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RESEARCH ARTICLE

EFFECT OF RICE HUSK ASH-BASED ENRICHED AMENDMENTS ON SOIL PHYSICO-CHEMICAL PROPERTIES OF MAIZE FIELD IN KHAIRAHANI, CHITWAN

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ABSTRACT

The search for sustainable soil management practices is crucial for enhancing soil health and reducing reliance on chemical fertilizers. Utilizing agricultural waste products like rice husk ash (RHA) presents a promising strategy for improving soil quality. This study aimed to evaluate the efficacy of various RHA-based organic amendments, combined with reduced doses of recommended fertilizer (RDF), on key physico-chemical properties. A field experiment was conducted employing a randomized complete block design with seven treatments: control (no amendment), recommended fertilizer, and five combinations of RHA (enriched with farmyard manure (FYM), poultry manure (PM), RDF, cattle urine and human urine) with a 50% reduction of RDF. Soil samples were tested for bulk density, particle density, pH, organic matter (OM) content, total nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) after maize cultivation. The analysis of variance showed that the application of RHA combined with organic manures and half-dose RDF significantly enhanced soil health. Treatment RHA+FYM+1/2RDF recorded the highest organic matter content (3.02%) and phosphorus availability (39.23kg/ha), which were significantly superior to the control and the recommended fertilizer treatment. Similarly, most RHA-amended treatments significantly increased available P_2O_5 compared to the control. Bulk density was significantly reduced to its lowest value (0.82 g cm^{-3}) in the RHA enriched with RDF treatment while particle density was seen insignificant. While changes in total nitrogen and pH were not statistically significant. Potassium levels were highly variable and significantly different across different treatments with treatment FYM+RHA+1/2RDF showing the highest value. These findings concluded that the integration of enriched rice husk ash with a 50% reduction of chemical fertilizers effectively improves soil quality. The combination of RHA with farmyard manure emerged as the most promising strategy to waste recycling and soil fertility management that can reduce dependency on synthetic fertilizers.

KEYWORDS

Rice Husk Ash, Soil Amendment, Soil fertility, Waste recycling

1. INTRODUCTION

1.1 Background

Maize (Zea mays L) is Nepal's most important cereal crop by area, production, and use. It supports the livelihoods of Nepalese hill farmers, serving as food, poultry and livestock feed, and fodder. Approximately 0.98 million hectares are cultivated, yielding 3.10 million metric tons (FAOSTAT, 2024). However, the national average productivity remains low at 3.15 t/ha, particularly when compared to global standards. Key issues include acidic soils, low organic carbon, and unbalanced fertilizer use especially the overuse of nitrogen (urea) while neglecting phosphorus and potassium. Such practices result in low nitrogen use efficiency (NUE), increased nutrient losses, environmental pollution, and a wide gap between potential and actual yields. Low productivity of maize is largely attributed to poor soil fertility and imbalanced nutrient management practices, including deficiencies in organic carbon (OC), nitrogen (N), phosphorus (P), potassium (K), and cation exchange capacity (CEC) (Nartey and Zhao, 2014). Furthermore, the continuous overuse of chemical fertilizers has been found to degrade soil physicochemical properties reducing permeability, increasing bulk density, and eventually lowering yields due to the accumulation of harmful salts (Brassard et al., 2016). As a result, the need for sustainable soil fertility management approaches that can enhance soil pH, organic matter content, and nutrient availability has become increasingly urgent (Bajracharya and Sherchan, 2009).

The overuse of synthetic fertilizers has also disrupted soil balance and structure, while common practices like crop residue burning further reduce soil organic content. This highlights the urgent need for sustainable, low-cost alternatives to restore and maintain soil fertility. One promising solution is the use of rice husk ash (RHA), a byproduct of rice milling rich in beneficial minerals like silica, potassium, calcium, and magnesium. While RHA improves certain soil properties, it lacks sufficient organic matter and key nutrients like nitrogen. Enriching RHA with organic and inorganic inputs can create a more balanced amendment. (De la Rosa et al., 2023). Studies show that organic inputs such as poultry manure, farmyard manure (FYM), and human urine significantly improve soil health. Poultry manure is nitrogen-rich, FYM offers balanced nutrients, and human urine provides concentrated nitrogen, phosphorus, and potassium enhancing nutrient levels and microbial activity. Combining these with RHA can improve soil structure and fertility, addressing long-standing degradation. (Zhang et al., 2019; Rasool et al., 2023).

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This study aims to assess the effect of rice husk ash enriched with organic and inorganic inputs (e.g., poultry manure, FYM, human and cow urine, and recommended NPK doses) on soil physicochemical properties. It will evaluate changes in nutrient content, organic matter, pH, water retention, and overall fertility. The goal is to promote sustainable farming practices that boost productivity and support long-term soil health in Nepal's agriculture.

1.2 Statement of Problem

Soil degradation remains a critical issue in Nepal, especially in the Terai region, where excessive use of chemical fertilizers, poor residue management, and declining organic matter have severely impacted soil health. The soil organic matter (SOM) in the Terai averages just 1.8%, far below optimal levels, leading to nutrient depletion and reduced agricultural productivity (Paudel et al., 2019). While conventional fertility management relies heavily on synthetic fertilizers, there is growing interest in sustainable alternatives like utilizing agricultural residues such as rice husk for soil improvement. Rice husk ash (RHA), a byproduct of rice milling, offers potential as a soil amendment due to its high silica content, which can enhance soil structure, nutrient retention, and plant growth (Gupta et al., 2017). Research has linked RHA application to improved soil pH, better phosphorus availability, and increased cation exchange capacity, making it a promising tool for restoring degraded soils in rice-wheat systems (Singh et al., 2013). However, the benefits of RHA can be further enhanced by enriching it with organic and inorganic inputs. Previous studies on biochar, a similar carbon-rich material, have shown that combining it with organic sources like cattle and human urine improves nutrient availability and soil fertility (Pandit et al., 2024; Derakhshan Nejad and Jung, 2017). Despite this potential, the combined effects of RHA with amendments such as poultry manure, FYM, and urine have not been thoroughly studied in Nepal's farming systems. This study, therefore, aims to evaluate the impact of rice husk ash enriched with organic and inorganic inputs on key soil properties. The goal is to improve nutrient availability, soil structure, and support more sustainable, cost-effective farming practices. By exploring these combinations, the research hopes to offer practical solutions for rehabilitating degraded soils and boosting productivity in Nepal's agricultural sector.

1.3 Rationale of Study

Soil degradation in Nepal, particularly in the Terai region, has become a critical issue due to declining organic matter, excessive use of chemical fertilizers, and poor residue management. The organic matter content in Terai soils has dropped to just 1.8%, well below the optimal 2.5% found in the western hills, contributing to reduced fertility, lower crop productivity, and environmental pollution from synthetic inputs (Gairhe et al., 2021). As a result, there's an urgent need for sustainable soil fertility practices that minimize chemical dependence. Rice husk ash (RHA), a rice milling byproduct abundant in the Terai, is rich in silica, potassium, and other minerals that can improve soil pH, structure, and nutrient retention (Rana et al., 2018). However, RHA alone lacks sufficient nutrients, particularly nitrogen. Its effectiveness can be significantly improved when combined with nutrient-rich organic inputs.

Human urine, poultry manure (PM), and farmyard manure (FYM) are excellent nutrient sources urine being high in nitrogen, phosphorus, and potassium, PM offering concentrated nitrogen, and FYM contributing a balanced nutrient profile (Zhang et al., 2019; Agarwal et al., 2017). When used together with RHA, these inputs can enhance soil nutrient content, organic carbon levels, and moisture retention. The integration of rice husk ash (RHA) offers a sustainable alternative to agrochemical fertilizers while addressing the issue of agricultural waste management. As a by-product rich in nutrients, RHA can enhance soil fertility and structure, supporting environmentally friendly and low-cost farming practices. This study focuses on the enrichment of RHA with locally available materials such as urine, providing a practical solution to improve nutrient availability in the soil. By promoting the use of organic amendments, the research aims to improve soil health, reduce dependency on synthetic inputs, and contribute to narrowing the maize yield gap, ultimately supporting long-term agricultural productivity and sustainability in Nepal.

1.4 Objectives

1.4.1 Broad objective

- To explore the potentiality of nutrient enriched rice husk ash on soil physico-chemical properties.

1.4.2 Specific objectives

- To examine the effect of nutrient enriched RHA on soil organic matter.
- To examine the effect of nutrient enriched RHA on soil pH.
- To examine the effect of nutrient enriched RHA on NPK.

1.5 Hypothesis

1.5.1 Null hypothesis

- Null hypothesis (H0): RHA amendments does not enhance soil physico-chemical properties.

1.5.2 Alternate hypothesis

- Alternate hypothesis (H1): RHA amendments significantly enhances maize physico-chemical properties.

2. Literature Review

2.1 Maize production scenario

Maize is one of the world's most important crops, cultivated on about 205 million hectares in 2022/23 with a production of 1,163 million tons, which grew to nearly 1.2 billion tons in 2023 showing a steady 3% annual rise since 1993 (FAO, 2024). By 2024/25, global output is expected to reach 1,220 million tons, with the USA as the leading producer, contributing over 30%, followed by China at 23%, Brazil at 8.8%, the EU at 5.9%, and Argentina at 4.5% (CARP, 2024). In contrast, Nepal grows maize on 0.91 million hectares, producing only about 3.19 million tons (MoALD, 2023/24), much lower than global levels. With demand increasing by 4–6% annually, Nepal's modest yield growth of just 0.5% cannot keep pace, leading to large imports. Forecasts suggest that by 2029/30, cultivation area may rise slightly, and production and yield will see modest gains, yet these improvements still fall short of meeting the country's rapidly growing maize demand (Poudel, 2024).

2.2 Rice Husk Ash (RHA)

Rice husk ash (RHA) is a byproduct generated from the combustion of rice husks, which make up about 20–22% of the total weight of rice grains. With increasing rice production in countries like Nepal and China, the disposal of rice husk has posed environmental challenges, especially due to practices like open burning and landfilling. However, controlled burning transforms rice husk into RHA, a nutrient-rich material containing potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), and silicon (Si). RHA is characterized by its porous structure, high specific surface area, and moderate alkalinity. These properties contribute to its excellent moisture retention, adsorption capacity, and cation exchange ability, as observed through scanning electron microscopy (SEM). This makes RHA a valuable agricultural input for neutralizing acidic soils and improving soil structure and fertility.

In agricultural use, RHA functions as an eco-friendly and cost-effective soil amendment, offering similar benefits to materials like biochar and peat. It enhances aeration, nutrient retention, and can even reduce heavy metal uptake in crops by immobilizing toxic elements such as cadmium (Cd) and lead (Pb) (Derakhshan Nejad and Jung, 2017; Bian et al., 2022). As a result, RHA holds great promise for sustainable soil management and crop production in rice-growing regions.

2.3 Physical Properties of RHA

Rice husk ash (RHA) is highly valued for its physical properties, especially its high porosity and large specific surface area (SSA), which enhance water-holding capacity, air permeability, and soil aggregation. These characteristics improve soil aeration and reduce bulk density, making RHA beneficial for degraded or compacted soils (Gupta et al., 2017). Its lightweight and porous nature also supports better root penetration and moisture retention, similar to biochar and peat but at a lower cost.

2.4 Chemical Properties of RHA

Rice husk ash (RHA) is chemically rich in essential nutrients like potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), and silicon (Si), which are vital for plant metabolism and growth. . In addition to silica, RHA was reported to have a total nitrogen content of 0.14%, organic carbon content of 10.53%, potassium content of about 2%, and various other elements including magnesium, calcium, copper, sodium, aluminium, phosphorus, sulphur, chloride, and iron, depending on its origin and processing method (Dedik Budianta et al., 2022; Rahmaniah and Azwana, 2023; Singh et al., 2019). The presence of these minerals and significant amounts of C, N, and S shows their potential as soil ameliorants.

Similarly, RHA was found to have a moderately alkaline pH (10.54 ± 0.03), potentially due to carbonates formed during heating or lime treatment after silica extraction (Singh et al., 2019)

2.5 RHA for Soil Health and Sustainability

Rice husk ash (RHA), a byproduct of rice milling, has gained attention as an effective soil amendment due to its rich silica, potassium, and phosphorus content. When applied alone or enriched with organic sources like farmyard manure (FYM), poultry manure, or urine, RHA enhances soil structure, organic matter, and nutrient retention, improving crop productivity and reducing dependency on chemical fertilizers (Derakhshan Nejad and Jung, 2017). Additionally, urine-enriched biochar, a similar carbon-rich form of RHA has shown to increase maize yield by up to 62%, improve nitrogen use efficiency, and regulate soil pH more effectively than standard biochar (Subendra Shrestha and Amatya, 2022). Such integrated nutrient management strategies offer promising solutions for degraded soils, especially in Nepal, where declining soil fertility remains a significant challenge.

Beyond nutrient enhancement, RHA also support environmental sustainability. Studies have shown that biochar from rice husk significantly reduces the mobility and plant uptake of heavy metals like cadmium (Cd), lead (Pb), and nickel (Ni), enhancing food safety (Bian et al., 2022; Derakhshan Nejad and Jung, 2017). In rice–wheat cropping systems, combining RHA with mineral fertilizers and FYM has improved soil biophysical properties, crop yields, and phosphorus use efficiency. Notably, human and cattle urine used as nutrient-enriching agents have been effective in boosting maize growth and yields, offering eco-friendly and low-cost alternatives to synthetic fertilizers. These approaches also reduce greenhouse gas emissions and nutrient runoff, promoting long-term soil and environmental health in smallholder systems.

2.6 Organic and Inorganic Nutrient Amendment with RHA

Combining RHA with organic inputs like FYM, poultry manure, and urine enhances nutrient supply, microbial activity, and organic matter content. Human and cattle urine, rich in nitrogen and micronutrients, have shown effectiveness in boosting fertility when used with RHA (Shrestha and Amatya, 2023). Inorganic fertilizers like NPK provide immediate nutrient availability, and when integrated with RHA, they improve phosphorus and potassium uptake while reducing dependence on synthetic inputs. This synergy improves both physical and chemical soil properties, supporting sustainable and productive farming systems (Pandit et al., 2024).

3. Materials And Methodology

3.1 Description of Experimental site

The experiment was conducted from Chaitra 12, 2081 to Ashad 2082 at the Agronomical Research Farm of Rampur Campus in Khairahani-6, Chitwan. The location of the farm was at 27.65°N latitude, 84.35°E longitude, with an elevation of 215 masl according to NASA POWER data.

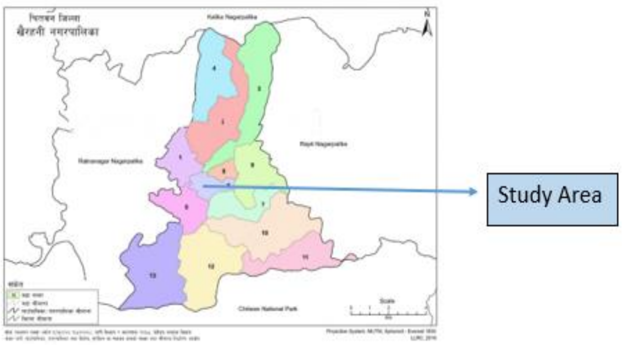

Figure 1: Map of Khairahani district showing research location

3.2 Experimental Details

3.2.1 Experimental Design

In this study, a Randomised Complete Block Design (RCBD), experimental design was employed to investigate the effects of different factors on soil physical and chemical properties.

3.3 Experimental Setup

Design = Randomized Complete Block Design

No. of plot per replication = 7

Total no of replication= 3

Total area of field= 4.8m^2

No. of plants per row= 10

No. of plants per plot= 40

Spacing of plants = 60×20 cm^2

Spacing in between plots= 50 cm

Spacing in between replication = 1m

3.4 Treatment Details

Table 1: Treatments Details

Treatments	Details
T1	Control
T2	Recommended dose of fertilizer (RDF)
T3	RHA + FYM + 50% RDF
T4	RHA + PM + 50% RDF
T5	RDF Enriched RHA
T6	CU Enriched RHA + 50% RDF
T7	HU Enriched RHA + 50% RDF

RDF= Recommended dose of fertilizer (130: 60: 40 kg NPK/ha)

RHA=Rice husk ash (10t/ha)

PM=Poultry Manure (10t/ha)

FYM =Farmyard manure (10t/ha)

CU =Cow urine (2l / m^2)

HU= Human urine (2l / m^2)

3.5 Experimental Layout

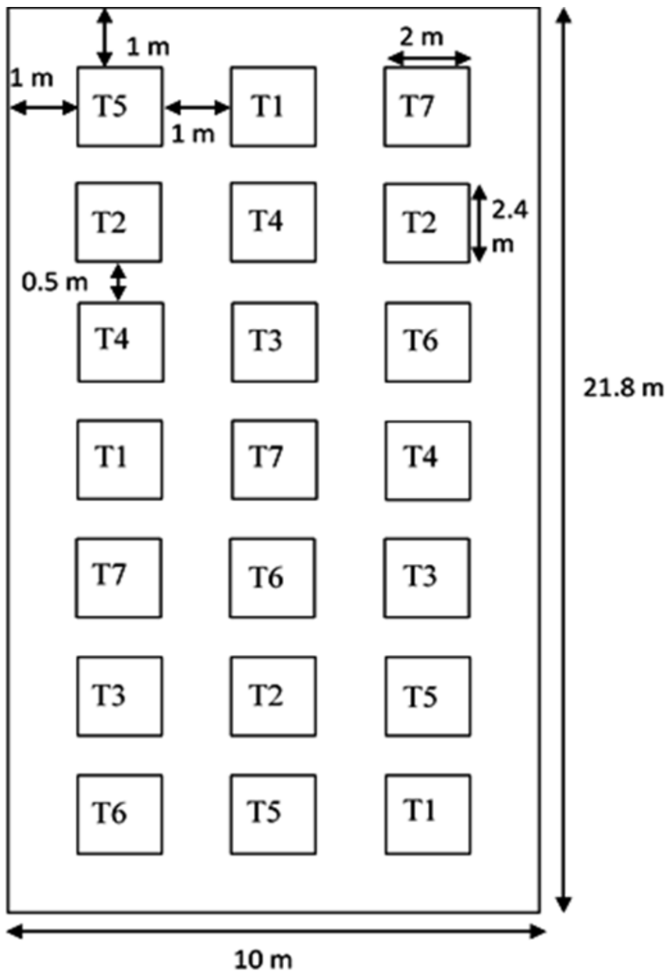

Figure 2: Field layout and Randomization

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3.6 Rice Husk Ash production, collection and enrichment

Rice husk ash (RHA) used in this study was obtained from a local rice mill, where it is produced as a byproduct through the combustion of rice husks during milling. The ash was collected from the mill's designated dumping area where it is usually discarded. After collection, the RHA was subjected to enrichment treatments using various organic and inorganic nutrient sources to enhance its soil amendment potential. Five different enrichment methods were used: (1) RHA soaked in cow urine for 48 hours, (2) RHA soaked in human urine for 48 hours, (3) RHA mixed with the recommended dose of NPK fertilizers, (4) RHA combined with poultry manure, and (5) RHA mixed with farmyard manure (FYM). These enriched RHA formulations were then applied to the field to evaluate their effects on soil properties and crop performance.

3.7 Cultural Practices

3.7.1 Field preparation

The field was tilled twice with a tractor-driven cultivator 20 days prior to sowing to aerate and prepare the soil. Weeds and stubbles were cleared to reduce competition with the crop. Farm Yard Manure (FYM) was incorporated into the soil using spades 15 days before planting, creating the ideal conditions for crop growth.

3.7.2 Manure, fertilizer and RHA application

- RHA was soaked with cow and human urine for 48 hours before incorporation
- RHA was uniformly incorporated with FYM and poultry manure before applying into the field.
- RHA was enriched with recommended dose of fertilizer uniformly before applying into the field
- Basal dose of NPK was applied except in control plot and where RDF enriched RHA was to be applied.
- The treatments were assigned to their respective plots.

3.7.3 Seed sowing

3.7.3.1 Seed rate

2 seeds/planting hole were applied which was calculated as 8gm/plot.

3.7.3.2 Sowing method

- Row Spacing: A row spacing of 60 cm between rows and 20 cm between plants within a row was implemented. This arrangement promotes efficient plant growth and facilitates agricultural operations.
- Seed Placement: Furrows were created at a depth of 5-6 cm. Two seeds were sown in a line within each furrow and covered with a thin layer of soil. This method ensures proper seed-to-soil contact, promoting germination and early growth.

3.7.4 Irrigation

One irrigation was applied before sowing maize to enhance soil moisture for germination. Subsequently, irrigation was provided at critical stages, with soil moisture levels monitored visually. Irrigation was carried out at the knee-high stage and again at 45-50 days, precisely during the tasseling stage.

3.7.5 Thinning and gap filling

Thinning and gap filling in maize cultivation was carried out precisely 15 days after sowing, to ensure proper spacing and optimize crop productivity.

3.7.6 Plant protection

Pheromone trap along with foliar application of Emamectin Benzoate were integrated.

3.7.7 Weeding

Manual weeding was carried out 3-4 times.

3.7.8 Earthing up

Earthing up was done once at knee height stage.

3.7.9 Harvesting and Threshing

Manual Harvesting was done by dismantling the cobs.

3.8 Soil sampling procedure and analysis

The soil sample was collected after harvest of the maize from each plot i.e. 21 plots in Z pattern and further analysis was done in the laboratory.

3.9 Observations taken

Table 2: Observations taken of residual soil after maize harvest.

S.N	Parameters	Unit	Method
1.	Soil bulk density	gm/cm^3	Undisturbed core sampling method.
2.	Soil Particle Density	gm/cm^3	Using pycnometer
3.	Soil pH	-	Digital pH meter (potentiometry)
4.	Organic matter	%	Walkley and Black (1934)
5.	Total Nitrogen	%	OM * 0.05
6.	Available Phosphorus	Kg/ha	Olsen's bicarbonate (Olsen et al.,1954)
7.	Available Potassium	Kg/ha	Ammonium acetate (Jackson,1967)

3.10 Statistical Analysis

Data entry will be done through MS-EXCEL and analysis through Rstudio, ANOVA at 5% level of significance.

4. Results And Discussion

4.1 Soil Bulk Density

Table 9 reveals significant differences in soil bulk density (BD) across treatments with T3 (RHA + FYM + 1/2 RDF) and T5 (RDF Enriched RHA) showing the lowest BD compared to the control. The reduced BD indicates less compacted, more porous soil, promoting stable aggregate formation, organic matter accumulation, and enhanced microbial and earthworm activity (Qu et al., 2014). The lightweight, porous nature of RHA, combined with organic amendments like FYM and human urine, likely improved soil porosity and reduced compaction (Blanco-Canqui, 2017). These findings suggest that RHA and organic amendments effectively improve soil physical properties, supporting better root growth and nutrient cycling, though long-term applications may further optimize soil health.

4.2 Soil Particle Density

There was no significant differences in soil particle density across treatments (F-test: NS), though most treatments had numerically lower density than the control, indicating less compacted, more porous soil that aids root penetration and water infiltration. This likely stems from low-density organic matter (FYM, PM) and porous RHA, which enhance soil structure (Pansu and Gautheyrou, 2006; Ghobadi and Abdilor, 2013). The lack of significance suggests short-term applications were insufficient to overcome soil variability (Brady and Weil, 2016). Long-term use of RHA and organic amendments could further improve soil physical properties.

Table 3: Effects of different nutrients enriched RHA on Bulk Density and Particle Density of soil in Khairahani, Chitwan.

Treatment	BD(gm/cm^3)	PD(gm/cm^3)
T1(Control)	1.10[a]	1.70[a]
T2(Recommended Fertilizer)	0.91[bc]	1.33[ab]
T3(RHA+FYM+1/2RDF)	0.83[c]	1.35[ab]
T4(RHA+PM+1/2RDF)	0.88[bc]	1.28[b]
T5(RDF Enriched RHA)	0.82[c]	1.25[b]
T6(CU Enriched RHA+1/2RDF)	0.97[b]	1.31[ab]

Table 3 (Conts): Effects of different nutrients enriched RHA on Bulk Density and Particle Density of soil in Khairahani, Chitwan.

T7(HU Enriched RHA+1/2RDF)	0.84[c]	1.15[b]
Grand mean	0.91	1.34
LSD	0.11	0.296
F-test	**	NS
SEM(±)	0.04	0.06
CV%	6.96	12.73

Note : NS, not significant; **, significant at the 0.01 probability level., Figure sharing same letter did not differ significantly at 5% level of significance, CU=Cow urine ,HU=Human urine, RHA=rice husk ash, RDF=recommended dose of fertilizer, FYM= Farmyard manure ,PM= Poultry manure, LSD=Least significant difference ,CV= coefficient of variance , SEM=Standard error of mean.

4.3 Soil pH

We observed no significant increase in soil pH, this is likely due to the soil's high clay and organic matter content, which buffers pH shifts through high cation exchange capacity (Brady and Weil, 2016; Bohn et al., 2001). Despite slight pH increases in RHA-based treatments (e.g., T4 and T6 at 5.56), attributed due to RHA's alkaline properties and synergy with poultry manure or cow urine, the soil's buffering capacity limited significant changes (Prasetyo et al., 2018; Hue and Licudine, 1999). Acidic inputs like fertilizers and human urine (T2: 5.30, T7: 5.43) were similarly neutralized (Bolan et al., 1991).

Table 4: Effects of different nutrients enriched RHA on pH of soil in Khairahani, Chitwan.

Treatment	pH
T1(Control)	5.50
T2(Recommended fertilizer)	5.30
T3(RHA+FYM+1/2RDF)	5.46
T4(RHA+PM+1/2RDF)	5.56
T5(RDF Enriched RHA)	5.40
T6(CU Enriched RHA+1/2RDF)	5.56
T7(HU Enriched RHA+1/2RDF)	5.43
Grand Mean	5.462
LSD	0.365
F-test	NS
SEM(±)	0.12
CV%	3.76

Note: NS, not significant, CU=Cow urine, HU=Human urine, RHA=rice husk ash, RDF=recommended dose of fertilizer, FYM= Farmyard manure, PM= Poultry manure, LSD=Least significant difference, CV= coefficient of variance, SEM= Standard error of mean.

These findings suggest that while RHA and organic amendments show potential for gradual pH improvement, long-term applications are needed for significant effects in highly buffered soils (Fageria and Baligar, 2008). But there was increase in pH after addition of RHA.

4.4 Soil Organic Matter

Table 4 reveals significant differences in soil organic matter (OM) across treatments, with T3 (RHA + FYM + 1/2 RDF) recording the highest OM at 3.02%, significantly higher than the control and other treatments. The superior OM in T3 is likely due to farmyard manure (FYM), a stable source of complex organic matter with slowly decomposing plant fibers and animal waste, which promotes long-term carbon accumulation (Singh et al., 2018). Compared to the control, all treatments (T2–T7) significantly increased OM, driven by carbon and nutrient inputs from RHA, poultry manure (PM), and urine amendments (De la Rosa et al., 2023). These findings underscore the efficacy of integrating organic amendments like FYM with RHA to enhance soil OM, supporting long-term soil fertility and carbon sequestration (Lal, 2004).

4.5 Soil Total Nitrogen

There was no significant differences in soil total nitrogen (N %) across treatments, ranging from 0.12% (T1, T4, T5) to 0.14% (T3). This is likely due to maize's high nitrogen uptake, depleting available N, and losses via leaching and volatilization (Havlin et al., 2014; Zhu and Chen, 2002). RHA may have immobilized some N by stimulating microbes, similar to biochar (Clough et al., 2013). T3 (RHA + FYM + 1/2 RDF) showed slightly higher N, likely from FYM's slow-release N, but short-term applications limited significant buildup (Tiessen et al., 1994).

Table 5: Effects of different nutrients enriched RHA on Organic matter and total Nitrogen of soil in Khairahani, Chitwan.

Treatment	O.M%	N%
T1(Control)	2.05[c]	0.12
T2(Recommended Fertilizer)	2.52[b]	0.13
T3(RHA+FYM+1/2RDF)	3.02[a]	0.14
T4(RHA+PM+1/2RDF)	2.57[b]	0.12
T5(RDF Enriched RHA)	2.57[b]	0.12
T6(CU Enriched RHA+1/2RDF)	2.75[b]	0.13
T7(HU Enriched RHA+1/2RDF)	2.66[b]	0.13
Grand mean	2.593	0.13
LSD	0.264	0.02
F-test	***	NS
SEM(±)	0.0857	0.007
CV%	5.722	9.78

Note : NS, not significant; ***, significant at the 0.001 probability level, Figure sharing same letter did not differ significantly at 5% level of significance, CU=Cow urine ,HU=Human urine, RHA=rice husk ash, RDF=recommended dose of fertilize, FYM= Farmyard manure ,PM= Poultry manure, LSD=Least significant difference ,CV= coefficient of variance , SEM=Standard error of mean.

4.6 Soil available Phosphorus

We observed significant increases in soil available phosphorus (P_2O_5) across treatments with T3 (RHA + FYM + 1/2 RDF) highest. RHA enhances P availability by increasing cation exchange capacity, reducing P fixation, and supplying P_2O_5 (0.32–0.44%) (Hashim et al., 1996). FYM (0.49% P_2O_5) and urine (0.58–0.87% P_2O_5) further boost P through mineralization (Chahal et al., 2020; Bationo et al., 2007). The control had the lowest P due to no amendments. Combining RHA with organic inputs is effective for improving P availability, but long-term studies are needed to assess sustainability (Nziguheba et al., 2016).

4.7 Soil available Potassium

Table 7 shows a significant increase in soil available potassium (K_2O) across treatments with T3 (RHA + FYM + 1/2 RDF) highest, followed by T6. RHA's high potassium content (0.85–1.50% K_2O) ; and FYM's release of available K^+ boosted levels in T3 (Hashim et al., 1996; Priyadharshini and Seran, 2009). T6 benefited from cow urine's rapid K supply (Pradhan et al., 2017). The control was lowest due to no amendments. These findings highlight the efficacy of combining RHA with FYM or cow urine to boost soil K availability, supporting improved crop nutrition.

Table 6: Effects of different nutrients enriched RHA on available Phosphorus and Potassium of soil in Khairahani, Chitwan.

Treatment	P_2O_5(kg/ha)	K_2O(kg/ha)
T1(Control)	31.73 [c]	109.65 [d]
T2(Recommended fertilizer)	35.50 [b]	181.12 [bcd]
T3(RHA+FYM+1/2RDF)	39.23 [a]	310.18 [a]
T4(RHA+PM+1/2RDF)	36.71 [b]	210.35 [bc]
T5(RDF Enriched RHA)	38.36 [a]	177.92 [bcd]
T6(CU Enriched+RHA+1/2RDF)	37.96 [a]	250.72 [ab]
T7(HU Enriched RHA+1/2RDF)	38.50 [a]	147.52 [cd]
Grand Mean	36.86	198.21
LSD	1.21	83.09
F-test	***	**
SEM(±)	0.39	26.966
CV%	1.84	23.56

Note; **,Significant at 0.01 probability level ;***, significant at the 0.001 probability level, Figure sharing same letter did not differ significantly at 5% level of significance ,CU=Cow urine ,HU=Human urine, RHA=rice husk ash, RDF=recommended dose of fertilizer, FYM= Farmyard manure ,PM= Poultry manure, LSD=Least significant difference ,CV= coefficient of variance , SEM=Standard error of mean.

5. Conclusion

This research demonstrated that application of Rice Husk Ash (RHA) with organic amendments and reduced fertilizer doses improved soil physical structures and the availability of nitrogen, phosphorus, and potassium, enhancing overall soil health. Moreover, the integration of RHA accelerated organic matter accumulation that contributed to better soil structure and microbial activity. The combination of RHA and Farmyard Manure (FYM) proved most effective, yielding the highest nutrient levels and outperforming both the control and the full fertilizer dose. These results highlight that integrating RHA with FYM and lower fertilizer inputs is a sustainable approach for improving soil fertility and long-term productivity.

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