SOC and hazardous level of exchangeable Al due to sharp drop in pH (Thakur *et al.,* 2023) are the primary factors contributing to yield decrease in long-term experiments, especially in plots receiving 100 % N. Our findings align with the study of Manna *et al.* (2007), advocating that continuous application of NPK + lime or NPK + FYM can sustain maize-wheat system yield without soil quality degradation. The β-Glucosidase activity varied from 26.2 to 50.8 µg PNP g^{-1} soil hr^{-1} (Table 2). The combination of organic residues and inorganic fertilizer may induce a microbial switch in carbon-cycling populations, resulting in higher β-glucosidase activity (BGA) in T_4 treatment as compared to plots receiving only NPK fertilization. This is attributed to abudant carbon present in soil and increased microbial activity under integrated treatment (Mohapatra *et al.,* 2024). The lower BGA observed in sole FYM treatment may be attributed to the reduced availability of nutrients (Trivedi *et al.,* 2021). Conversely, the addition of lime improved pH, favouring augmentation of microbes primarily associated with nutrient acquisition rather than carbon cycling microbiota, resulting in lower BGA in T_6 and T_7 treatments (Table 2) (Vishwanath *et al.,* 2022). Control treatment exhibited the lowest β-glucosidase activity, consistent with the findings of Hazarika *et al.* (2021). Amidase activity varied within the range of 99 to 214 NH_4-N µg g^{-1} hr^{-2} across different treatments (Table 2). Treatment T4 exhibited a noteworthy 116% increase in amidase activity over control. Application of lime and FYM aids in moderating the soil environment and provides additional carbon to soil microbes through increased root biomass resulting from larger yields. The observed increase in amidase activity upon application of nutrients and soil amendments supports the notion that integrated nutrient management involving FYM or lime favours the growth and activities of soil microbes (Wanjari, 2013).

The highest alkaline phosphatase activity (95.6 µg PNP g^{-1} soil hr^{-1}) was observed on adding FYM in conjunction with chemical fertilizers (T4) (Table 2). In the presence of inorganic fertilizers, the breakdown of organic matter tends to liberate organic acids, which promotes mineralization and release fixed P in soil (Kumari *et al.,* 2024). Higher activity of alkaline phosphatase in the manure treated soil is attributed to increased diversity of P solubilizing bacteria due to manuring over the years (Tamilsilivi *et al.,* 2015). The integrated manure and inorganic fertilizer use generates abundant easily decomposable substrates, promoting higher ester and hydride hydrolysis of phosphoric acid, thereby positively affecting the alkaline phosphatase activity (Biswas *et al.,* 2018, Borase *et al.,* 2020). The application of lime had a beneficial effect on phosphatase activities (Table 2) by improving the soil pH. Soil pH can influence enzyme-mediated reaction rates by

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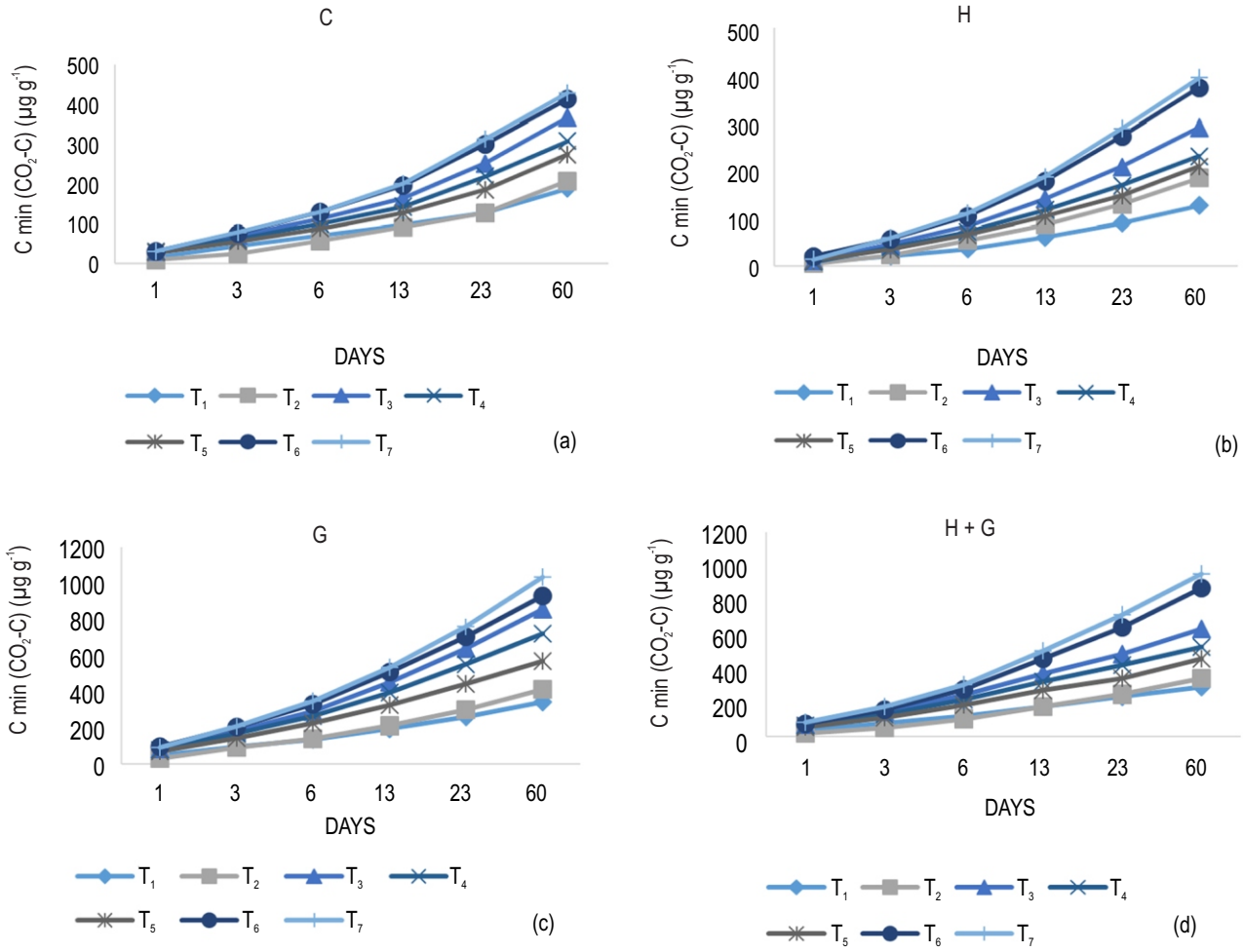

Fig. 1: Cumulative substrate induced soil respiration (CO_2-C µg g^{-1}) after heat stress and substrate addition over 60 days of incubation in (a) Soil + without heat stress and glucose (C), (b) Soil + heat stress without glucose (H), (c) Soil + glucose (G), (d) Soil + heat stress + glucose (H+G). T_1: Control, T_2: 100 % N, T_3: 100 % FYM, T_4: ½ (N+FYM) + P X/2 + K Y/2, T_5: 100 % NPK, T_6: Lime + NPK, T7: Lime + FYM +P(A-X) + K(B-Y).

affecting maximum enzyme activities, as well as substrate and cofactor solubility (Laxminarayana, 2021). Significantly higher arylsulphatase activity was found in integrated treatment (42.4 µg PNP g^{-1} soil hr^{-1}) over T_1 control (8.4 µg PNP g^{-1} soil hr^{-1}) (Table 2). Application of form yard manure either alone or in combination with inorganic fertilizers resulted in significantly higher arylsulphatase activity compared to fully inorganic treatment. This is ascribed to higher accumulation of SOC in FYM treated plots as compared to inorganic fertilized plots. SOC serves as a heat insulator, safeguarding extracellular arylsulfatase from denaturation caused by high soil temperatures and large diurnal fluctuations (Srinivasarao *et al.,* 2018). The benefits of lime application on ASP as observed in lime amended treatments is consistent with the findings of Ekenler and Tabatabai (2003). The lower enzyme activities in control plot might be due to little substrate accessibility for microbes. During 60-day incubation period, there was a consistent increase in cumulative respiration rate across all conditions, regardless of stress or substrate addition. Among the four conditions tested, soil supplemented with glucose exhibited the highest respiration rate, followed by soil subjected to heat stress with glucose, control, and lowest respiration rate observed in soils under heat stress alone (Fig. 1). Significant variations in cumulative respiration rates were observed among treatments in both heat-stressed samples with and without glucose (H+G and H) as well as normal samples with and without glucose (G and C).

The highest cumulative soil respiration was found in T7 treatment whereas the heat treatment had the lowest value (396 CO_2-C µg g^{-1}). Heat stress can indeed lead to increased microbial cell mortality by causing cell breakdown. These findings corroborate with Tiemann and Billings (2011), who suggested that stressed microorganisms may allocate a higher proportion of nutrients and carbon to their survival pathways compared to

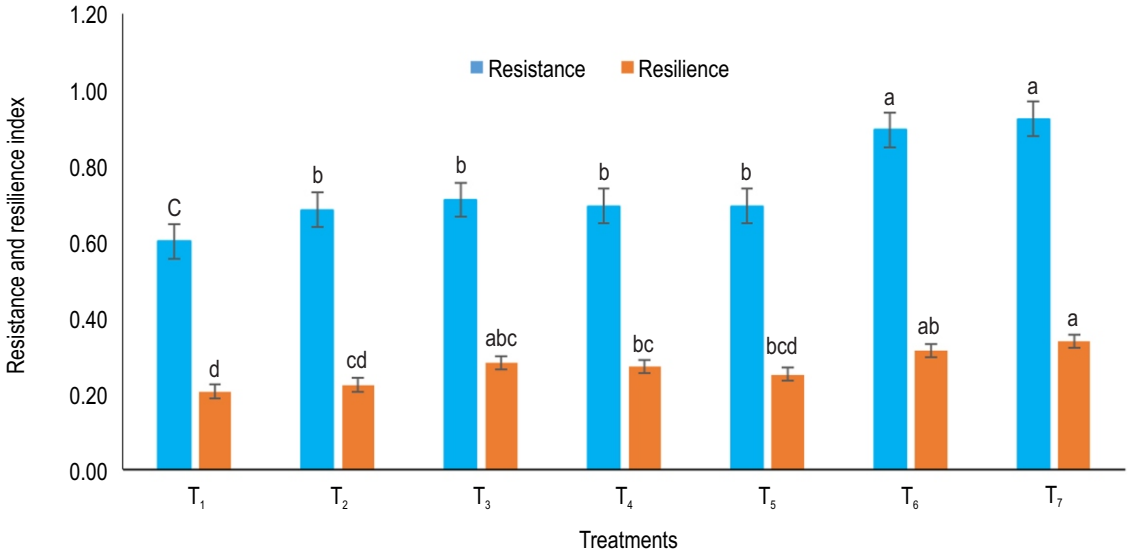

Fig. 2: Soil resistance index and soil resilience index as a function of carbon mineralization. T_1: Control, T_2: 100 % N, T_3: 100 % FYM, T_4: ½ (N+FYM) + P X/2 + K Y/2, T_5: 100 % NPK, T_6: Lime + NPK, T7: Lime + FYM +P(A-X) + K(B-Y).

pathways related to growth and resource acquisition. The requirement for the production of specific energy-intensive compounds, such as amino acids or polyols, in a survival regime can slow down CO_2 production (Tripathy *et al.,* 2023). In both heat-stressed samples with (H+G) and without (H) glucose, as well as in normal samples, carbon mineralization increased up to 60 days of incubation. Barnard *et al.* (2013) attributed this rise to increased substrate availability or release of newly produced microbial residues due to heating. However, in soils treated with glucose (G), the substrate's easy availability promotes greater soil organic carbon mineralization rate (SIR) due to enhanced microbial activity. The cumulative respiration rate in each of the four sets of soils, irrespective of substrate addition or heat stress, followed the order: $T_7 > T_6 > T_3 > T_4 > T_5 > T_2 > T_1$ (Fig 1).

This indicates that fertilizer selection influences soil respiration. When combined with 100% NPK fertilizers, farmyard manure or lime significantly influenced soil respiration compared to the control and chemical fertilizers alone. As opposed to inorganic alone, the frequent addition of manure enhanced water-soluble carbon may have served as source of bioenergy (Tripathy *et al.,* 2023). Farm yard manure, being a rich carbon source, encourages high levels of microorganisms, including r and K strategists. The former proliferates rapidly in the presence of abundant substrate, while the latter can thrive when resources are scarce, resulting in a physiologically active microbiome (Tejada *et al.,* 2008) and higher rates of soil organic carbon mineralization rate (SIR) compared to unbalanced fertilized soil. Elevated soil respiration was also observed as influenced by increased microorganism biomass in farm yard manure and lime supplemented plots (Tamilsilivi *et al.,* 2015). Additionally, organically maintained agricultural soil exhibited higher respiration rates than intensively farmed soil (Griffiths *et al.,* 2001). Upon comparing the heat-stressed samples with and without glucose (H+G and H), the microbiome exhibited lower resistance to abiotic stress (Kumar *et al.,* 2014), and resulted in decreased SIR across all treatments. The improved microbial activity and larger root biomass from increased productivity in lime-treated plots may have contributed to greater CO_2 evolution compared to NPK treatments. Verma *et al.* (2022) also noted elevated CO_2 evolution in response to lime or FYM application when combined with chemical fertilizers in Alfisols. Less active microorganisms and low soil pH due to long term use of urea may be the cause of lower SIR in 100% NPK and 100% N treatments compared to FYM or lime treatment, potentially affecting ecosystem functioning and increasing vulnerability to abiotic stresses like drought (Kumar *et al.,* 2014). Vishwanath *et al.* (2022) similarly found increased respiration rates in organically amended agricultural soil.

The highest resistance index after 60 days of incubation was found in two lime treated treatments T_7 (0.92) and T6 (0.89), which were at par with each other, while control (0.60) showed the lowest resistance index (Fig. 2). The resilience index across various treatments ranged from 0.20 to 0.34, while T_7 treatment showed the highest resilience index (0.34) (Fig. 2). The higher resistance index observed in FYM and lime treated soils is likely attributed to the abundance of organic material substrate consumption, indicating a more diversified population of microorganisms (Chakrabarti *et al.,* 2000). The application of farm yard manure to soil likely maintains a microbial community capable of reacting more rapidly to increased substrate availability. Additionally, higher organic matter content enhances moisture retention, thereby reducing the impact of excessive heat

and increased resistance to dryness (Mandal *et al.,* 2007; Hueso *et al.,* 2012). Moreover, continual farm yard manure use may enhance the thermal stability of organic clay-enzyme complex, increase microbial species diversity, and improve substrate utilization ability, thereby enhancing soil resilience to heat stress and substrate addition (Griffiths *et al.,* 2008). The highest resilience index in FYM-treated soil suggests that FYM may possess a higher inherent functional redundancy, allowing for a quicker recovery to the pre-stress state. Lime treatments have been shown to have significant positive impacts on soil quality, including physical, chemical, and biological environments, as well as mitigating soil acidity (Dhiman *et al.,* 2019). Consequently, soil microbial activity can sustain itself and continue performing its role, thereby increasing resilience to abiotic stress.

The long-term application of farmyard manure (FYM) and lime in conjunction with NPK significantly enhanced soil pH, soil organic carbon, enzyme activities, and system productivity. Over 67 years of maize-wheat system cultivation with chemical fertilizers, FYM, and lime, markedly improved the substrate induced respiration and resistance and resilience of soil to heat stress. Integrated nutrient management practices proved more effective in enhancing system productivity, enzymatic activity, and soil resilience. Among treatments, Lime + FYM + P(A-X) + K(B-Y) exhibited the highest resistance and resilience, indicative of a robust and resilient microbiome capable of withstanding heat stress. Therefore, the inclusion of lime or organic fertilizer along with balanced inorganic fertilizers is recommended to maintain soil quality, resilience, and productivity in acidic Alfisols under the scenario of climate change.

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Authors' contribution: K. Patil: Laboratory analysis, data analysis, manuscript writing; **S. Biswas:** Conceptualization, designed experiment, manuscript writing, fund acquisition; **P. Mahapatra:** Conduct field experiment; **T.J. Purakayastha:** Manuscript editing; **D. Das:** Manuscript preparation; **R. Raj:** Manuscript preparation; **P. Pramanik:** Manuscript preparation; **P. Singh:** Sample collection, laboratory analysis; **R. Rahaman:** Sample collection, laboratory analysis.

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