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Effect of Integrated Nutrient Management Practices on Soil Nutrient Availability, Growth and Yield of Sunflower in Kailari, Kailali

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Abstract

The experiment was conducted from February 2024 to June 2024 in Kailari Rural Municipality, Kailali, Nepal to evaluate the effect of different organic fertilizers and sulfur on soil nutrient availability, growth and yield of sunflower. The experiment was carried out in a randomized complete block design with nine treatments and three replications. The nine treatments comprised of T1- Control, T2- Recommended Dose of Fertilizer(RDF), T3- RDF + Compost manure, T4- RDF + Poultry Manure, T5- RDF + Sulfur, T6- RDF + Compost Manure + Poultry Manure, T7- RDF + Compost Manure + Sulfur, T8- RDF + Poultry Manure + Sulfur, T9- RDF + Compost Manure + Poultry Manure + Sulfur. Results showed that combined application of RDF+CM+PM+Sulfur was found significantly superior on plant height (113.59 cm), stem diameter (22.20mm), flower diameter (11.60cm), grain per flower (570.11), grain yield (1179.95 kg/ha), biological yield (5799.25 kg/ha). Similarly, the treatments that received organic manure significantly affected soil parameters such as pH, organic matter, available nitrogen, water-holding capacity and porosity. The highest yield was observed in RDF+CM+PM+S (1179.95kg/ha) followed by RDF+PM+S (1121.52 kg/ha) which was 37.77 % and 30.95 % higher than control. This combination also enhanced soil quality by improving various soil parameters, underscoring the benefits of integrated nutrient management for sustainable agriculture. Recommended dose of fertilizers alone had a higher BC ratio

(1.79), however recommended dose of fertilizers with compost manure (RDF+CM) was more eco-friendly (1.39 BC ratio).

Keywords: Integrated nutrient management, poultry manure, soil parameters, Suryamukhi

Introduction

Sunflower (*Helianthus annuus* L.), commonly referred to as "Suryamukhi," in Nepal is a day-neutral, short-lived, oil seed and ornamental crop grown worldwide (Thapa et al., 2022; Shahi & Dhakal, 2022). It bears high nutrients (Bharose et al., 2014) as well as medicinal properties (Adeleke & Babalola, 2020). Sunflowers are widely grown in many countries around the world with a global production of 5.4 million tons in a cultivation area of 2,925.7 hectares (FOASTAT, 2022). In Nepal, the area, production and productivity of the sunflower is 4,217 ha, 5,525t and 1.31 t/ha respectively (MoALD, 2023). At present oil seed demand is increasing in Nepal day by day and oilseed produced in Nepal is unable to meet this demand due to lower productivity of sunflower in Nepal as compared to other countries. (Thapa et al., 2022). The lower productivity of sunflowers might be due to lack of improved seed, improper water and nutrient management, increased insect pest attack etc. Among them, the nutrient is the most important factor for better production of sunflower. The continuously improper application of chemical fertilizers not only increase the yield but also changes soil physicochemical and biological properties along with declined microbial activity and diversity in soil, reduced soil fertility, polluted air, water and losses important nutrients with decreased quality of agricultural soil (Pahalvi et al., 2021; Jote, 2023).

Integrated and balanced use of nutrient management practices for sunflower can contribute to justifiable growth, yield and quality, influences plant health and diminishes environmental risks. Organic fertilizers are biological and derived from plants, animals and manures while inorganic fertilizers are synthetically derived chemical constituents. When organic manures and inorganic fertilizers are used in balance and harmony, sunflower vegetative development is significantly increased in terms of plant height, leaf area, stem and disc diameter and fresh biomass (Thapa et al., 2022). Compost and other natural fertilizers can stabilize soil pH, increase soil nutrient status and eventually make strides in plant development and yields (Adebayo et al., 2012). Composted poultry manure has been demonstrated to reduce plant pathogenic fungus and perhaps increase microbial activity when applied to soil (Raja & Rajkumar, 2020). Sulfur played a significant effect on the enzymatic processes, achene output, oil and protein production, improved quality, and chemical makeup of seeds in oil seed plants. Applying sulfur resulted in a notable increase in sunflower plant height, dry matter and seed weight, head diameter, oil %, and biological yields (Saleem et al., 2019).

The addition of organic amendments may improve soil physicochemical, biochemical and microbiological properties involved in biogeochemical cycles and thus positively influence plant productivity parameters. The organic amendments are a source of slow-releasing nutrients and highly available energy for soil microorganisms (Gomez et al., 2006). Therefore, this research was conducted at Kailari municipality, Kailali, Nepal with an objects to find discover the effect of integrated nutrient management practices on soil nutrient availability, growth and yield of sunflower.

Materials and Methods

Experimental Site

The experiment was carried out at Kailari-08 Lausa, Kailali, Nepal. Geographically, it is located at an elevation of 176 meters above mean sea level on the latitude of 28º40'50"N and longitude of 80º49'17"E. The average maximum temperature was 35.46ºC, minimum temperature was 18.02ºC, rainfall (4.23 mm) and relative humidity was 55.83% during the experimental period.

Initial Soil Properties of the Research Site

The soil tested was classified as sandy clay loam, with a slightly alkaline pH of 7.32. It had a bulk density of 1.37 gcm^{-3} and a particle density of 2.14 gcm^{-3}, suggesting moderate compaction. The water holding capacity was relatively high at 53.84%, while the porosity is 35.5%, which may limit soil aeration. Organic matter content was low at 0.71%, and the available nutrients were also modest, with nitrogen at 0.04%, phosphorus at 12.58 kg ha^{-1}, and potassium at 88.15 kg ha^{-1}. These characteristics indicated that while the soil retains moisture well, it may require fertilization to support optimal plant growth.

Table 1

Initial soil properties of the research site.

Parameters	Results
Soil pH	7.32
Bulk Density (g cm^{-3})	1.37
Particle Density (g cm^{-3})	2.14
Water Holding Capacity	53.84
Porosity (%)	35.5
Organic Matter (%)	0.71
Available Nitrogen (%)	0.04
Available Phosphorus (kg ha^{-1})	12.58
Available Potassium (kg ha^{-1})	88.15
Sulfur (kg ha^{-1})	6.95
Soil Texture	Sandy clay loam

Source: Soil and Fertilizer Testing Laboratory Sundarpur, Kanchanpur, 2024

Experimental Design

The experiment followed a Randomized complete block design (RCBD) with nine treatments viz. T_1- Control, T_2- Recommended Dose of Fertilizer (RDF) @60:40:20 NPK kg ha^{-1}, T_3- RDF+Compost manure @6 t ha^{-1}, T_4- RDF+Poultry manure@6 t ha^{-1}, T_5- RDF+Sulfur@40 kg ha^{-1}, T_6- RDF+Compost manure+Poultry manure, T_7- RDF+Compost manure+Sulfur, T_8- RDF+Poultry manure+Sulfur, T_9- RDF+Compost manure+Poultry manure+Sulfur and treatment each replicated three times. There were 27 plots in total, with 0.5 meters between plots and 1 meter between replications. The total area of the experimental area was 370.5m^2 with each plot size 7.5m^2.

Cultural Practices

The seed of sunflower was sown at a spacing of 30 cm plant to plant and 60 cm row to row. Each plot contained 40 plants, arranged in rows having 8 plants each. Compost manure (6t ha^{-1}), Poultry manure (6tha^{-1}), Sulfur (40kg ha^{-1}) and RDF (60:40:20 kg NPK ha^{-1}) was applied according to the treatment combination. A full dose of Phosphorus, Potassium, Sulfur and half dose of Nitrogen was applied as a basal application while half dose of nitrogen was top dressed in two split doses viz. at 30 days after sowing and at flowering stage.

Soil and Manure Test

Following sunflower harvest, a soil sample was collected from each treatment from a depth of 15 cm and subjected to routine test. Similarly, the sample of compost and poultry manure was forwarded to the seed and fertilizers testing laboratory at Sundarpur, Kanchanpur for nutrient analysis.

Table 2

Composition of Poultry Manure and Compost Manure.

Parameters	Poultry Manure	Compost Manure
Moisture (%)	18.88	33.3
pH	5.61	6.68
Organic Carbon (%)	18.63	21.70
Nitrogen (%)	1.01	0.96
Phosphorus (%)	0.74	0.88
Potassium (%)	1.34	2.40
C:N ratio	18.4:1	22.6:1

Source: Soil and Fertilizer Testing Laboratory Sundarpur, Kanchanpur, 2024

Statistical Analysis

The data collected for various characteristics were statistically analyzed to determine significant differences among the treatments of sunflowers and their interactions. The significant differences among treatment means were assessed using the Duncan Multiple Range Test (DMRT) at a 5% level of significance. The recorded data were entered in MS-excel and analyzed using R, The calculation of the cost of cultivation and gross return of all the 9 treatments were done and B:C ratio was observed.

Results and Discussion

Growth Parameters

Fertilizer application significantly influenced sunflower growth parameters at harvest but not at 60 DAS. The highest plant height (113.53 cm) and stem diameter (22.20 mm) were recorded in RDF+CM+PM+S, with plant height increasing by 17.83% and stem diameter by 34.55% compared to the control. Similar findings were reported by Singh et al. (2023), Permual et al. (2019), Rasool et al. (2013), Khan et al. (2022). In stem diameter similar trends were observed for RDF+PM+S and RDF+CM+S treatments i.e. 21.37mm. The positive effects are attributed to improved nutrient availability from the combined use of organic and inorganic fertilizers, enhancing vegetative growth traits such as plant height, stem diameter, and seed length (Kareem et al., 2021).

Table 3

Effect of integrated nutrient management on plant height and stem diameter of sunflower

Treatments	Plant Height (cm)		Stem diameter (mm)	
	60 DAS	At harvest	60 DAS	At harvest
Control	55.37	96.40^{b}	13.25	17.20^{c}
RDF	58.29	103.45^{ab}	13.25	19.54^{bc}
RDF+CM	61.79	107.13^{a}	14.29	19.66^{a-c}
RDF+PM	61.37	107.20^{a}	14.87	19.41^{bc}
RDF+S	61.16	111.05^{a}	14.95	19.12^{bc}
RDF+CM+PM	63.29	110.64^{a}	15.45	19.20^{bc}
RDF+CM+S	64.7	111.41^{a}	15.45	20.66^{ab}
RDF+PM+S	65.25	112.48^{a}	15.66	21.37^{ab}
RDF+CM+PM+S	68.29	113.59^{a}	15.29	22.20^{a}
$CD_{0.05}$	10.51	9.06	1.74	2.36
SEm (±)	3.50	3.02	0.58	0.78
F-test	Ns	*	Ns	*
P value	0.36	0.02	0.06	0.01
CV %	9.77	4.84	6.85	6.89
Grand Mean	62.17	108.15	14.73	19.82

Note. CV: Coefficient of Variation; CD: Critical Difference; SEm: Standard Error of the Mean, ns: Non-Significant; Significant at 5%, 1% and 0.1% were denoted by *, ** &

*** respectively; RDF: Recommended Dose of Fertilizers, CM: Compost Manure, PM: Poultry Manure, S: Sulfur

Yield Parameters

The application of organic fertilizers and sulfur significantly improved yield parameters in sunflower. The highest grains per flower (570.11) and flower diameter (11.60 cm) were recorded in RDF+CM+PM+S, while the control had the lowest values (395.88 grains, 8.55 cm), indicating a 30.5% reduction in grain number per flower without integrated nutrient management. This result is supported by (Sarker et al., 2021; Zehra, 2011; Raja et al., 2007; Deepika et al., 2022). Although 1000 grain weight was not significantly affected, higher values (43.66 g) were observed in RDF+CM+PM+S and RDF+CM+PM, likely due to genetic potentially overshadowing the impact of changes in cultivation practices. This result was in line with the findings of with Aleem et al. (2015).

Table 4

Effect of integrated nutrient management on yield attributing traits of sunflower

Treatments	Grains per flower	Flower diameter (cm)	1000 grain weight (g)
Control	395.88^{c}	8.55^{c}	42.66
RDF	458.88^{bc}	10.13^{b}	43.33
RDF+CM	531.00^{ab}	10.70^{ab}	43.33
RDF+PM	540.77^{a}	10.83^{ab}	42.66
RDF+S	519.55^{ab}	10.54^{ab}	42.66
RDF+CM+PM	547.44^{a}	11.06^{ab}	43.66
RDF+CM+S	546.22^{a}	10.94^{ab}	43.33
RDF+PM+S	559.33^{a}	11.31^{ab}	43.33
RDF+CM+PM+S	570.11^{a}	11.60^{a}	43.66
$CD_{0.05}$	73.54	1.28	1.9
SEm(±)	24.53	0.42	0.63
F-test	**	**	Ns
P value	0.002	0.006	0.89
CV %	8.19	6.98	2.55
Grand Mean	518.8	10.63	43.14

Note. CV: Coefficient of Variation; CD: Critical Difference; SEm: Standard Error of the Mean, ns: Non-Significant; Significant at 5%, 1% and 0.1% were denoted by *, ** & *** respectively; RDF: Recommended Dose of Fertilizers, CM: Compost Manure, PM: Poultry Manure, S: Sulfur

The application of fertilizers had a statistically significant effect on sunflower grain and biological yields. The highest grain yield was recorded in RDF+CM+PM+S (1179.95

kg/ha), followed by RDF+PM+S (1121.52 kg/ha), with the lowest in the Control (856.43 kg/ha), showing a 37.7% increase in RDF+CM+PM+S over Control. The integrated use of organic and inorganic fertilizers enhances sunflower seed yield, with sulfur and compost further boosting production (Thapa et al., 2022; Naseri & Heidari, 2023). Similarly, biological yield was highest in RDF+CM+PM+S (5799.25 kg/ha), followed by RDF+C and RDF+PM+S, while the Control had the lowest (4437.03 kg/ha), reflecting a 30.7% increase. The use of organic manure and sulfur enhances soil structure, microbial biomass, and nutrient availability, boosting grain and biological yields (Barbara et al., 2008; Mahapatra et al., 2021; Dambale, 2018). However, the harvest index showed no significant variation among treatments, with values ranging from 0.19 to 0.20, likely due to the proportional increase in both grain and biological yields, which are in line with our result by Shah & Ahmad (2006).

Table 5

Effect of integrated nutrient management on grain yield, biological yield and harvesting index of sunflower

Treatments	Grain yield (kgha^{-1})	Biological yield (kgha^{-1})	Harvest index
Control	856.43^{c}	4437.03^{c}	0.19
RDF	1016.05^{b}	4919.05^{bc}	0.2
RDF+CM	1070.56^{ab}	5544.87^{ab}	0.19
RDF+PM	1076.81^{ab}	5343.05^{ab}	0.2
RDF+S	1068.27^{ab}	5508.44^{ab}	0.19
RDF+CM+PM	1095.06^{ab}	5508.44^{ab}	0.19
RDF+CM+S	1087.30^{ab}	5316.63^{ab}	0.2
RDF+PM+S	1121.52^{ab}	5538.24^{ab}	0.2
RDF+CM+PM+S	1179.95^{a}	5799.25^{a}	0.2
$CD_{0.05}$	120.35	671.56	0.018
SEm(±)	40.14	224	0.006
F-test	**	*	Ns
P value	0.003	0.021	0.77
CV %	6.53	7.3	5.4
Grand Mean	1063.55	5311.23	0.2

Note. CV: Coefficient of Variation; CD: Critical Difference; SEm: Standard Error of the Mean, ns: Non-Significant; Significant at 5%, 1% and 0.1% were denoted by *, ** & *** respectively; RDF: Recommended Dose of Fertilizers, CM: Compost Manure, PM: Poultry Manure, S: Sulfur

Residual Soil Properties in the Experiment Plot

Soil properties varied significantly across treatments. Soil pH ranged from 7.6 to 8.1, with the lowest in Control (7.57) and highest in RDF+PM+S (8.1), likely due to evaporation and salt accumulation (Corwin, 2021), aligning with Citak & Sonmez (2011) but contrasting with Katkar et al. (2005) recorded highest pH with only RDF and it decreased with increasing organic nutrient sources. Organic matter was highest in RDF+CM+PM+S (1.25%), followed by RDF+CM and RDF+CM+PM, while the Control had the lowest (0.81%), showing a 35.2% reduction, consistent with findings by Khalid et al. (2014). Available nitrogen was significantly higher in RDF+CM+PM, RDF+CM+PM+C, and RDF+CM by (0.06%) compared to Control (0.04%), as also reported by Ayeni & Adetunji (2010) and Ewulo (2005). Phosphorus levels were enhanced in RDF+CM+PM and RDF+CM (13.37 and 13.05 kg/ha), while sulfur-containing treatments like RDF+PM+S showed reduced phosphorus due to sulfur-induced depletion (Mokgolo et al., 2019; Allahham et al., 2020). Potassium ranged from (58 kg/ha) in the Control to (166.8 kg/ha) in RDF+PM+S varied significantly across treatments, followed by RDF+CM (94.8 kg/ha) and RDF+CM+PM (92.4 kg/ha), attributed to the use of organic fertilizers (Kumar et al., 2008). Available sulfur after harvest was greatest in RDF+CM+PM+S (32.47 kg/ha), followed by RDF+S and RDF+PM+S by 30.22kg/ha and 27.22 kg/ha respectively, showing sulfur application of sulfur resulted in a positive sulfur balance, which increased as the sulfur level, whereas it was negative under control, the result is in line with (Singh et al., 2014).

Table 6

Effect of integrated nutrient management in soil pH, Organic Matter, NPK and Sulfur

Treatments	pH	Organic Matter (%)	Nitrogen (%)	Phosphorus (kg/ha)	Potassium (kg/ha)	Sulfur (kg/ha)
Control	7.6^{c}	0.81^{c}	0.04^{c}	11.14^{c}	58.8^{e}	16.71^{d}
RDF	7.7^{c}	1.006^{b}	0.05^{b}	8.29^{e}	68.4^{d}	16.71^{d}
RDF+CM	7.9^{b}	1.22^{a}	0.06^{b}	13.05^{b}	94.8^{b}	12.96^{e}
RDF+PM	8.0^{ab}	1.06^{b}	0.05^{b}	9.57^{d}	54^{f}	18.71^{cd}
RDF+S	8.1^{a}	0.88^{c}	0.04^{c}	15.86^{a}	73.2^{d}	30.22^{a}
RDF+CM+PM	8.0^{ab}	1.22^{a}	0.06^{a}	13.37^{b}	92.4^{b}	18.21^{cd}
RDF+CM+S	8.1^{a}	1.06^{b}	0.05^{b}	9.24^{de}	73.2^{d}	21.96^{c}
RDF+PM+S	8.1^{a}	1.06^{b}	0.05^{b}	7.97^{e}	166.8^{a}	27.22^{b}
RDF+CM+PM+S	7.7^{c}	1.25^{a}	0.06^{a}	10.51^{c}	82.8^{c}	32.47^{a}
$CD_{0.05}$	0.14	0.11	0.008	1.21	4.7	2.99
SEm ((±)	0.04	0.03	0.0028	0.4	1.57	0.99
F test	***	***	***	***	***	***

CV %	1.04	6.46	9.64	6.31	3.2	8.009
Grand Mean	7.91	1.06	0.05	11.11	84.93	21.57

Note. CV: Coefficient of Variation; CD: Critical Difference; SEm: Standard Error of the Mean, ns: Non-Significant; Significant at 5%, 1% and 0.1% were denoted by *, ** & *** respectively; RDF: Recommended Dose of Fertilizers, CM: Compost Manure, PM: Poultry Manure, S: Sulfur

Bulk density decreased from 1.35 g/cm³ in Control to 1.15 g/cm³ in RDF+CM+PM+S and 1.16 g/cm³ in RDF+CM+PM, indicating that organic manures reduce the ratio of soil to moisture to air, which in turn results in a decrease in bulk density. An increase in the amount of organic manure applied immediately correlates with an improvement in the bulk density of the soil (Rajput et al., 2019). Particle density similarly declined from 2.34 g/cm³ to as low as 2.09 g/cm³ in RDF+CM+PM+S, 2.10 g/cm³ in RDF+CM+PM and 2.12 g/cm³ in RDF+PM. The application of organic manure lowers particle density by increasing organic carbon, which reduces soil weight per unit volume and enhances the formation of stable aggregates and soil pores (Dhaliwal et al., 2015). Porosity, is not significantly different, ranged from 42.38% to 48.87%, peaking in RDF+PM+S (48.85%) and RDF+S (45.05%) as a result of reduced bulk density obtained from the treated plots can be as a result of the improved soil structure, hence the increase in the soil granulation and improving the soil porosity (Nwite et al., 2012; Masood et al., 2013). Water-holding capacity improved by 19.8% from 52% in Control to 62.3% in RDF+CM+PM+S (and 62% in RDF+PM+S), underscoring the positive impact of organic amendments on soil moisture retention (Talathi et al., 2010).

Table 7

Effect of integrated nutrient management in bulk density, particle density, porosity and water holding capacity

Treatments	Bulk Density (g/cm^3)	Particle Density (g/cm^3)	Porosity (%)	WHC (%)
Control	1.35^{a}	2.34^{a}	42.38	52^{e}
RDF	1.29^{ab}	2.33^{a}	44.94	54.1^{de}
RDF+CM	1.23^{a-c}	2.24^{ab}	44.96	57^{b-d}
RDF+PM	1.18^{bc}	2.12^{b-d}	44.62	60^{a-c}
RDF+S	1.25^{a-c}	2.31^{a}	45.74	55^{c-e}
RDF+CM+PM	1.16^{bc}	2.1^{cd}	44.97	62^{ab}
RDF+CM+S	1.22^{bc}	2.22^{a-c}	45.05	57.75^{a-d}
RDF+PM+S	1.18^{bc}	2.31^{a}	48.87	60^{a-c}

RDF+C-M+PM+S	1.15[c]	2.09[d]	44.85	62.3[a]
$CD_{0.05}$	0.11	0.12	4.84	4.58
SEm(±)	0.03	0.04	1.61	1.53
F test	*	***	ns	**
CV %	5.5	3.23	6.19	4.58
Grand Mean	1.22	2.22	45.15	57.79

Note. CV: Coefficient of Variation; CD: Critical Difference; SEm: Standard Error of the Mean, ns: Non-Significant; *: significant at ≤0.05 level of significance, **: significant at ≤0.01 level of significance, ***: significant at ≤0.001 level of significance; RDF: Recommended Dose of Fertilizers, CM: Compost Manure, PM: Poultry Manure, S: Sulfur

Economic Analysis

The data assesses the economic viability of various crop treatments by analyzing cost of cultivation, gross income, net income, and the benefit-cost (B:C) ratio. The Control treatment shows moderate profitability with a B: C ratio of 1.65, while RDF is the most profitable with a B: C ratio of 1.79. Adding Compost to RDF increases gross income but lowers profitability B: C ratio of 1.39. RDF combined with Poultry manure, Compost, and Sulfur results in financial losses, with a B:C ratio as low as 0.70. RDF with Sulfur alone remains profitable, though less so than RDF alone. Overall, combinations involving Compost, Poultry manure, and Sulfur tend to be economically unviable under the studied conditions.

From the economic analysis of each treatment, treatment having RDF is the most cost- effective and most profitable for farmers with a B:C ratio of 1.79, the highest among all treatments. Although the RDF+CM treatment shows a lower B:C ratio as compared to RDF alone, it promotes sustainable farming by enriching the soil with organic material, leading to better soil health over time. Compost introduces microorganism into the soil, which helps in nutrient cycling and reduces the nutrient leaching.

Table 8

Economic analysis of Sunflower with each of the treatments

Treatments	Cost of cultivation (Rs)	Gross income (Rs)	B:C ratio
Control	78000.00	128464.56	1.65
RDF	85148.71	152408.45	1.79
RDF+CM	115148.71	160585.05	1.39
RDF+PM	205148.71	161522.92	0.79
RDF+S	103148.71	160241.32	1.55

RDF+CM+PM	235148.71	164260.42	0.70
RDF+CM+S	133148.71	163095.49	1.22
RDF+PM+S	223148.71	168229.17	0.75
RDF+CM+PM+S	253148.71	176992.64	0.70

Note. RDF: Recommended Dose of Fertilizers, CM: Compost Manure, PM: Poultry Manure, S: Sulfur

Conclusion

The study concluded that the combination of organic fertilizers and sulfur significantly enhances sunflower growth and yield. The most effective treatment was RDF+CM+ PM+ S, which consistently produced the tallest plant height, stem diameter, flower diameter, grain per flower, grain yield, and biological yield, making it a beneficial strategy for sunflower cultivation. These findings indicate the positive effects of integrating organic fertilizers and sulfur on crop performance. Additionally, the application of organic fertilizers and sulfur significantly enhances soil quality by improving soil pH, organic matter, nitrogen, phosphorus, potassium, bulk density, water-holding capacity, and porosity. From the economic analysis of each treatment, treatment having RDF is the most cost- effective and most profitable for farmers with a B: C ratio of 1.79, the highest among all treatments. Although the RDF+CM treatment shows a lower B:C ratio as compared to RDF alone, it promotes sustainable farming by enriching the soil with organic material, leading to better soil health over time. Compost introduces microorganism into the soil, which helps in nutrient cycling and reduces the nutrient leaching. The combination of RDF, Compost, poultry manure, and sulfur particularly showed the most significant improvements across various soil and plant parameters, highlighting the benefits of integrated nutrient management for sustained yield and soil health.

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