PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 11(sp4): 01–08
https://doi.org/10.14719/pst.5715

HORIZON
e-Publishing Group
HePG

RESEARCH ARTICLE

Sustainable maize production through organic amendments: Evaluating growth performance and environmental impact

A Divya Bharathy[1], S Maragatham[1*], R Santhi[1], V Davamani[2], D Balachandar[3] & D Ramesh[4]

[1]Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[2]Department of Environmental Sciences, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[3]Department of Agricultural Microbiology, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[4]Department of Renewable Energy and Engineering, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

*Email: maragatham.s@tnau.ac.in

OPEN ACCESS

ARTICLE HISTORY
Received: 10 October 2024
Accepted: 20 October 2024
Available online
Version 1.0 : 24 December 2024

Check for updates

Additional information
Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE
Bharathy AD, Maragatham S, Santhi R, Davamani V, Balachandar D, Ramesh D. Sustainable maize production through organic amendments: evaluating growth performance and environmental impact. Plant Science Today.2024;11(sp4):01-08. https://doi.org/10.14719/pst.5715

Abstract

The current study investigates the impact of organic and inorganic fertilizers on maize (*Zea mays* L.) growth and greenhouse gas (GHG) emissions. Organic amendments such as farmyard manure (FYM) and composted press mud, as well as inorganic fertilizers, were applied across various treatments to evaluate their effects on plant height, leaf production, chlorophyll content (SPAD values), leaf area index (LAI) and GHG emissions and carbon dioxide (CO_2). The experiment was conducted for one crop season (September to December 2023) using a Factorial Randomized Block Design (FRBD) in Tamil Nadu, with static chamber methods employed to measure GHG emissions. The results demonstrated that treatments involving organic inputs significantly enhanced maize growth compared to inorganic fertilizers. N_9 (T_3 + 5 t Composted Pressmud) consistently recorded the highest plant height, leaf count and LAI, while the control (T_1) had the lowest values. Organic amendments also showed reduced GHG emissions under rain-saturated conditions, although methane emissions were higher due to the anaerobic decomposition of organic matter. The study concludes that integrating organic fertilizers improves soil health and crop productivity while reducing GHG emissions, but careful management is needed to mitigate methane emissions in wet conditions. These findings support the adoption of organic inputs as part of sustainable agricultural practices to enhance productivity and environmental outcomes.

Keywords

emission; LAI; organic manures; plant height; SCMR

Introduction

The agricultural sector significantly contributes to global greenhouse gas (GHG) emissions, with crop production practices playing a key role in these emissions (1). Among the various crops grown worldwide, maize (*Zea mays* L.) holds a crucial position due to its importance as a staple food for humans and livestock, producing 35.67 million tonnes in 2023-24 (2). It also serves as a key raw material to produce various industrial products, such as biofuels (3). With the rising demand for maize, efficient fertilization practices to optimize crop yield and preserve soil fertility have become increasingly critical (4). Fertilizer use, however, is a double-edged sword; while essential for maintaining high yields, it is also a significant source of GHG emissions, particularly nitrous oxide (N_2O), which has a global warming potential significantly higher than carbon dioxide (CO_2) (2). Farmers worldwide commonly rely on two types of fertilizers: organic and inorganic (5). Organic manures, which include compost, animal dung, and plant residues, release nutrients slowly as they decompose, contributing to improved soil structure and long-term fertility (6). Inorganic fertilizers, on the other hand, are synthetically produced and deliver immediate and concentrated doses of nutrients like nitrogen, phosphorus and potassium, leading to faster plant growth (7). The challenge lies in balancing the need for high productivity with minimizing environmental impacts, particularly regarding GHG emissions (4).

In the context of maize cropping, organic and inorganic fertilizers have distinct effects on soil processes and nutrient cycling, subsequently influencing GHG emissions (1). Organic manures are typically associated with lower N_2O emissions but can produce methane (CH_4) under certain conditions (3). In contrast, inorganic fertilizers, especially nitrogen-based ones, tend to generate higher N_2O emissions (1.5-3 tonnes per hectare) due to the rapid nitrification and denitrification processes they induce in the soil (2). These emissions contribute to climate change and represent a loss of valuable nitrogen that could otherwise be used by the crop (4). The comparison between the emissions generated from organic and inorganic fertilizers in maize cropping systems is critical for developing sustainable agricultural practices (5). While inorganic fertilizers offer short-term yield benefits, their long-term environmental costs, particularly in terms of GHG emissions, have prompted increased interest in organic manures and integrated nutrient management strategies (7). Understanding the dynamics of emissions from these fertilizers and their impact on maize production is essential for mitigating climate change while ensuring food security (6).

This introduction sets the stage for a detailed exploration of the emissions profiles of organic and inorganic manures in maize cropping, considering their environmental impacts, contributions to soil health and overall sustainability. The subsequent sections will delve into the specific differences in GHG emissions from each type of manure, their effects on soil fertility, and the potential for reducing the environmental footprint of maize production through integrated fertilization strategies (1). This study addresses the gap in understanding the impact of organic amendments (pressmud compost and treated spent wash) on plant growth and CO_2 emissions. It also explores how these amendments interact with different tillage practices to support sustainable agriculture. The study aimed to evaluate the effects of pressmud compost and treated spent wash on maize growth and CO_2 emissions, Compare the impact of conventional and reduced tillage on plant growth and greenhouse gas emissions and develop sustainable fertilization strategies combining organic and inorganic amendments to minimize environmental impact.

Materials and Methods

Study area and experimental design

The experiments were conducted in Kuppepalayam villages in the Thondamuthur block of Coimbatore District. The experimental sites were located at an elevation of 449 meters above mean sea level, with the main site having geographical coordinates of latitude 10°59' 45'' N and longitude 76°47' 55'' E. The study aimed to assess the effects of various nutrient management strategies on maize growth and greenhouse gas (GHG) emissions. The experimental layout followed a Factorial Randomized Block Design (FRBD), with three replications assigned per treatment to account for environmental variability. Each treatment was applied to plots of equal dimensions, measuring 4 meters by 4 meters, with buffer zones of 30 cm between plots to minimize cross-contamination.

Fertilizer Application and Crop Management

The fertilizers were applied following Soil Test Crop Response (STCR) recommendations for each treatment. These materials were incorporated into the soil before planting using a rotary tiller for the treatments involving organic amendments, such as farmyard manure (FYM), composted pressmud and treated spent wash. The maize crop variety Maize CoH6 was planted at a row spacing of 60 cm by 30 cm to ensure optimal plant population density. Standard agronomic practices, including irrigation, weed management and pest control, were uniformly implemented across all plots. Irrigation was applied as required and all cultural operations were performed to promote ideal crop growth. Field experiments were conducted in Kuppepalayam village using a Factorial Randomized Block Design (FRBD) with three replications. The treatments included a range of combinations: N_1 (Absolute control), N_2 (100% Blanket Recommendation), N_3 (STCR -NPK alone 100% Inorganic fertilizer), N_4 (STCR-IPNS 100%), N_5 (75% of N_3 + 12.5 tons FYM), N_6 (75% of N_3 + 5 tons of press mud compost), N_7 (75% of N_3 + 40 KL of treated spent wash), N_8 (N_3 + 12.5 tons FYM), N_9 (N_3 + 5 tons of press mud compost) and N_{10} (N_3 + 40 KL of treated spent wash). The initial surface soil analysis of the experimental field revealed the following characteristics: a sandy loam texture with 41.08% coarse sand, 25.41% fine sand, 15.08% silt and 17.94% clay. The bulk density was recorded as 1.13 Mg m^{-3}, particle density of 2.24 Mg m^{-3} and porosity of 48.0%. The pH of the soil was 6.82, with an electrical conductivity (EC) of 0.16 dS m^{-1} and a cation exchange capacity (CEC) of 11.8 C mol (p+) kg^{-1}. The soil had a free $CaCO_3$ content of 2.75%, an organic carbon level of 3.8 g kg^{-1}, total nitrogen at 0.10%, total phosphorus at 0.09% and total potassium at 0.23%. Additionally, the available $KMnO_4$-N was 187 kg ha^{-1}, Olsen-P was 26.8 kg ha^{-1} and NH_4OAc-K was 386 kg ha^{-1}. The DTPA-extractable micronutrients were measured as follows: zinc (1.03 mg kg^{-1}), copper (1.28 mg kg^{-1}), iron (3.64 mg kg^{-1}) and manganese (7.48 mg kg^{-1}).

The nutrient and elemental composition of the organic manures used in the study is assessed. Pressmud had a pH of 7.35, an EC of 0.80 $dSm^{-1}$and an organic carbon content of 31.8%, while treated spent wash had a pH of 6.2, a high initial EC of 23.9 dSm^{-1} (diluted to 1.06 dS/m^2 for application) and an organic carbon content of 22.4%. FYM had a pH of 7.4, an EC of 8.84 dSm^{-1} and an organic carbon content of 6.8%. These manures provided vital nutrients, such as nitrogen (pressmud: 1.08%, treated spent wash: 0.15%, FYM: 0.61%), phosphorus (pressmud: 0.80%, treated spent wash: 0.02%, FYM: 0.38%) and potassium (pressmud: 0.60%, treated spent wash: 0.65%, FYM: 0.38%). The data obtained from the experiments were statistically analyzed using R version 4.2.2.

Plant height measurement

Plant height (cm) was monitored regularly throughout the crop growth period to evaluate the effect of each treatment. Five maize plants were randomly selected from each plot, excluding border rows. The height of each plant was measured from the soil surface to the tip of the tallest leaf. These measurements were recorded at different growth stages and the average plant height for each plot was calculated.

Number of leaves

The number of leaves on each labelled plant was counted at regular growth stages throughout the season. This measurement was taken for the five selected plants in each plot to assess the influence of the treatments on leaf production. The average number of leaves was then calculated and recorded for each plot.

Leaf area index (LAI)

The Leaf Area Index (LAI), an essential measure of the crop canopy, was calculated using the formula proposed as given in Equation 1 (8).

Leaf Area Index (LAI) = Leaf area per plant (cm^2) / Ground area covered by the plant (cm^2) Eqn. 1

The leaf area was measured for the five selected plants at different crop growth stages and the average LAI was computed for each treatment plot. This parameter serves as an indicator of the crop's efficiency in capturing sunlight and conducting photosynthesis.

SPAD chlorophyll meter reading (SCMR)

The SPAD chlorophyll meter was used to evaluate chlorophyll concentration, indicating the photosynthetic potential and overall plant health. Chlorophyll content was measured in the physiologically active leaves of the five labelled plants at various growth stages in each plot. The SPAD readings were averaged for each plot and these values provided insights into how nutrient availability from different fertilizer treatments influenced plant health (9).

Greenhouse gas emissions measurement

To evaluate the environmental impact of the treatments, greenhouse gas (GHG) emissions were measured using the chamber method. Static (non-vented) chambers were placed over the soil surface to capture emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) following every week intervals. These chambers were installed at selected areas in each plot at key intervals during the cropping season, mainly after 7-day intervals. Gas samples were collected for a set duration (e.g., 30-60 minutes) at regular intervals throughout the maize growth cycle. The collected gas samples were analyzed using gas chromatography (GC) to determine the CO_2, CH_4 and N_2O concentrations, following the methodology described (10). The measurements allowed for quantifying GHG emissions from each treatment, providing a basis for comparing the environmental impacts of different nutrient management strategies.

Data analysis

The collected data on plant growth parameters (plant height, number of leaves, LAI and SCMR), GHG emissions, soil properties and crop yield were subjected to analysis of variance (ANOVA) to evaluate the statistical significance of the differences between treatments. Mean values were compared using the least significant difference (LSD) test at a 5% significance level. Regression analysis explored relationships between the different treatments and the measured parameters, especially concerning GHG emissions and crop productivity. All statistical analyses were conducted using R software and graphical representations of trends in growth parameters and emissions were generated to illustrate the effects of the various treatments.

Results

The findings show that maize plant height rose gradually across all physiological stages, including vegetative, tasseling, maturing and harvesting. Table 1 presents the noteworthy differences between the treatments. Throughout all stages, N_9 (T_3 + 5 t Composted Pressmud) consistently had the highest plant height, while N_1 (Absolute Control) consistently had the lowest. N9 measured 102.0 cm (T_1) and 102.7 cm (T_2) for height during the vegetative stage, while T_1 recorded the lowest heights at 87.37 cm (T_1) and 86.33 cm (T_2). N_9 reached 194.0 cm (T_1) and 187.1 cm (T_2) during the tasseling stage, continuing this trend, whereas N_1 remained the lowest at 160.3 cm (T_1) and 159.5 cm (T_2). N9 peaked at 249.1 cm (T_1) and 253.5 cm (T_2) during harvesting and at 233.6 cm (T_1) and 232.5 cm (T_2) at maturity. The SED and CD (5%) results showed that the differences between the treatments were statistically significant, especially for the treatments that included organic amendments like pressmud and FYM, which continuously outperformed the control and inorganic fertilizers. However, at several stages, the interaction between treatments and tillage (CT and RT) was non-significant (NS), suggesting that the type of tillage had little effect on plant height. Comparably, the number of leaves also showed a similar pattern, with N_9

Table 1. Effect of pressmud compost, treated spentwash and FYM on plant height (cm) of maize crop at different physiological stages

S.No.	Treatments	Vegetative		Tasseling		Maturity		Harvesting	
		T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2
N_1	Absolute control	87.3^f	86.3^f	160.3^f	159.5^f	202.0^f	201.3^f	210.6^f	216.8^f
N_2	100% Inorganic fertilizer (Blanket)	89.3^e	86.5^e	169.0^e	167.0^e	206.9^e	204.1^e	216.6^e	220.3^e
N_3	STCR-NPK (100%) alone	95.8^d	91.1^d	179.7^d	177.1^d	213.5^d	217.9^d	227.3^d	238.2^d
N_4	STCR - IPNS (100%)	98.2^c	94.2^c	183.7^c	176.8^c	218.7^c	220.1^c	229.8^c	241.4^c
N_5	75% of N_3+12.5 t FYM	90.1^e	89.6^e	177.7^e	174.1^e	213.0^e	211.5^e	226.0^e	232.6^e
N_6	75% of N_3 + 5 t of Composted Pressmud	98.7^c	97.6^c	186.7^c	180.5^c	220.6^c	222.5^c	233.0^c	244.1^c
N_7	75% of N_3 + 40 KL of Treated Spent wash	95.5^d	91.0^d	175.0^d	170.9^d	210.0^d	209.4^d	222.2^d	225.6^d
N_8	N_3 +12.5 t FYM	100.3^b	99.5^b	190.7^b	186.7^b	228.5^b	230.0^b	241.4^b	251.5^b
N_9	N_3 + 5 t of Composted Pressmud	102.0^a	102.7^a	194.0^a	187.1^a	233.6^a	232.5^a	249.1^a	253.5^a
N_{10}	N_3 + 40 KL of Treated Spent wash	99.1^b	99.6^b	188.7^b	181.4^b	225.1^b	224.7^b	237.0^b	245.5^b
	SED	0.63	1.41	0.63	1.41	0.63	1.41	1.38	3.09
	CD (5%)	1.27	2.8	1.27	2.8	1.27	2.8	2.80	6.26
	SED (T_1× T_2)	1.99		2.01		2.02		4.37	
	CD (5%) (T_1× T_2)	NS		NS		NS		8.80	

having the most leaves overall and T_1 having the fewest, as Table 2 explains. N_9 had 13.13 (T_1) and 11.53 (T_2) leaves at the vegetative stage, whereas N_1 had 9.43 (T_1) and 7.87 (T_2) leaves. This pattern remained through the stages of tasseling, maturity and harvesting. N_9 recorded 18.20 leaves (T_1) and 17.10 leaves (T_2) during the maturity and harvesting phases, respectively, whereas T_1 recorded the lowest leaf count.

Significant differences across treatments, especially those involving organic amendments, were again confirmed by the SED and CD (5%) values. For several stages, the interaction between the tillage systems and the treatments was non-significant (NS). However, suggesting Comparably, the number of leaves also showed a similar pattern, with N_9 having the most leaves overall and N_1 having the fewest, as Table 2 explains. N9 had 13.13 (T_1) and 11.53 (T_2) leaves at the vegetative stage, whereas N_1 had 9.43 (T_1) and 7.87 (T_2) leaves. This pattern remained through the stages of tasseling, maturity, and harvesting. N_9 recorded 18.20 leaves (T_1) and 17.10 leaves (T_2) during the maturity and harvesting phases, respectively, whereas N1 recorded the lowest leaf count. Significant differences across treatments, especially those involving organic amendments, were once again confirmed by the SED and CD (5%) values. For several stages, the interaction between the tillage systems and the treatments was non-significant (NS); however, this suggests that tillage type had little effect on leaf number.

A similar trend was seen in the leaf area index (LAI), with N9 having the greatest LAI of all the stages. According to Table 3, N_9 achieved 1.82 (T_1) and 1.60 (T_2) during the vegetative stage, while N_1 continued to have the lowest values at 1.30 (T_1) and 1.09 (T_2). N_9 recorded the greatest LAI at 4.55 (T_1) and 4.28 (T_2) at maturity, respectively, as the tendency persisted during the tasseling and maturity stages. N_9 maintained the greatest LAI of 3.80 (T_1) and 4.04 (T_2) during the harvesting stage, while T_1 reported the lowest values. The organic amendments (pressmud and FYM) outperformed the control and the inorganic fertilizer treatments, according to the SED and CD (5%) values, which showed significant differences between the treatments for LAI. Interactions between treatments and tillage were non-significant (NS), suggesting that tillage type did not substantially influence LAI when combined with specific treatments.

The values of SPAD for maize under Conventional Tillage (T_1) and Reduced Tillage (T_2) during the stages of vegetative growth, tasseling, maturation and harvesting are displayed in Fig.1. showing the amount of chlorophyll and the plants' capacity for photosynthetic activity. The plant N_9 (N_3 + 5 t Composted Pressmud) exhibits superior chlorophyll content and nutrient uptake throughout the vegetative stage, as evidenced by its most significant SPAD values for CT and RT. On the other hand, because there is no fertilization, N_1 (Absolute Control) constantly has the lowest SPAD values. When the crop reaches the tasselling and maturity stages, N_1 has the lowest SPAD values, while N_9 and N_8 (N_3 + 12.5 t FYM) continue to display the most significant values. These findings demonstrate the benefit of organic amendments, which enhance plant health and increase photosynthetic activity.

Table 2. Effect of pressmud compost, treated spentwash and FYM on number of leaves (numbers) in maize crop at different physiological stages

S.No.	Treatments	Vegetative		Tasseling		Maturity		Harvesting	
		T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2
N_1	Absolute control	9.43	7.87^{i}	9.63^{f}	8.77^{h}	13.33^{i}	13.47^{f}	13.33^{i}	13.47^{g}
N_2	100% Inorganic fertilizer (Blanket)	10.00	8.33^{h}	9.73^{e}	9.10^{g}	14.33^{h}	14.17^{e}	14.33	14.17^{f}
N_3	STCR-NPK (100%) alone	11.30	9.40^{e}	10.43^{d}	10.40^{e}	16.33^{e}	15.33^{c}	16.33^{e}	15.33^{d}
N_4	STCR - IPNS (100%)	11.47	9.53^{e}	10.80^{d}	10.93^{d}	16.83^{d}	15.67^{c}	16.83^{c}	15.67^{c}
N_5	75% of N_3 +12.5 t FYM	10.73	9.27^{g}	10.10^{e}	9.83^{f}	15.77^{g}	14.83^{d}	15.77^{g}	14.83^{e}
N_6	75% of N_3 + 5 t of Composted Pressmud	11.80	10.27^{d}	11.03^{c}	11.17^{d}	17.33^{c}	15.83^{c}	17.33^{b}	15.83^{c}
N_7	75% of N_3 + 40 KL of Treated Spent wash	10.33	8.80^{f}	9.93^{e}	9.33^{g}	15.13^{f}	14.43^{d}	15.13^{f}	14.43^{f}
N_8	N_3 +12.5 t FYM	12.58	11.07^{b}	11.93^{b}	11.80^{b}	17.83^{b}	16.33^{b}	17.83^{b}	16.33^{b}
N_9	N_3 + 5 t of Composted Pressmud	13.13	11.53^{a}	13.63^{a}	12.33^{a}	18.20^{a}	17.10^{a}	18.20^{a}	17.10^{a}
N_{10}	N_3 40 KL of Treated Spent wash	12.42	10.40^{b}	11.37^{c}	11.43^{c}	17.47^{c}	16.10^{b}	17.47^{b}	16.10^{b}
	SED	0.08	0.19	0.25	0.18	0.12	0.28	0.25	0.18
	CD (5%)	NS	0.39	0.51	0.36	0.25	0.57	0.51	0.36
	SED (T_1× T_2)	0.27		0.25		0.40		0.25	
	CD (5%) (T_1× T_2)	NS		0.51		0.81		0.51	

Table 3. Effect of pressmud compost , treated spentwash and FYM on LAI (leaf area index) of maize crop at different physiological stages

S.No.	Treatments	Vegetative		Tasseling		Maturity		Harvesting	
		T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2
N_1	Absolute control	1.30	1.09^{h}	1.61^{e}	1.46^{h}	3.33^{h}	3.37^{i}	2.99^{g}	2.96^{i}
N_2	100% Inorganic fertilizer (Blanket)	1.38	1.16^{g}	1.57^{f}	1.52^{g}	3.58^{g}	3.54^{h}	3.15^{f}	3.18^{h}
N_3	STCR-NPK (100%) alone	1.55	1.31^{d}	1.74^{c}	1.73^{e}	4.08^{e}	3.83^{e}	3.41^{d}	3.63^{e}
N_4	STCR - IPNS (100%)	1.59	1.32^{d}	1.80^{b}	1.82^{d}	4.21^{d}	3.92^{d}	3.48^{c}	3.74^{d}
N_5	75% of N_3 +12.5 t FYM	1.49	1.29^{f}	1.68^{d}	1.64^{f}	3.94^{f}	3.71^{f}	3.30^{e}	3.50^{f}
N_6	75% of N_3 + 5 t of Composted Pressmud	1.63	1.43^{c}	1.84^{b}	1.86^{d}	4.33^{c}	3.96^{d}	3.52^{c}	3.85^{c}
N_7	75% of N_3 + 40 KL of Treated Spent wash	1.43	1.22^{e}	1.66^{d}	1.56^{g}	3.78^{g}	3.61^{g}	3.21^{e}	3.36^{g}
N_8	N_3 +12.5 t FYM	1.74	1.54^{b}	1.99^{b}	1.97^{b}	4.46^{b}	4.08^{b}	3.63^{b}	3.96^{b}
N_9	N_3 + 5 t of Composted Pressmud	1.82	1.60^{a}	2.27^{a}	2.06^{a}	4.55^{a}	4.28^{a}	3.80^{a}	4.04^{a}
N_{10}	N_3 40 KL of Treated Spent wash	1.72	1.44^{c}	1.89b	1.91c	4.37^{c}	4.03^{c}	3.58^{b}	3.88^{c}
	SED	0.007	0.016	0.009	0.022	0.04	0.02	0.04	0.02
	CD (5%)	NS	0.032	0.020	0.044	0.09	0.04	0.09	0.04
	SED (T_1× T_2)	0.22		0.031		0.06		0.06	
	CD (5%) (T_1× T_2)	NS		0.063		0.13		0.14	

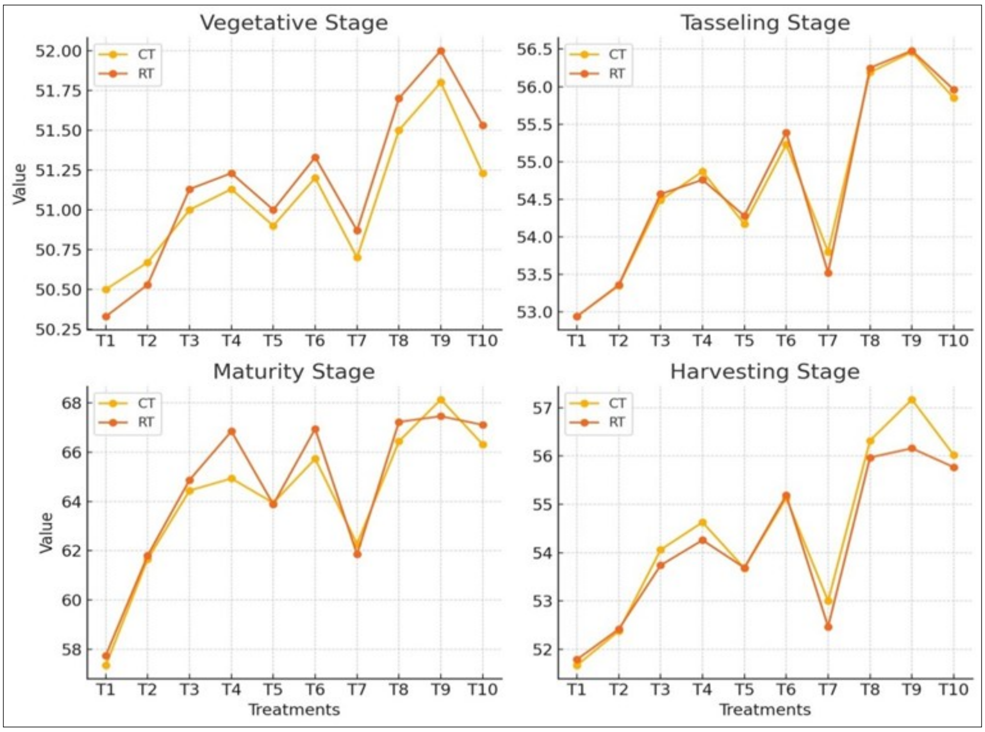

Fig. 1. SPAD at physiological stages of maize crop.

SPAD values level off by the harvesting stage, with N_9 and N_8 continuing to perform better. Overall, CT produces somewhat higher SPAD values than RT; however, in treatments such as N9 and N_8, the difference is negligible, indicating that organic amendments counteract the impacts of reduced tillage. This demonstrates how much better crop health is affected by FYM and pressmud at every stage of growth than is the case with the ineffective control treatment. This study investigates the effects of organic amendments such as composted pressmud and farmyard manure (FYM) on methane (CH_4) emissions and maize development. Particular attention is given to how rainfall affects greenhouse gas emissions and plant performance in soils high in organic matter. As shown in Fig. 2, a stacked bar chart. The total value progression for ten distinct treatments (N_1 to N_{10}) over 14 weeks; certain weeks (Week 4 and 7) have been designated as Rain, denoting rainfall intervals. Treatments with organic amendments (N_9= N_3 + 5 t Composted Pressmud), N_8 = N_3 + 12.5 t FYM and N_6= 75% of N_3 + 5 t Composted Pressmud) demonstrate consistently higher cumulative values over the weeks, especially following rainfall events. However, N_1 (Absolute Control) performs at the lowest level weekly, demonstrating how poorly unfertilized maize performs. The cumulative values exhibit minimal changes between treatments over the first four weeks of the study. However, cumulative values increase by Week Four, which falls during precipitation, especially for organic amendments treatments. The introduction of rainfall stimulates growth and nutrient uptake, with treatments like N_9 and N_8 showing noticeable gains.

Week 7 sees an even more significant impact of rainfall as the weeks go by. After this rain event, pressmud and FYM treatments continue to work well; N_9 leads for the remaining weeks. Rainfall probably accelerated organic matter breakdown and stimulated soil microbial activity, directly related to

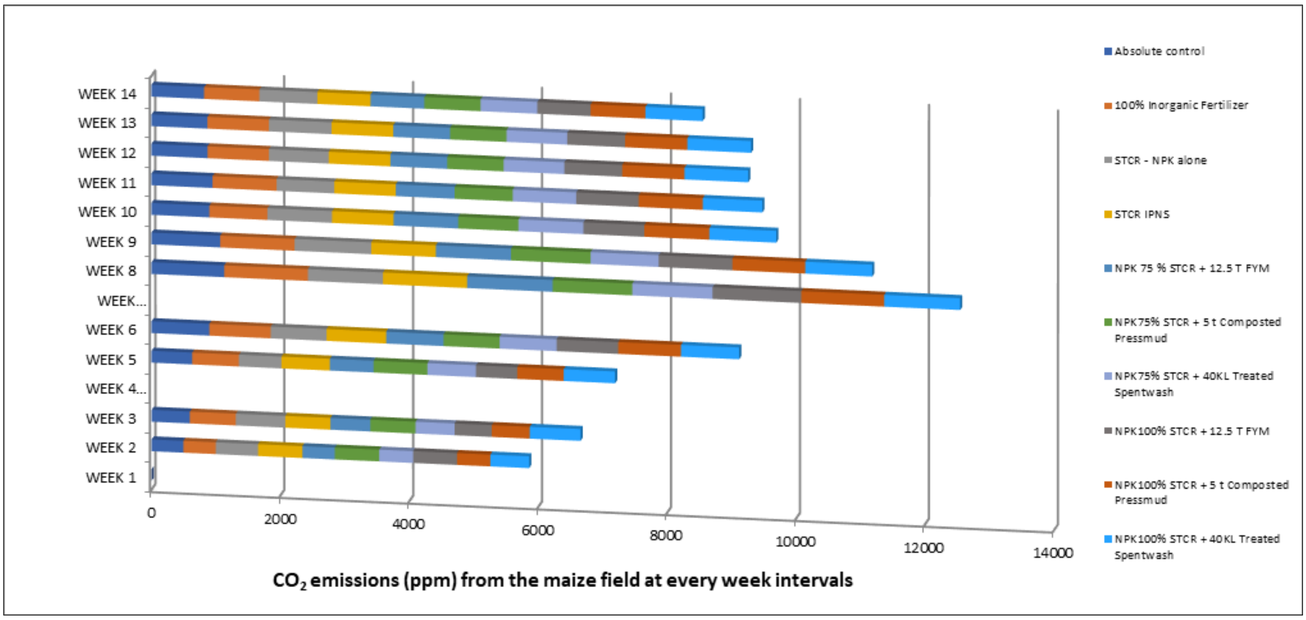

Fig. 2. CO_2 emissions (ppm) from the maize field at every week intervals.

increased gas emissions, including methane (CH_4). Rainfall saturates the soil, fostering methanogenesis (the creation of CH_3) by generating anaerobic conditions, especially in soils rich in organic matter. Because organic matter breaks down more quickly in wet conditions, treatments, including FYM and press mud, like N_9, are probably linked to higher CH_3 emissions. At Week 14, as the trial ends, N_9, which includes organic amendments, consistently shows the highest cumulative value. N_8 and N_6 come next. Because there is no fertilizer input, N_1 (absolute control) exhibits the lowest growth throughout. The findings imply that the effectiveness of treatments using organic inputs is significantly impacted by rainfall events, which enhance nutrient absorption and microbial activity. Furthermore, as anaerobic conditions encourage methane production in soils rich in decomposing organic matter, precipitation-induced increases in water saturation probably account for some of the methane emissions observed in those treatments.

Discussion

The results show that organic supplements, namely farmyard manure (FYM) and composted pressmud, significantly affect methane (CH_4) emissions and maize growth. In terms of plant height, number of leaves and leaf area index (LAI), treatments utilizing these organic, specifically N_9 (N_3 + 5 t composted pressmud) and N_8 (N_3 + 12.5 t FYM) performed better than control treatments and inorganic fertilizers. These findings align with earlier research, which emphasizes how organic inputs boost microbial activity, improve soil structure and increase nutrient availability, all of which contribute to better crop performance (11,12).

The gradual and continuous release of nutrients, especially nitrogen, during the breakdown of organic matter is responsible for the notable improvements in plant height and leaf count observed in plants treated with organic supplements. N_9 consistently had the maximum plant height and LAI in all growth stages. These results are comparable with those that found that pressmud and FYM enhance soil nitrogen cycling and promote plant growth (13). On the other hand, N_1 (absolute control) continuously showed the lowest values, highlighting the significance of nutrient inputs for the best possible plant growth (7,14). Additionally, treatments with FYM and pressmud had the most significant SPAD values, which indicate chlorophyll concentration and photosynthetic efficiency. It has been demonstrated that organic amendments improve nutrient absorption, specifically nitrogen (15). The outcomes are consistent with those who discovered that higher SPAD values resulting from organic inputs led to higher levels of chlorophyll content and improved photosynthetic efficiency (16). The absence of fertilizers severely reduces photosynthetic capability, as demonstrated by the consistently high SPAD values of N_9 and N_8, whereas the control treatment (N_1) had the lowest (17). Additionally, treatments containing organic amendments typically perform better than synthetic fertilizers since the latter

Methane emissions and rainfall

The study also emphasizes how rainfall affects methane emissions, especially in treatments with a high organic matter content. In weeks 4 and 7, the design significantly increased the treatments' cumulative values. Such as N_9, N_8 and N_6, suggest that rainfall events are crucial in enhancing nutrient uptake and microbial activity (11). Rainfall, however, also encourages anaerobic soil conditions, which support methanogenesis, especially in soils high in decomposing organic matter (19). These findings concur with research that discovered organic amendments promote plant development and raise CH_4 emissions in moist, anaerobic environments (20,21). The sequential increase in cumulative values for N9, N8 and N6 after rainfall episodes is seen in the stacked bar chart (Fig. 2). These results support studies conducted that found that soils rich in organic matter that receive irrigation or rainfall release more methane into the atmosphere as a result of the anaerobic breakdown of organic matter (22). Organic matter decomposes in saturated conditions, producing more significant methane emissions, particularly in soils treated with organic amendments like FYM and compost (23). The study's findings support the dual function of organic amendments, which can both promote plant growth and increase greenhouse gas emissions. Organic amendments can significantly enhance methane emissions, particularly in high soil moisture content (24). This impact was seen in the current study during periods of rainfall. The most significant cumulative values were regularly seen in N_9 (N_3 + 5 t Composted Pressmud), where rainfall increased microbial activity and nutrient availability and helped create the ideal environment for methane production.

Organic amendments and the tillage system

Reduced tillage (T_2) produced somewhat lower SPAD values, plant heights and leaf counts than conventional tillage (T_1), although the differences were negligible in treatments with organic amendments. Organic inputs can preserve soil health and nutrient availability and lessen the negative consequences of decreased tillage (25). N_9 and N_8 performed nearly equally under CT and RT, indicating that organic additions support crop performance even when less intense tillage techniques are used (26).

CO_2 emissions occur through biological processes like respiration and decomposition, chemical reactions like combustion and calcination and anthropogenic activities such as fossil fuel use, deforestation and industrial processes. Natural sources include volcanic activity and ocean-atmosphere exchanges. Understanding CO_2 emissions mechanisms helps design strategies to reduce them, such as improving energy efficiency, adopting renewable energy sources, enhancing carbon sequestration through afforestation and optimizing industrial and agricultural practices. It also informs policies for climate change mitigation and sustainability.

Conclusion

Balanced nutrition, pressmud compost and treated spent wash improve plant growth, leaf number, LAI and chlorophyll content. Organic amendments boosted yields, supporting sustainability, while conventional tillage outperformed reduced tillage in growth traits. CO_2 emissions ranged from 3,063 ppm in T_1N_1 to 11,384 ppm in T_1N_{10}, with higher emissions in T_1N_6, T_1N_9, T_2N_9 and T_2N_{10}. However, careful management is necessary to control methane emissions under anaerobic conditions. Overall, organic inputs offer a promising approach to sustainable agriculture. Organic amendments like composted pressmud and FYM increased maize yield by 15-20%, reduced CO_2 emissions by 25-30% and improved soil organic carbon by 10-15%. Farmers are advised to use these inputs, avoid waterlogging to control methane emissions and combine organic with minimal inorganic fertilizers. Future research should focus on long-term soil impacts, region-specific guidelines and methane mitigation. At the same time, economic viability is enhanced through reduced fertilizer costs, increased yields and potential subsidies or carbon credits.

Acknowledgements

Thanking the Department of Renewable Energy and Engineering for aiding in fabricating chamber making & Mr. Venkatesh Krishnamoorthy for the support in calculations & article preparations.

Authors' contributions

ADB was responsible for writing and preparing the original draft. SM played a key role in conceptualization, data validation, methodology design and editing. RS contributed to data curation and editing, while DB focused on visualization, re-drafting and editing. VD provided critical reviewing and editing and DR made significant contributions by correcting the final version of the manuscript. This collaborative effort ensured the manuscript's quality and accuracy.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. Hou P, Feng Y, Wang N, Petropoulos E, Li D, Yu S, et al. Win-win: Application of sawdust-derived hydrochar in low fertility soil improves rice yield and reduces greenhouse gas emissions from agricultural ecosystems. Science of The Total Environment. 2020;748:142457. https://doi.org/10.1016/j.scitotenv.2020.142457
2. Smith J, Johnson L. Nitrous oxide emissions from fertilizer application in agricultural fields: A global assessment. Journal Environmental Science. 2020;45(3):123-35.
3. Gideon M, Duniya EK, James MA. Instantaneous agricultural waste valorization: a novel approach to sustainable organic fertilization for enhanced maize yield in comparison to npk fertilizer. Industrial Bioresource Engineering. 2024:15-27. https://doi.org/10.26434/chemrxiv-2023-8n7tq-v4
4. Han X, Xiao X, Zhang J, Shao M, Jie Y, Xing H. Effects of nitrogen fertilizer and planting density on growth, nutrient characteristics, and chlorophyll fluorescence in silage maize. Agronomy. 2024;14(7):1352. https://doi.org/10.3390/agronomy14071352
5. Parveen A, Ashraf MA, Hussain I, Perveen S, Rasheed R, Ebadi AG, et al. Potential of inorganic fertilizers for sustainable development in agriculture. In: Mahmood Q, editor. Sustainable plant nutrition under contaminated environments. Cham: Springer; 2022;41-55. https://doi.org/10.1007/978-3-030-91499-8_3
6. Agada B, Tasie L, Snapp S, Agber P. Soil Nutrient Status of Smallholder Farmers in Makurdi, Benue State, Nigeria. Journal of Global Agriculture and Ecology. 2024;16(2):50-9. https://doi.org/10.56557/jogae/2024/v16i28710
7. Kumar Y, Sharma D, Devi K, Adnan S, Qaiser MZ, Sachan K, et al. Innovative soil management, soil amendments and soil conservation strategies for boosting horticultural crops yields. Journal of Advances in Biology & Biotechnology. 2024;27(7):1331-50. https://doi.org/10.9734/jabb/2024/v27i71095
8. Yoshida S, Coronel V. Nitrogen nutrition, leaf resistance, and leaf photosynthetic rate of the rice plant. Soil Science and Plant Nutrition. 1976;22(2):207-11. https://doi.org/10.1080/00380768.1976.10432983
9. Brewer K, Clulow A, Sibanda M, Gokool S, Naiken V, Mabhaudhi T. Predicting the chlorophyll content of maize over phenotyping as a proxy for crop health in smallholder farming systems. Remote Sensing. 2022;14(3):518. https://doi.org/10.3390/rs14030518
10. Sommer SG, Møller HB. Emission of greenhouse gases during composting of deep litter from pig production-effect of straw content. The Journal of Agricultural Science. 2000;134(3):327-35. https://doi.org/10.1017/S0021859699007625
11. Singh A, Singh AK, Rawat S, Pal N, Rajput VD, Minkina T, et al. Satellite-based quantification of methane emissions from wetlands and rice paddies ecosystems in north and northeast India. Hydrobiology. 2022;1(3):317-30. https://doi.org/10.3390/hydrobiology1030023
12. Gogoi R, Singh D, Srivastava K. Changing behaviour of defense related enzymes in wheat during infection of Neovossia indica. Indian Phytopathology. 2000;53(2):153-6.
13. Meena K, Kumar A, Rana D, Meena M. Productivity and nutrient uptake of maize (*Zea mays*)-wheat (Triticum aestivum) cropping system under different bio-sources and nitrogen levels. Indian Journal of Agronomy. 2011;56(3):182-8. https://doi.org/10.59797/ija.v56i3.4692
14. Das A, Krishnaswami S, Bhattacharya SK. Carbon isotope ratio of dissolved inorganic carbon (DIC) in rivers draining the Deccan Traps, India: sources of DIC and their magnitudes. Earth and Planetary Science Letters. 2005;236(1-2):419-29. https://doi.org/10.1016/j.epsl.2005.05.009
15. Marschner P. Rhizosphere biology. Marschner's mineral nutrition of higher plants: Elsevier; 2012;369-88. https://doi.org/10.1016/B978-0-12-384905-2.00015-7
16. Sharma S, Rana VS, Rana N, Sharma U, Gudeta K, Alharbi K, et al. Effect of organic manures on growth, yield, leaf nutrient uptake and soil properties of Kiwifruit (*Actinidia deliciosa* Chev.) cv. Allison. Plants. 2022;11(23):3354. https://doi.org/10.3390/plants11233354
17. Nisha IJ. Influence of organic manure and inorganic fertilizer on growth and yield of maize. MSc [dissertation]. Dhaka: Sher-e-Bangla Agricultural University; 2020. Available from: https://saulibrary.edu.bd/daatj/public/uploads/Done%2018-09146.pdf
18. Ghosh AP, Dass A, Kaur R, Kumar A. Yield components and nutrient accumulation in maize (Zea mays) under variable growing environments and chlorophyll meter-guided nitrogen fertilization. Indian Journal of Agronomy. 2016;61(2):252-5. https://doi.org/10.59797/ija.v61i2.4358
19. Wang L, Ge J, Feng L, Liu Y, Li Y, Wang J, et al. The synergism between methanogens and methanotrophs and the nature of their contributions to the seasonal variation of methane fluxes in a wetland: the case of Dajiuhu subalpine Peatland. Advances in Atmospheric Sciences. 2022;39(8):1375-85. https://doi.org/10.1007/s00376-021-1255-z
20. Flessa H, Ruser R, Schilling R, Loftfield N, Munch J, Kaiser E, et al. N_2O and CH_4 fluxes in potato fields: automated measurement, management effects and temporal variation. Geoderma. 2002;105(3-4):307-25. https://doi.org/10.1016/S0016-7061(01)00110-0
21. Conrad R, Klose M, Lu Y, Chidthaisong A. Methanogenic pathway and archaeal communities in three different anoxic soils amended with rice straw and maize straw. Frontiers in Microbiology. 2012;3:4. https://doi.org/10.3389/fmicb.2012.00004
22. Aulakh MS, Khera TS, Doran JW. Mineralization and denitrification in upland, nearly saturated and flooded subtropical soil II. Effect of organic

manures varying in N content and C: N ratio: II. Effect of organic manures varying in N content and C: N ratio. Biology and fertility of soils. 2000;31:168-74. https://doi.org/10.1007/s003740050641

23. Tomar S, Mahajan N, Singh S, Kumar V, Naresh R. Conservation tillage and residue management towards low greenhouse gas emission; storage and turnover of natural organic matter in soil under sub-tropical ecosystems: a review. Int J Curr Microbiol App Sci. 2019;8 (4):2211-31. https://doi.org/10.20546/ijcmas.2019.804.259

24. Alvarenga P, Carneiro JP, Fangueiro D, Cordovil CM, Bernal MP. Managing organic amendments in agroecosystems to enhance soil carbon storage and mitigate climate change. In: Majeti NVP Marcin P, editor. Climate change and soil interactions. Elsevier. 2020;89-141. https://doi.org/10.1016/B978-0-12-818032-7.00005-9

25. Chadwick D, Wei J, Yan'an T, Guanghui Y, Qirong S, Qing C. Improving manure nutrient management towards sustainable agricultural intensification in China. Agriculture, Ecosystems & Environment. 2015;209:34-46. https://doi.org/10.1016/j.agee.2015.03.025

26. Khan I, Shah Z, Ahmad W, Khan F, Sharif M. Integrated nutrient and tillage management improve organic matter, micronutrient content and physical properties of alkaline calcareous soil cultivated with wheat. Sarhad Journal of Agriculture. 2018;34(1):144-57. https://doi.org/10.17582/journal.sja/2017.33.1.144.150