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Improving Soil Fertility: The Impact of Organic Amandements and Basal Fertilizers

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ABSTRACT
This study aimed to determine the optimal combination of soil amendments and basal fertilizer application to maximize cucumber yield. A factorial experiment was conducted in 2021, assessing the effects of two factors: soil amendments (cow manure and raw rice husk) and basal fertilizer application (with and without). The experiment employed a Randomized Complete Block Design (RCBD) with two replications. Soil analysis prior to the experiment revealed low nitrogen, high phosphorus, and high potassium levels. Data on cucumber yield, plant biomass, and nutrient use efficiency were collected and analyzed using ANOVA and Duncan's Multiple Range Test (DMRT). Results showed that cow manure significantly increased cucumber yield compared to rice husk. The combination of basal fertilizer and cow manure resulted in the highest yield and most efficient nutrient use. These findings highlight the importance of integrated soil fertility management strategies for maximizing cucumber production. The interaction between organic amendments and basal fertilizer application significantly impacted cucumber growth and yield.

Keywords: Fertilizer, Amendments, Growth, Yield, Efficiency

INTRODUCTION

Optimal plant growth and yield are fundamentally dependent on the balanced availability and efficient uptake of essential macronutrients (nitrogen, phosphorus, potassium) and micronutrients. Deficiencies in any of these nutrients can lead to stunted growth, reduced yield, and increased susceptibility to diseases, highlighting the importance of precise nutrient management (Wang et al., 2024). Soil nutrient availability is inherently variable, influenced by a complex interplay of factors including parent material, weathering processes, previous fertilization practices, microbial activity, and the specific nutrient demands of the cultivated crop. A thorough understanding of soil formation (CLORPT: climate, organisms, relief, parent material, time) is therefore crucial, as each factor significantly influences the nutrient content and availability within the soil profile.

The practice of repeated cropping significantly alters soil nutrient status over time. Successive harvests deplete available nutrients, necessitating replenishment through fertilization to maintain soil fertility and productivity. The specific nutrient demands of the cultivated crop greatly influence depletion patterns, with some crops exhibiting a stronger preference for certain nutrients than others (Noulas et al., 2023). Continuous cropping without adequate nutrient replenishment can lead to soil degradation, reduced fertility, and decreased crop yields, underscoring the importance of sustainable nutrient management practices (Kartini et al., 2024). Effective agricultural management requires a comprehensive understanding of soil physical (texture, structure, porosity, water holding capacity), chemical (pH, nutrient levels, organic matter, cation exchange capacity), and biological (microbial biomass,

enzyme activity) properties. Regular soil testing is therefore paramount for identifying nutrient deficiencies or excesses, guiding the selection of appropriate fertilizers and application rates, and optimizing nutrient use efficiency while minimizing environmental pollution from excess fertilizer (Sarma, Talukdar, et al., 2024).

The strategic use of basal fertilizers provides an initial, concentrated supply of essential nutrients, crucial for establishing robust root systems and promoting early vegetative growth. However, the timing and amount of basal fertilizer application must be carefully calibrated to avoid nutrient imbalances or losses, emphasizing the need for site-specific recommendations based on soil testing (Sarma, Talukdar, et al., 2024). Soil amendments, such as farmyard manure and rice husk, play a complementary role in enhancing nutrient availability and improving soil health. Farmyard manure, rich in organic matter and nutrients, improves soil structure, water retention, and nutrient availability through slow-release mechanisms and enhanced microbial activity. Rice husk, while not a direct source of readily available nutrients, primarily enhances soil physical properties such as porosity and drainage, indirectly benefiting nutrient uptake by improving root penetration and aeration (Sarma, Talukdar, et al., 2024). The combined application of basal fertilizers and soil amendments aims to create a synergistic effect, maximizing nutrient availability and utilization while promoting overall soil health.

Integrated Nutrient Management (INM), the integration of organic and inorganic nutrient sources, is increasingly recognized as a sustainable approach to crop production. INM leverages the benefits of organic amendments, such as improved soil structure and water retention, while simultaneously providing readily available nutrients through inorganic fertilizers (Meena & Reddy, 2021). This approach aims to optimize crop yields while minimizing environmental impacts by reducing reliance on synthetic fertilizers and promoting soil biodiversity. The selection of appropriate organic amendments and inorganic fertilizers should be guided by site-specific soil conditions and crop nutrient requirements. While extensive research supports the benefits of both organic amendments and balanced fertilization, further investigation is needed to optimize strategies for specific soil types and cropping systems. Long-term studies are crucial to assess the sustainability of different management practices, and research on the interaction between organic amendments and inorganic fertilizers is essential for developing effective integrated nutrient management strategies. Economic and environmental analyses of different approaches are also necessary for ensuring the long-term viability and sustainability of these practices.

The inherent variability in soil properties necessitates site-specific nutrient management strategies. Factors such as soil texture (sandy, clay, loam), organic matter content, cation exchange capacity (CEC), and pH significantly influence nutrient availability and plant uptake. Clay soils, for example, often exhibit high water retention but can suffer from poor aeration and restricted root penetration, impacting nutrient uptake. Conversely, sandy soils, while well-drained, may have low water retention and nutrient-holding capacity (Shaheb et al., 2021). Understanding these variations is crucial for tailoring fertilizer application rates and selecting appropriate soil amendments to optimize nutrient use efficiency and minimize losses due to leaching or volatilization. The integration of soil testing into nutrient management strategies is essential for identifying specific nutrient deficiencies or excesses, guiding the selection of appropriate fertilizers and amendments, and optimizing application rates (de Sousa & Moreira, 2024). This site-specific approach is crucial for maximizing crop yields while minimizing environmental impacts associated with excessive fertilizer use.

The choice of fertilizer type and application method also significantly impacts nutrient availability and uptake. While inorganic fertilizers provide readily available nutrients, their use can lead to nutrient imbalances and environmental concerns if not carefully managed. Organic amendments, such as farmyard manure and compost, offer a more sustainable approach by improving

soil structure, enhancing water retention, and providing a slow-release source of nutrients (Singh et al., 2024). However, the nutrient content of organic amendments can vary considerably, requiring careful consideration when formulating integrated nutrient management strategies. The timing of fertilizer application is also critical, with early-season applications providing a foundation for early growth while later applications address nutrient demands during specific growth stages. Furthermore, the interaction between different nutrient elements and their impact on overall plant growth and yield must be considered when developing effective fertilization strategies (Sarma, Borah, et al., 2024). A balanced approach that considers the specific needs of the crop, the characteristics of the soil, and the environmental conditions is essential for maximizing nutrient use efficiency and achieving sustainable crop production.

The nutrient use efficiency (NUE) of different crops and management practices is a crucial consideration in sustainable agriculture. NUE refers to the plant's ability to absorb and utilize nutrients for growth and yield. Improving NUE is crucial for reducing fertilizer inputs, minimizing environmental impacts, and enhancing the economic viability of agricultural practices. Factors influencing NUE include nutrient availability, plant genotype, and environmental conditions. Strategies to improve NUE include balanced fertilization, efficient irrigation, and the use of nutrient-efficient crop varieties (Suman et al., 2023). Furthermore, understanding the interactions between different nutrient elements and their impact on overall plant growth and yield is critical for developing effective fertilization strategies.

This research aims to optimize cucumber yield and nutrient use efficiency by determining the optimal combination of basal fertilizers and soil amendments (farmyard manure and rice husk) under specific soil conditions characterized by nutrient imbalances (e.g., low nitrogen, high phosphorus, high potassium). The study employs a novel integrated approach, combining organic and inorganic fertilization strategies within a factorial experimental design to analyze their interactive effects on cucumber growth and yield parameters. This detailed analysis, including nutrient use efficiency calculations, provides site-specific recommendations for improving cucumber production in similar agricultural environments while promoting sustainable practices.

MATERIALS AND METHODS

This research employed a quantitative research paradigm using a factorial experimental design. The experiment investigated the interactive effects of two factors: (1) soil amendments (cow manure and raw rice husk) and (2) basal fertilizer application (with and without). A Randomized Complete Block Design (RCBD) with two replications was utilized to minimize the impact of environmental variability on the results. In an RCBD, treatments are randomly assigned within each block, which is a relatively homogenous subset of the experimental area. This design controls for spatial variation in soil fertility or other environmental factors that might confound the results. Each replication consisted of a single bed, approximately 20 meters in length, containing 80-100 cucumber plants. Therefore, each treatment consisted of 3 beds, resulting in a total of 240-300 plants per treatment.

The field experiment was conducted at Campaka Village, Benteng District, Purwakarta Regency, West Java Province, Indonesia, in 2021. The experimental plots were prepared according to standard agricultural practices, including land clearing, plowing, and mulching. Soil amendments (cow manure and raw rice husk) were applied according to the experimental design, followed by planting cucumber seedlings. Standard agricultural practices, including irrigation, pest and weed control, were consistently applied across all plots to ensure uniformity. All soil analyses and plant tissue analyses (N, P, K content) were conducted by PT Pupuk Kujang Cikampek. The N, P, and K content of the farmyard manure was assumed to be 0.4%, 0.2%, and 0.1%, respectively (Hariatik, 2014). Calculations of total N, P, and K levels after amendment application were made by summing the N, P, and K values from

the soil analysis (conducted by PT Pupuk Kujang Cikampek) and the N, P, and K values of the farmyard manure obtained from the literature.

Data were collected on plant growth parameters (stem diameter, number of branches, shoot dry weight, and plant dry weight) and yield components (total number of fruits, fruit weight, fruit weight per plant, and fruit dry weight per plant). Data on nutrient content in plant tissues (N, P, K) were collected at harvest. The efficiency of nutrient uptake (N, P, and K) was calculated using the following formula:

Efficiency (%) = [(Nutrient in plant (mg/plant) / Nutrient applied (mg/plant)] x 100

Data were analyzed using Analysis of Variance (ANOVA) to determine the statistical significance of the treatment effects. Duncan's Multiple Range Test (DMRT) was used for post-hoc comparisons to identify significant differences between treatment means. Correlation analysis was performed to examine the relationships between different variables. The results were presented using tables and figures to facilitate interpretation and understanding.

RESULTS AND DISCUSSION

Description of Soil Nutrients Status

Based on soil analyses (Table 1), the N, P, and K content in research plot was 180 kg/ha, 260 kg/ha, and 96 kg/ha, respectively (assuming a soil weight of 2,000,000 kg per hectare). The amount of basal N, P, and K applied followed Balitsa's recommendation was 100 kg/ha, 72 kg/ha, and 120 kg/ha, respectively. The topdressing fertilizer commonly used by local farmers consisted of 1 kg of NPK Mutiara 16-16-16 per 200 L of water, applied at 200 mL per planting hole. The topdressing fertilizer applied three times and the supplemented with 10 g of fertilizer per plant applied via topdressing. Assuming a cucumber population of 40,000 plants per hectare with a planting distance of 30 x 60 cm, the amount of NPK fertilizer applied via topdressing was 115.2 kg/ha for each nutrient. This trial did not analyze the nutrient content of the farmyard manure and raw rice husk; therefore, the data obtained are based on references.

Table 1. Result of soil analysis in research plot

Parameters	Unit	Value
pH	-	
- H2O		7.3
- KCl		(neutral) 5.8
Exchangeable cation	Cmol(+)/kg	
- Al		0
- H		0.76
P_2O_5 (Olsen)	ppm	151 (very high)
P_2O_5 (HCl 25%)	mg/100 g	127 (very high)
K_2O (HCl 25%)	mg/100 g	48 (high)
N Total	%	0.09 (very high)
C organic	%	4.1 (high)
C/N Ratio	%	45.56 (very high)

Figure 1. show that the application of basal fertilizer, regardless of soil amendment, resulted in significantly higher levels of N, P, and K in the plants compared to treatments without basal fertilizer. For example, the basal fertilizer treatments show N levels ranging from 395.2 to 475.2 units, while the treatments without basal fertilizer show N levels between 295.2 and 462.2 units. A similar trend is observed for P and K. This significant increase reflects the combined effect of the readily available nutrients from the basal fertilizer and the substantial nutrient contribution of the farmyard manure. The high levels of phosphorus, in particular, are noteworthy and may reflect the inherent phosphorus content of the farmyard manure, a common characteristic of this type of organic amendment (S. Xie et al., 2023). The substantial increase in potassium also suggests a significant contribution from the farmyard manure. In contrast, the treatments without basal fertilizer and either with rice husk or without any soil amendment showed the lowest NPK levels, highlighting the importance of both inorganic and organic nutrient sources for optimal soil fertility. The rice husk, at the time of measurement, did not contribute to nutrient levels, indicating that its

decomposition and nutrient release were not yet significant during the experimental period. This is consistent with the known slow decomposition rate of rice husk, which primarily contributes to improved soil structure rather than immediate nutrient availability (Zhao et al., 2024).

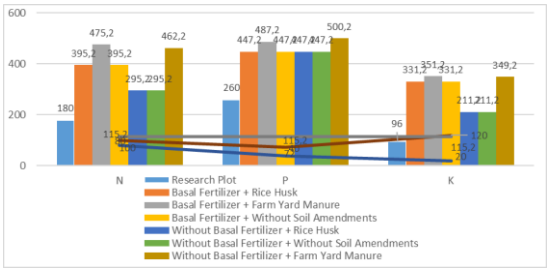


Figure 1. The amount of N, P, and K after amendment materials and basal fertilizer applied

However, both rice husk and farmyard manure decreased soil bulk density, improving soil porosity (1.01 g/cm³ in the control, 0.7889 g/cm³ with rice husk, and 0.94 g/cm³ with farmyard manure). This improvement in soil structure is a crucial factor influencing nutrient availability and root penetration. The reduced bulk density indicates improved aeration and water infiltration, creating a more favorable environment for root growth and nutrient uptake. The lower bulk density in the rice husk treatment, despite its lack of immediate nutrient contribution, highlights its beneficial effect on soil physical properties. The amounts of NPK applied through basal fertilizer (100 kg/ha N, 72 kg/ha P, 120 kg/ha K), top-dressing fertilizer (115.2 kg/ha of each nutrient), and the estimated nutrient content of the farmyard manure contributed to the final NPK levels observed in each treatment. The observed differences in NPK levels across treatments underscore the complex interplay between fertilizer type, application method, and soil amendment effects. Further research could investigate the optimal balance between these factors to maximize nutrient use efficiency and minimize environmental impacts. Specifically, determining the precise nutrient content of the farmyard manure would allow for a more accurate assessment of its contribution to the overall nutrient balance in each treatment.

The contrasting effects of farmyard manure and rice husk on nutrient availability are evident in their differing mechanisms. Farmyard manure acts as a slow-release fertilizer, providing a sustained supply of nutrients through the gradual decomposition of organic matter. This process improves soil structure, increasing water retention and aeration, which in turn stimulates microbial activity and nutrient mineralization (Zhao et al., 2024). The enhanced organic matter content significantly raises the cation exchange capacity (CEC), resulting in greater nutrient retention within the soil and reduced leaching losses (Bashir et al., 2021). In contrast, rice husk, while not a direct source of readily available nutrients at the time of application, significantly improves soil physical properties. Its incorporation enhances porosity and water infiltration, leading to better root penetration and aeration, thereby indirectly promoting nutrient uptake. While the rice husk will eventually decompose and release nutrients, this is a slower process compared to the immediate nutrient release from the farmyard manure (Omar et al., 2021). Therefore, the observed differences in plant growth likely reflect the immediate nutrient availability from the manure versus the longer-term, indirect benefits of improved soil structure provided by the rice husk.

The application of basal fertilizer at the beginning of the growing season provides a crucial foundation for plant development. This initial surge of nutrients is vital for establishing a strong root system and promoting early vegetative growth (Kang et al., 2022). The carefully chosen NPK ratio in the basal fertilizer ensures that the plant has the necessary building blocks for healthy leaf development, stem elongation, and overall structural integrity. Without this initial nutrient boost, plants may experience stunted growth and reduced overall vigor, making them more susceptible to stress and disease (Kang et al., 2022). The timing and composition of the basal fertilizer are critical factors in determining the success of the subsequent growth stages.

Topdressing fertilizer plays a vital role in sustaining nutrient supply throughout the plant's life cycle. Unlike the initial, concentrated application of basal fertilizer, topdressing provides a more gradual and continuous release of nutrients. This is particularly important during periods of rapid growth, such as flowering and fruiting, when nutrient demands are significantly higher. The frequency and amount of topdressing are adjusted based on the crop's specific needs and the observed nutrient levels in the soil. By providing a continuous supply of essential nutrients, topdressing helps to maximize yield potential and ensure the production of high-quality produce (Ma et al., 2023). Without topdressing, nutrient deficiencies might arise, leading to reduced yield and compromised fruit quality.

The incorporation of farmyard manure offers a unique approach to nutrient management, going beyond the simple provision of NPK. Its role extends to improving the overall soil health and creating a more favorable environment for nutrient uptake. The slow-release nature of the nutrients in farmyard manure provides a sustained supply over time, minimizing the risk of nutrient leaching and maximizing nutrient availability to the plant. Furthermore, the organic matter in farmyard manure enhances soil structure, increasing water retention and aeration. This improved soil environment promotes beneficial microbial activity, leading to enhanced nutrient cycling and mineralization, making existing soil nutrients more readily available to the plants. The synergistic effect of improved soil health and sustained nutrient release from farmyard manure contributes significantly to increased plant growth and yield.

The Impact of Amendment Materials and Basal Fertilizers in Growth and Yield of Cucumber Plants

Analysis of variance (ANOVA) in Table 2 revealed a significant interaction effect between basal fertilizer application and soil amendment type on several key cucumber growth parameters. Specifically, the combined application of basal fertilizer and soil amendments significantly influenced stem diameter ($p=0.001$), number of branches ($p=0.001$), fruit weight per plant ($p=0.037$), overall efficiency ($p=0.01$), nitrogen content in the plant ($p=0.04$), phosphorus content in the plant ($p=0.001$), and potassium content in the plant ($p=0.046$). This indicates that the effect of basal fertilizer on these parameters was dependent on the type of soil amendment used, and vice versa, highlighting a complex interplay between these factors. The synergistic or antagonistic effects observed underscore the importance of considering both factors simultaneously when optimizing cucumber cultivation practices.

In addition to the interaction effects, the ANOVA also indicated significant main effects for both basal fertilizer and soil amendments on specific parameters. Basal fertilizer application alone significantly affected fruit weight per plant ($p=0.115$). This suggests that the readily available nutrients from the basal fertilizer played a crucial role in enhancing fruit production, even in the absence of soil amendments. However, the magnitude of this effect was likely modulated by the type and amount of soil amendment present, as evidenced by the significant interaction effect. The main effect of soil amendments was also significant for fruit weight per plant ($p=0.069$), indicating that the improved soil structure and nutrient release associated with these amendments contributed independently to fruit yield. This suggests that soil amendments, while not directly providing readily available nutrients to the same extent as basal fertilizer, still play a crucial role in plant growth and yield.

The significant interaction effects observed for stem diameter, number of branches, efficiency, and nutrient content (N, P, K) further emphasize the complex relationship between basal fertilizer and soil amendments. The observed effects are likely due to a combination of factors, including the provision of readily available nutrients by the basal fertilizer, improved soil structure and water retention by the amendments, and enhanced nutrient mineralization by soil microbes. The specific nature of these interactions would require further investigation, potentially involving detailed analysis of soil properties and plant nutrient

uptake kinetics. Nevertheless, the results clearly demonstrate the importance of considering both basal fertilizer application and soil amendment type when optimizing cucumber cultivation practices to maximize yield and nutrient use efficiency.

Table 2. ANOVA analyses on implemented factors on observed variables

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Basal Fertilizer	Stem Diameter	0.711	1	0.711	1.386	0.262
	Number of Branches	0.018	1	0.018	0.437	0.521
	Number of Fruits per Plant	0.928	1	0.928	2.491	0.141
	Fruit Weight per Plant	279536.8	1	279536.8	2.896	0.115
	Fruit Dry Weight per Plant	454.45	1	454.45	44.418	0
	Plant Dry Weight	31.912	1	31.912	0.146	0.709
	Shoot Dry Weight	19.117	1	19.117	0.276	0.609
	Efficiency	299.625	1	299.625	0.704	0.418
	N in Plant	6141.655	1	6141.655	3.018	0.108
	P in Plant	564.757	1	564.757	33.1	0
	K in Plant	25.404	1	25.404	5.689	0.034
Amendments Materials	Stem Diameter	8.244	2	4.122	8.035	0.006
	Number of Branches	0.292	2	0.146	3.533	0.062
	Number of Fruits per Plant	1.622	2	0.811	2.177	0.156
	Fruit Weight per Plant	651810.4	2	325905.2	3.376	0.069
	Fruit Dry Weight per Plant	504.16	2	252.08	24.638	0
	Plant Dry Weight	246.67	2	123.335	0.563	0.584
	Shoot Dry Weight	327.46	2	163.73	2.367	0.136
	Efficiency	3021.325	2	1510.663	3.551	0.061
	N in Plant	10025.89	2	5012.942	2.464	0.127
	P in Plant	376.362	2	188.181	11.029	0.002
	K in Plant	31.503	2	15.751	3.527	0.062
Basal Fertilizer * Amendments Materials	Stem Diameter	14.644	2	7.322	14.273	0.001
	Number of Branches	1.026	2	0.513	12.408	0.001
	Number of Fruits per Plant	1.902	2	0.951	2.553	0.119
	Fruit Weight per Plant	845845.5	2	422922.8	4.381	0.037
	Fruit Dry Weight per Plant	74.779	2	37.39	3.654	0.058
	Plant Dry Weight	695.27	2	347.635	1.587	0.245
	Shoot Dry Weight	371.639	2	185.82	2.686	0.109
	Efficiency	5809.371	2	2904.685	6.828	0.01
	N in Plant	17303.04	2	8651.522	4.252	0.04
	P in Plant	482.088	2	241.044	14.127	0.001
	K in Plant	36.073	2	18.036	4.039	0.046
Error	Stem Diameter	6.156	12	0.513		
	Number of Branches	0.496	12	0.041		
	Number of Fruits per Plant	4.47	12	0.372		
	Fruit Weight per Plant	1158501	12	96541.74		
	Fruit Dry Weight per Plant	122.775	12	10.231		
	Plant Dry Weight	2628.328	12	219.027		
	Shoot Dry Weight	830.225	12	69.185		
	Efficiency	5104.643	12	425.387		
	N in Plant	24417.44	12	2034.786		
	P in Plant	204.745	12	17.062		
	K in Plant	53.586	12	4.465		
Total	Stem Diameter	2039.737	18			
	Number of Branches	172.117	18			

Number of Fruits per Plant	1375.787	18
Fruit Weight per Plant	46613890	18
Fruit Dry Weight per Plant	59280.71	18
Plant Dry Weight	100498.2	18
Shoot Dry Weight	301861.7	18
Efficiency	153388.8	18
N in Plant	990928.7	18
P in Plant	115685.2	18
K in Plant	13976.27	18

Table 3. presents the results of a cucumber growth experiment comparing the effects of different fertilizer and soil amendment treatments. The data reveal that the basal fertilizer + farmyard manure treatment resulted in the most significant improvements across most growth parameters. This treatment showed the largest stem diameter (12 cm), the highest number of branches (3.45), the greatest number of fruits per plant (10.73), the highest total fruit weight per plant (1826.04 g), and the highest fruit dry weight per plant (69.99 g). It also resulted in a relatively high plant dry weight (73.5 g) and shoot dry weight (143.49 g), and the highest efficiency (95.24%). These results strongly suggest a synergistic effect between basal fertilizer and farmyard manure, maximizing both vegetative growth and fruit production.

Table 3. Ducan's Multiple Range Test on observed variables

Treatments	Stem Diameter	Number of Branches	Number of Fruit/Plant	Plant Weight/Plant	Fruit Dry Weight/Plant	Plant Dry Weight	Shoot Dry Weight	Efficiency
Basal Fertilizer + No Amendment Materials	9.91 b	2.76 b	8.60 b	1370.96 b	54.08 bc	70.17 b	132.83 a	77.06 b
No Basal Fertilizer + Farmyard Manure	9.40 b	2.82 ab	8.42 b	1461.39 b	57.78 b	72.43 a	135.33 a	72.02 b
Basal Fertilizer + Rice Husk	10.14 b	3.00 ab	8.47 b	1254.23 b	60.89 bc	78.25 a	122.73 c	76.13 b
No Basal Fertilizer + No Amendment Materials	10.01 b	3.04 b	8.81 b	2200.28 b	49.79 bc	63.94 c	118.65 c	70.16 b
No Basal Fertilizer + Rice Husk	12.88 a	3.27 a	8.23 b	1385.42 b	47.83 c	64.76 c	130.43 b	73.66 b
Basal Fertilizer + Farmyard Manure	11.05 a	3.56 a	9.75 a	1674.18 a	70.58 a	67.70 bc	135.03 a	95.35 a

Several negative correlations are presented in Table 4, notably between stem diameter and number of branches with plant dry weight (r = -0.46 and r = -0.25) and fruit dry weight (r = -0.45 and r = -0.27). This unexpected result suggests that in this dataset, excessively large plants or those with many branches did not necessarily translate to higher fruit yields. The negative correlation between plant dry weight and efficiency (r = -0.17) is also noteworthy and requires further investigation. It might indicate that in this

specific dataset, a higher plant dry weight did not always correspond to higher efficiency. The observation that the highest plant dry weights were achieved without basal fertilizer but with the addition of organic amendments warrants further investigation. This unexpected result highlights the importance of considering pre-existing soil fertility and the immediate impact of soil amendments on water availability and aeration. The farmyard manure and rice husk likely improved soil structure, leading to enhanced water retention and root penetration, thereby increasing nutrient uptake from the existing soil nutrient pool. This suggests that in situations with sufficient inherent soil fertility, the immediate benefits of improved soil structure might outweigh the added nutrient input from basal fertilizer, at least in the early growth stages. Further research could explore the optimal balance between soil amendment application and basal fertilization based on initial soil nutrient levels.

Table 4. Correlation analyses on cucumber growth and yield parameters

	Total Fruit Number	Total Fruit/ Plant	Total Fruit Weight	Fruit Weight/ Plant	Stem Diameter	Number of Branch	Plant Dry Weight	Fruit Dry Weight	Shoot Weight	Efficiency
Total Fruit Number	1	1	0.82	0.82	0.47	0.47	0.1	0.21	0.64	0.93
Total Fruit/ Plant	1	1	0.82	0.82	0.47	0.47	0.1	0.21	0.64	0.93
Total Fruit Weight	0.82	0.82	1	1	0.53	0.54	0.12	0.31	0.58	0.81
Fruit Weight/ Plant	0.82	0.82	1	1	0.53	0.54	0.12	0.31	0.58	0.81
Stem Diameter	0.47	0.47	0.53	0.53	1	0.74	-0.46	-0.45	-0.12	0.53
Number of Branch	0.47	0.47	0.54	0.54	0.74	1	-0.25	-0.27	0.04	0.47
Plant Dry Weight	0.1	0.1	0.12	0.12	-0.46	-0.25	1	0.85	0.82	-0.17
Fruit Dry Weight)	0.21	0.21	0.31	0.31	-0.45	-0.27	0.85	1	0.84	0.11
Shoot Weight	0.64	0.64	0.58	0.58	-0.12	0.04	0.82	0.84	1	0.43
Efficiency	0.93	0.93	0.81	0.81	0.53	0.47	-0.17	0.11	0.43	1

The superior performance of the basal fertilizer + farmyard manure treatment likely stems from a synergistic interaction between the readily available nutrients provided by the basal fertilizer and the improved soil conditions created by the farmyard manure. Basal fertilizers, applied at the beginning of the growing season, provide a crucial initial boost of essential nutrients (N, P, K) for establishing a strong root system and promoting early vegetative growth (Yahaya et al., 2023). This initial surge of nutrients is particularly important for establishing vigorous seedlings and ensuring healthy early development. However, the effects of basal fertilizers are often short-lived, as nutrients can be quickly depleted by the plant or lost through leaching (T. Xie et al., 2025). Farmyard manure, on the other hand, offers a sustained release of nutrients through the gradual decomposition of organic matter. This slow-release mechanism ensures a more consistent supply of nutrients throughout the growing season, complementing the initial boost from the basal fertilizer. Furthermore, the organic matter in farmyard manure improves soil structure, water retention, and aeration, creating a more favourable environment for root growth and nutrient uptake. The improved soil structure also enhances microbial activity, leading to increased nutrient mineralization and making existing soil nutrients more readily available to the plants (Singh et al., 2024). This synergistic

interaction between readily available nutrients and improved soil conditions explains the superior performance of the basal fertilizer + farmyard manure treatment.

The relatively poor performance of treatments lacking basal fertilizer, even with the addition of farmyard manure or rice husk, underscores the importance of readily available nutrients, especially during the early growth stages. While farmyard manure provides a slow-release source of nutrients and improves soil structure, this process takes time. The initial nutrient deficiency in treatments without basal fertilizer may have limited early growth and development, impacting the plant's ability to fully utilize the benefits of the soil amendments. Rice husk, primarily improving soil structure through enhanced porosity and drainage, offers limited immediate nutrient release. Therefore, the combination of basal fertilizer and farmyard manure is crucial for providing both the initial nutrient boost necessary for rapid early growth and the long-term benefits of improved soil structure and nutrient availability. The control treatment, lacking both basal fertilizer and soil amendments, exhibited the lowest yields, clearly indicating the importance of both nutrient input and soil improvement for optimal cucumber growth. The significant differences observed between treatments highlight the complex interplay between nutrient availability, soil structure, and plant growth, emphasizing the need for a balanced and integrated approach to nutrient management (Meena & Reddy, 2021).

Total Fruit Number, Total Fruit/Plant, Total Fruit Weight, and Fruit Weight/Plant are all highly correlated with each other (r = 1 and r = 0.82) showed in Table 5. This strong positive correlation is expected, as a higher number of fruits naturally leads to a greater total fruit weight and a higher fruit weight per plant. Shoot weight also shows a strong positive correlation with fruit dry weight (r = 0.84) and plant dry weight (r = 0.82), indicating that greater vegetative growth is associated with higher fruit yields. Efficiency is also strongly correlated with total fruit number, total fruit per plant, and total fruit weight (r = 0.93 and r = 0.81), reflecting the fact that higher yields generally indicate better resource use. Stem diameter and number of branches show moderate positive correlations with total fruit weight (r = 0.53 and r = 0.54) and number of fruits (r = 0.47). This suggests that larger plants with more branches tend to produce more fruit. However, the correlation with plant dry weight is weak or even negative in some cases.

The consistent positive effect of farmyard manure on fruit yield, regardless of basal fertilizer application, underscores its multifaceted role in enhancing nutrient availability. The organic matter in farmyard manure not only provides a slow-release source of essential nutrients but also improves soil microbial activity. This increased microbial activity leads to enhanced nutrient mineralization and makes existing soil nutrients more readily available to the plant roots (Zhao et al., 2024). Furthermore, the improved soil structure resulting from farmyard manure application enhances water infiltration and retention, reducing the risk of nutrient leaching and ensuring a consistent supply of moisture for optimal fruit development. The comparatively lower fruit yield in treatments using rice husk alone points to the importance of readily available nutrients, particularly during the crucial fruiting stage.

The strong positive correlation between vegetative and reproductive growth underscores the importance of achieving a balanced nutrient allocation strategy. Sufficient vegetative growth provides the necessary photosynthetic capacity to support fruit development. Treatments that promoted robust vegetative growth, such as those incorporating farmyard manure, also tended to exhibit higher fruit yields. This highlights the need to consider the overall plant health and vigor when optimizing for fruit production (Shahane & Shivay, 2021). Simply focusing on maximizing fruit yield might be counterproductive if it compromises the plant’s overall health and ability to support fruit development. A balanced approach that promotes both vegetative and reproductive growth is crucial for maximizing overall yield.
The superior nutrient use efficiency of the basal fertilizer + farmyard manure treatment highlights the potential for synergistic

interactions between inorganic and organic nutrient sources. This combination offers both the immediate nutrient boost from the basal fertilizer and the long-term benefits of improved soil health from farmyard manure. This approach not only maximizes yield but also promotes sustainable agriculture by minimizing nutrient waste and optimizing resource utilization. Further research could focus on determining the optimal ratios of basal fertilizer and farmyard manure for different soil types and climatic conditions to further enhance nutrient use efficiency and promote sustainable crop production.

Nutrient Uptake by Cucumber Plants

Figure 2. presents data on nitrogen (N) levels in the soil and plants, along with nitrogen use efficiency (NUE), under six different treatments combining basal fertilizer application and soil amendments (farmyard manure and rice husk). The treatments included basal fertilizer with and without soil amendments (farmyard manure and rice husk) and no basal fertilizer with and without soil amendments. Soil nitrogen levels ranged from 295.2 units in treatments without farmyard manure to 475.2 units in the basal fertilizer + farmyard manure treatment. Nitrogen in plants ranged from 184.56 units (without basal fertilizer + rice husk) to 229.59 units (basal fertilizer + farmyard manure). Nitrogen use efficiency (NUE) varied considerably across treatments, ranging from 48.31% (basal fertilizer + farmyard manure) to 67.71% (without basal fertilizer + without soil amendments).

The data reveal that the application of basal fertilizer significantly increased soil nitrogen levels compared to treatments without basal fertilizer. The addition of farmyard manure further enhanced soil nitrogen levels, regardless of basal fertilizer application. Interestingly, the highest plant nitrogen content was observed in the basal fertilizer + farmyard manure treatment, but this treatment did not exhibit the highest NUE. The highest NUE was observed in the treatment without basal fertilizer and without soil amendments, suggesting that in the absence of added nitrogen, the plants were more efficient at utilizing the naturally available nitrogen. Treatments with rice husk showed no significant difference in soil or plant nitrogen compared to treatments without any soil amendment. This suggests that rice husk did not contribute significantly to nitrogen availability in the soil during the experimental period.

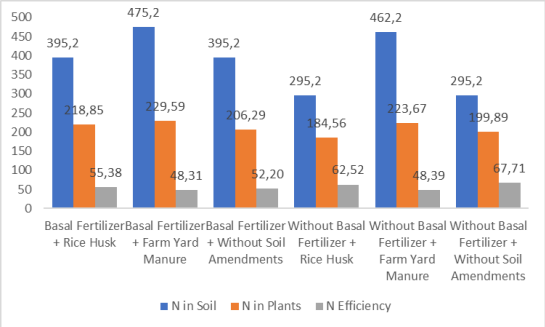


Figure 2. N in soil, plant, and N efficiency

Figure 3. presents data on phosphorus (P) levels in the soil and plants, along with phosphorus use efficiency (PUE), under six different treatments combining basal fertilizer application and soil amendments (farmyard manure and rice husk). The treatments included basal fertilizer with and without soil amendments (farmyard manure and rice husk) and no basal fertilizer with and without soil amendments. Soil phosphorus levels were relatively consistent across treatments, ranging from 447.2 units in treatments without farmyard manure to 500.2 units in the treatment without basal fertilizer + farmyard manure. Phosphorus levels in plants ranged from 72.06 units in the basal fertilizer + rice husk treatment to 79.07 units in the treatment without basal fertilizer + farmyard manure. Phosphorus use efficiency (PUE) varied considerably across treatments, with the highest PUE (17.26%) observed in the treatment without basal fertilizer and without soil amendments, and the lowest (15.81%) in the treatment without basal fertilizer + farmyard manure.

The data show that while soil phosphorus levels were not significantly affected by the treatments, plant phosphorus content and PUE were influenced by the combination of basal fertilizer and soil amendments. The highest plant phosphorus content was observed in the treatment without basal fertilizer + farmyard manure, suggesting

that farmyard manure may enhance phosphorus uptake even in the absence of added phosphorus fertilizer. However, this treatment did not show the highest PUE, indicating that the enhanced phosphorus uptake may not translate to higher efficiency. The highest PUE was observed in the treatment without basal fertilizer and without soil amendments, suggesting that in the absence of added phosphorus, the plants were more efficient at utilizing the naturally available phosphorus. The addition of rice husk did not significantly alter soil or plant phosphorus levels or PUE.

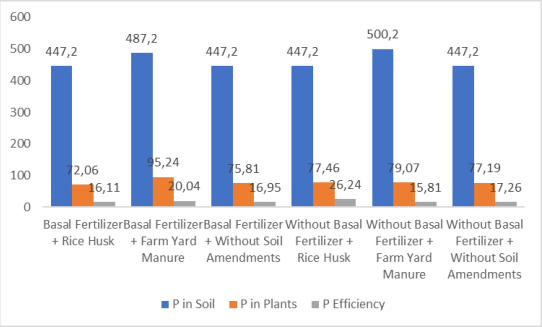


Figure 3. P in soil, plant, and P efficiency

Figure 4. displays the potassium (K) content in the soil and plants, along with potassium use efficiency (KUE), across six different treatments. Treatments involved the application of basal fertilizer with and without soil amendments (farmyard manure and rice husk). Soil potassium levels varied considerably across treatments, ranging from a low of 211.2 units in treatments without farmyard manure to a high of 351.2 units in the treatment with basal fertilizer and farmyard manure. Plant potassium content also varied, ranging from 117.6 units in treatments without basal fertilizer to 246.6 units in the treatment with basal fertilizer and farmyard manure. Potassium use efficiency (KUE) showed the highest value (70.22%) in the basal fertilizer + farmyard manure treatment.

The data reveal that both basal fertilizer application and the type of soil amendment significantly impacted potassium levels in the plants and KUE. Treatments including farmyard manure consistently exhibited higher soil and plant potassium levels compared to treatments without manure. The highest KUE was observed in the treatment with basal fertilizer and farmyard manure, indicating a synergistic effect between the readily available potassium from the fertilizer and the improved soil conditions provided by the manure. Conversely, treatments without basal fertilizer showed lower plant potassium and similar KUE, suggesting that basal fertilizer is crucial for efficient potassium uptake. The addition of rice husk alone did not significantly increase potassium levels in the soil or plants.

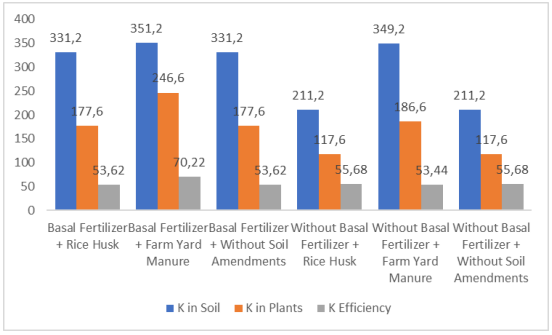


Figure 4. K in soil, plant, and K efficiency

The observed trends in nitrogen levels and NUE can be explained by several factors. The higher nitrogen levels in treatments with basal fertilizer are expected, as the fertilizer provides a readily available source of nitrogen. The increased nitrogen levels in treatments with farmyard manure are attributed to the slow release of nitrogen from the decomposing organic matter (Oyetunji et al., 2022). However, the lower NUE in the farmyard manure treatments, despite higher nitrogen levels, suggests that the rate of nitrogen release from the manure may not be perfectly synchronized with plant demand. A potential imbalance between nitrogen supply and plant uptake could lead to lower NUE. Furthermore, the higher NUE in the treatment without basal fertilizer and without soil amendments highlights the inherent efficiency of plants in utilizing naturally available nitrogen when external nitrogen sources are limited (Suman et al., 2023). The lack of effect of rice husk on nitrogen levels is consistent with its known slow decomposition rate and limited nitrogen content. These results emphasize the importance of optimizing nitrogen management strategies to maximize both nitrogen availability and utilization efficiency.

The relatively consistent soil phosphorus levels across treatments suggest that the applied amendments did not substantially alter the total phosphorus content in the soil. The higher plant phosphorus content in the farmyard manure treatments, even without added phosphorus fertilizer, indicates that farmyard manure may enhance phosphorus availability through improved soil structure, increased microbial activity, and the slow release of organically bound phosphorus (S. Xie et al., 2023). The higher PUE in the control treatment (no basal fertilizer, no amendments) indicates that plants are inherently efficient at utilizing phosphorus when external sources are limited. The lower PUE in some treatments with farmyard manure might be due to an imbalance between phosphorus supply from the manure and plant demand, or other factors influencing phosphorus uptake (Noulas et al., 2023). Further investigations are needed to understand the complex interactions between soil amendments, phosphorus availability, and plant phosphorus uptake.

These results align with general knowledge regarding potassium fertilization. Farmyard manure is a known source of potassium, and its addition to the soil improves potassium availability to plants. Basal fertilizer provides a readily available source of potassium, leading to higher uptake by plants (Sardans & Peñuelas, 2021). The synergistic effect of basal fertilizer and farmyard manure is likely due to the improved soil structure and enhanced nutrient availability resulting from the organic matter in the manure. Rice husk, while beneficial for soil structure and water retention, does not significantly contribute to potassium levels, highlighting the importance of targeted potassium sources like fertilizers and organic amendments rich in potassium (Xie et al., 2025).

The observed differences in soil NPK levels before and after treatment application highlight the complex interplay between fertilizer application, nutrient uptake by the plants, and the inherent nutrient content of soil amendments. The relatively low nitrogen fertilizer efficiency (approximately 30%) suggests that a significant portion of the applied nitrogen was either lost through volatilization, leaching, or immobilization by soil microorganisms. This emphasizes the importance of optimizing nitrogen management practices to maximize nutrient use efficiency and minimize environmental impact. Further investigation into the specific mechanisms of nitrogen loss in this system would be valuable.

The substantial accumulation of phosphorus (P) and potassium (K) in the soil, despite high fertilizer use efficiency, points to an imbalance between nutrient supply and plant demand. While the high fertilizer use efficiency for P and K is positive, the significant excess suggests that the application rates may be too high for the specific needs of the cucumber plants in this system (Li et al., 2024). This highlights the importance of conducting regular soil tests to determine the optimal nutrient application rates, avoiding excessive accumulation of nutrients that can have negative long-term consequences for soil health and environmental sustainability. The low potassium uptake, despite high efficiency, could be due to factors such as nutrient interactions or limitations in plant uptake mechanisms (Sardans & Peñuelas, 2021).

The findings regarding nutrient uptake and accumulation have significant implications for developing sustainable nutrient management strategies for cucumber production. The observed nitrogen deficiency and phosphorus and potassium accumulation highlight the need for a more precise and targeted approach to fertilizer application. This could involve optimizing fertilizer application rates based on regular soil testing, exploring alternative nitrogen sources with lower environmental impact, and potentially adjusting the P and K application rates to better match plant demand. Furthermore, the incorporation of organic amendments, such as farmyard manure, can contribute to improved nutrient cycling and potentially reduce the need for synthetic fertilizers.

To gain a more complete understanding of nutrient uptake dynamics, further investigation is needed. Isotopic labeling studies could be employed to trace the fate of applied nutrients within the soil-plant system,

providing detailed insights into nutrient uptake, transformation, and loss mechanisms. More detailed analysis of the nutrient content of the farmyard manure would allow for a more accurate assessment of its contribution to the overall nutrient balance. Finally, examining the nutrient content of plant tissues at different growth stages would provide a more comprehensive understanding of nutrient uptake patterns throughout the cucumber life cycle. This additional data would help refine nutrient management strategies for improved efficiency and sustainability.

CONCLUSION

This study demonstrates the significant interactive effects of basal fertilizers and soil amendments on cucumber growth and yield. The results reveal that while farmyard manure consistently enhanced fruit yield, regardless of basal fertilizer application, the highest overall plant dry weight was surprisingly observed in treatments without basal fertilizer but with farmyard manure or rice husk, suggesting sufficient pre-existing soil fertility and the strong impact of improved soil structure on water availability and nutrient uptake. The combination of basal fertilizer and farmyard manure, however, yielded the highest fruit weight and the best nutrient use efficiency, indicating a balanced allocation of resources towards both vegetative and reproductive growth. This highlights the importance of considering both readily available nutrients (from basal fertilizers) and improved soil conditions (from farmyard manure) for optimizing cucumber yield. Rice husk, while improving soil structure, required supplemental basal fertilizer for optimal fruit production. The strong positive correlation between vegetative and reproductive growth underscores the need for a balanced approach to nutrient management, maximizing both plant health and fruit yield. Further research should investigate the optimal balance between basal fertilizer and farmyard manure application for different soil types and climatic conditions to further enhance nutrient use efficiency and promote sustainable crop production.

REFERENCE

Bashir, O., Ali, T., Baba, Z. A., Rather, G. H., Bangroo, S. A., Mukhtar, S. D., Naik, N., Mohiuddin, R., Bharati, V., & Bhat, R. A. (2021). Soil Organic Matter and Its Impact on Soil Properties and Nutrient Status BT - Microbiota and Biofertilizers, Vol 2: Ecofriendly Tools for Reclamation of Degraded Soil Environs. In G. H. Dar, R. A. Bhat, M. A. Mehmood, & K. R. Hakeem (Eds.), Microbiota and Biofertilizer (pp. 129–159). Springer International Publishing. https://doi.org/10.1007/978-3-030-61010-4_7

de Sousa, R. N., & Moreira, L. A. (2024). Plant Nutrition Optimization: Integrated Soil Management and Fertilization Practices. In R. N. de Sousa (Ed.), Strategic Tillage and Soil Management. IntechOpen. https://doi.org/10.5772/intechopen.114848

Hariatik. (2014). Perbandingan Unsur NPK pada Pupuk Organik Kotoran Sapi dan Kotoran Ayam dengan Pembiakan Mikro Organisme Lokal (MOL). In Seminar Nasional Pendidikan Sains IV 2014 (pp. 1–23).

Kang, J., Peng, Y., & Xu, W. (2022). Crop Root Responses to Drought Stress: Molecular Mechanisms, Nutrient Regulations, and Interactions with Microorganisms in the Rhizosphere. International Journal of Molecular Sciences, 23(16), 1–26. https://doi.org/10.3390/ijms23169310

Kartini, N. L., Saifulloh, M., Trigunasih, N. M., Sukmawati, N. M. S., & Mega, I. M. (2024). Impact of Long-Term Continuous Cropping on Soil Nutrient Depletion. Ecological Engineering and Environmental Technology, 25(11), 18–29. https://doi.org/10.12912/27197050/191953

Li, N., Wang, X.-X., Xue, Z., & Li, Q. (2024). Water and potassium utilization efficiency and yield and quality of

cucumber (Cucumis sativus L.). Scientia Horticulturae, 330, 113025. https://doi.org/https://doi.org/10.1016/j.scienta.2024.113025

Ma, R., Jiang, C., Shou, N., Gao, W., & Yang, X. (2023). An Optimized Nitrogen Application Rate and Basal Topdressing Ratio Improves Yield, Quality, and Water- and N-use Efficiencies for Forage Maize (Zea mays L.). Agronomy, 13(1), 1–18. https://doi.org/10.3390/agronomy13010181

Meena, M., & Reddy, K. V. (2021). A review on Integrated nutrient management for sustainable agriculture. The International Journal of Analytical and Experimental Modal Analysis, 8(5), 541–551.

Noulas, C., Torabian, S., & Qin, R. (2023). Crop Nutrient Requirements and Advanced Fertilizer Management Strategies. Agronomy, 13(8), 1–10. https://doi.org/10.3390/agronomy13082017

Omar, L., Ahmed, O. H., Jalloh, M. B., & Majid, N. M. A. (2021). Rice husk compost production and use in mitigating ammonia volatilization from urea. Sustainability (Switzerland), 13(4), 1–23. https://doi.org/10.3390/su13041832

Oyetunji, O., Bolan, N., & Hancock, G. (2022). A comprehensive review on enhancing nutrient use efficiency and productivity of broadacre (arable) crops with the combined utilization of compost and fertilizers. Journal of Environmental Management, 317, 115395. https://doi.org/https://doi.org/10.1016/j.jenvman.2022.115395

Sardans, J., & Peñuelas, J. (2021). Potassium Control of Plant Functions : Ecological and. In Plants (Vol. 10, Issue 419).

Sarma, H. H., Borah, S. K., Chintey, R., Nath, H., & Talukdar, N. (2024). Site Specific Nutrient Management (SSNM): Principles, Key Features and its Potential Role in Soil, Crop Ecosystem and Climate Resilience Farming. Journal of Advances in Biology & Biotechnology, 27(8), 211–222. https://doi.org/10.9734/jabb/2024/v27i81133

Sarma, H. H., Talukdar, N., Bezbaruah, A., Kurmi, K. K., & Borkotoky, B. (2024). Identification of Sterility Mosaic Disease (Smd) Resistance Vegetable Pigeonpea Hybrids (Cajanus Cajan L. Millsp.). Plant Archives, 24(2), 1131–1140. https://doi.org/10.51470/plantarchives.2024.v24.no.2.135

Shahane, A. A., & Shivay, Y. S. (2021). Soil Health and Its Improvement Through Novel Agronomic and Innovative Approaches. Frontiers in Agronomy, 3(September), 1–31. https://doi.org/10.3389/fagro.2021.680456

Shaheb, M. R., Venkatesh, R., & Shearer, S. A. (2021). A Review on the Effect of Soil Compaction and its Management for Sustainable Crop Production. Journal of Biosystems Engineering, 46(4), 417–439. https://doi.org/10.1007/s42853-021-00117-7

Singh, N. K., Sachan, K., Ranjitha G., Chandana S., Manoj B. P., Panotra, N., & Katiyar, D. (2024). Building Soil Health and Fertility through Organic Amendments and Practices: A Review. Asian Journal of Soil Science and Plant Nutrition, 10(1), 175–197. https://doi.org/10.9734/ajsspn/2024/v10i1224

Suman, J., Rakshit, A., Patra, A., Dutta, A., Tripathi, V. K., Mohapatra, K. K., Tiwari, R., & Krishnamoorthi, S. (2023). Enhanced Efficiency N Fertilizers: an Effective Strategy to Improve Use Efficiency and Ecological Sustainability. Journal of Soil Science and Plant Nutrition, 23(2), 1472–1488. https://doi.org/10.1007/s42729-023-01237-z

Wang, H., Yang, Y., Yao, C., Feng, Y., Wang, H., Kong, Y., Riaz, U., Zaman, Q. uz,

Sultan, K., Fahad, S., & Deng, G. (2024). The Correct Combination and Balance of Macronutrients Nitrogen, Phosphorus and Potassium Promote Plant Yield and Quality Through Enzymatic and Antioxidant Activities in Potato. Journal of Plant Growth Regulation, 43(12), 4716–4734. https://doi.org/10.1007/s00344-024-11428-2

Xie, S., Tran, H.-T., Pu, M., & Zhang, T. (2023). Transformation characteristics of organic matter and phosphorus in composting processes of agricultural organic waste: Research trends. Materials Science for Energy Technologies, 6, 331–342. https://doi.org/https://doi.org/10.1016/j.mset.2023.02.006

Xie, T., Li, J., Lin, S., Ju, X., & Li, T. (2025). Integrating organic amendments and enhanced efficiency fertilizers for sustainable rice production——A case study in a tropic paddy system. Journal of Cleaner Production, 516, 145765. https://doi.org/https://doi.org/10.1016/j.jclepro.2025.145765

Yahaya, S. M., Mahmud, A. A., Abdullahi, M., & Haruna, A. (2023). Recent advances in the chemistry of nitrogen, phosphorus and potassium as fertilizers in soil: A review. Pedosphere, 33(3), 385–406. https://doi.org/https://doi.org/10.1016/j.pedsph.2022.07.012

Zhao, Y., Bian, Q., Dong, Z., Rao, X., Wang, Z., Fu, Y., & Chen, B. (2024). The input of organic fertilizer can improve soil physicochemical properties and increase cotton yield in southern Xinjiang. Frontiers in Plant Science, 15(January), 1–15. https://doi.org/10.3389/fpls.2024.1520272