Research Article

Integration of Urea-N with Biogas Slurry, Compost and FYM for Improving Aproductivity of Wheat

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Abstract | This study evaluated the effects of conventional fertilizers replaced by different nitrogen management strategies on wheat crop yield. The experiment consists of urea as a control and three organic sources (OS) as treatments, namely biogas plant slurry (BPS), compost, and farm yard manure (FYM). There were three levels for each L1 (100% N from OS), L2 (75% N from OS + 25% N from urea), and L3 (50% N from OS + 50% N from urea). The BPS resulted in the maximum thousand grain weight (46.8 g), plant height (96. 1 cm), grain yield (4.4 T ha^{-1}), harvest index (37.4%) and economic analysis (5.69) than the other organic sources. L3 (50% N from OS + 50% N from urea) had the highest thousand grains weight (47 g), plant height (96.8 cm), biological yield (12.1 T ha^{-1}), grain yield (4.3 T ha^{-1}) than the other levels. This study suggests that integrated N-strategies (50% from BPS + 50% urea) be utilized to promote crop development, grain production, and harvest index, whereas 50% N from compost + 50% N urea improves biological yield. The 50% N from OS has the potential to reduce the cost of inorganic fertilizers by up to 50%.

Received | 01 03, 2025; **Accepted** | Oct 9, 2025; **Published** | January 22, 2026
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Citation | Din, R.U., M. K. Khattak, M. Ramzan, S. Ahmad, I. Ahmad, M. Hanif and I.U. Haq. 2026. Integration of urea-n with biogas slurry, compost and fym for improving aproductivity of wheat. *Sarhad Journal of Agriculture,* 42(1): 35-43.
DOI | https://dx.doi.org/10.17582/journal.sja/2026/42.1.35.43
Keywords | Biogas plant slurry, Compost, Farm yard manure, Inorganic fertilizer.

Introduction

Wheat (*Triticum aestivum* L) an essential cereal crop belonging to the family poaceae plays a dynamic role in stable food. It is a chief source of and protein. Plant nutrients are the key factors of the productivity of any soil. Inorganic fertilizers are a convenient source of nutrients for crops. They are less massive and relaxed in handle and conveyance. Still, because of their high cost, farmers could not afford. Organic substances not only recover soil health, but also afford plant nutrients for sustainable crop yield. Inorganic fertilizers neither expensive, but have depreciated superiority of the food (Parshuram *et al*. 2024). Excessive and unremitting application of inorganic fertilizers can result in the contamination of watercourses and the soil health degradation occasionally consequential in harmful results instead of confident ones. Hereafter, a principal problem is to meet the N requirements of crops whereas preventive N wastage in order to reserve economic advantages for farmers and a sustainable ecosystem. It is vital to carry the crop with a combination of organic and chemical nutrients sources. The advanced degradation of soil eminence can be improved with the application of organic resources (Zada *et al*., 2024).

Of the agronomical aspects known to enhance wheat yield, nutrients subsidize to approximately 41%, mostly the exact rate and rank of the plant nutrients mostly nitrogen, phosphorus and potassium are more extensively understood today with micronutrients. Utilization of fertilizer and agro-production is in between correlation and its impact revealed on the growth of plant and yield quickly (Patel *et al*., 2018). The application of inorganic fertilizers is a normal practice in wheat production; however, earlier reports have exposed the negative impacts of the continuous use of these fertilizers on soil ecology and ecosystem. In crop production, BPS and other organic sources provides the major nutrients which are essential for optimum plant growth. As a result, crop yield increased with low input cost, since the purchase of fertilizers can be avoided. In summary, applying digested biogas slurry has been shown to enhance the growth of various crops by providing them with essential nutrients and promoting environmentally friendly soil health maintenance (Ferdous *et al*., 2020). Evaluations have demonstrated that biogas slurry has higher concentrations of N, P, and K than slurry compost and farmyard manure (Jared *et al*., 2016). They showed that bio-slurry contain more N, P and K concentration than slurry compost and farmyard manure. The combined application of bio-slurry and inorganic fertilizers significantly affected the head diameter, firmness, compactness, pH, and titratable acidity of cabbage juice. Higher titratable acidity was obtained with the integrated application of fertilizer and improved soil properties (Terefe *et al*., 2018). Traditional farming has played a significant role in enhancing food production to meet human demands through the intensive application of inorganic fertilizers (Phares *et al*., 2022).

Researchers have proposed that the optimal quantity of biogas slurry should be determined based on the soil's existing nutrient levels (Yafizham and Sumarsono, 2020). Studies have disclosed that the utilization of inorganic fertilizers is a common practice in crop production (Awodun, 2021); however, earlier reports have exposed the negative impacts of the continuous application of these inorganic fertilizers on soil ecology and ecosystem. BPS is already applied for the growth and yield of the crop, but still, the optimum combination of bio-slurry and urea is uncalculated for climate Khyber Pakhtunkhwa-Pakistan. Incorporation of organic with inorganic fertilizers develops the physiological system of the crop, supplies sufficient growth regulating essence and modifies soil physio-chemical properties. In crop production, BPS and other organic sources provide the major nutrients which are essential for optimum plant growth. As a result, crop yield increased with low input cost, since the purchase of fertilizers can be avoided. The escalating cost of inorganic fertilizers poses a substantial challenge for farmers, particularly in developing areas. This rise impacts agricultural profitability and results in environmental issues, such as soil and water pollution, and biodiversity loss. Identifying sustainable solutions to mitigate these effects and ensuring long-term food security are essential. Research studies on organic farming have recently shown that a biogas plant produces an enormous quantity of bio-manure per year, which can be used as a bio fertilizer to increase crop yield. In this study determined the significant combination of organic sources (BPS, compost and farm yard manure) with urea. The aim of study was;

To evaluate the impact of biogas plant slurry integrated with different N-management strategies on wheat crop production.

Materials and Methods

Research site

This study was conducted during 2019-2020 and 2020-2021 in Agriculture Research Farm, the University of Agriculture Peshawar. Before starting the experiment biogas plant slurry was collected from the University Research Dairy Farm at the University of Agriculture Peshawar, Pakistan, at a latitude of 34°02'N and longitude of 71° 63'E. The Chemical analysis BPS showed an average nitrogen content (N) 1.8%, phosphorus (P_2O_5) of 0.8%, and potassium (K_2O) of 1.2%. The Physio-chemical traits of the research site soil (Table 1) were tested in the laboratory of Department of Soil and Environmental Sciences. The soil texture was calculated by using Buyoucos hygrometer and the method followed by (Haq *et al*., 2022). The soil pH and electrical conductivity (ECe) was checked by multi-meter. The soil bulk density and soil organic matter were calculated on dried-soil basis through procedure followed by (Haq *et al*., 2022).

Table 1: *Physio-chemical characteristics of experimental soil before the initiation of the trial.*

Soil properties	Units	Values	Soil properties	Units	Values
Soil textural class	---	Silt clay loam	Soil textural class	---	Silt clay loam
pH	---	8.15	Organic matter	%	0.39
Ece	dSm^{-1}	0.37	Total Nitrogen	%	0.07
Silt	%	50.7	P	mg/kg	1.80
Sand	%	18.9	K	mg/kg	95.6
Clay	%	30.2	Bulk density	g/cm^3	1.48

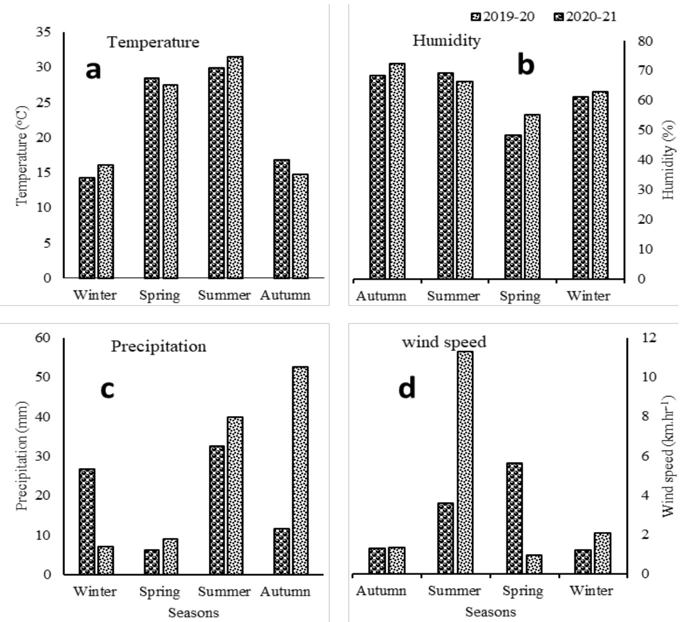

Figure 1: *Seasonal average (a) temperature (°C), (b) humidity (%), (c) total precipitation (mm) and (d) wind speed (km.hr^{-1}) data recorded during dehydration of bio-digester effluents.*

The research included three organic N sources (BPS, Compost, and FYM) and compared them with an inorganic N source (urea). The root bed was prepared using a disk plow twice at standard field capacity, whereas the seedbed was prepared using a rotavator once. Thereafter, Pirsabak-2015 (123.5 kg ha^{-1}) wheat cultivar was sown using seed drill with 20 cm row to row distance. In addition to rainfall, the need of crop and weather conditions the crop was irrigated and weeds were removed by the application of chemical "Affinity" @ 1.2 Lha^{-1} as well as applied fertilizer at the vegetative stage.

The treatments were applied randomly to the field. The following factors and levels were checked during the study: a control and three OS as treatments, namely biogas plant slurry (OS1), compost (OS2), and farm yard manure (OS3). The recommended dose of phosphorus at 60 kg ha $^{-1}$ was applied from DAP (130 kg ha $^{-1}$) incorporated at the time of sowing. A nitrogen dose of 23.5 kg ha $^{-1}$ was also applied from DAP at 130 kg ha $^{-1}$, while the rest of 96.5 kg N ha $^{-1}$ was obtained from integrated organic N sources and urea. Three treatment combinations were set for each OS with three levels and control shown in Figure 2.

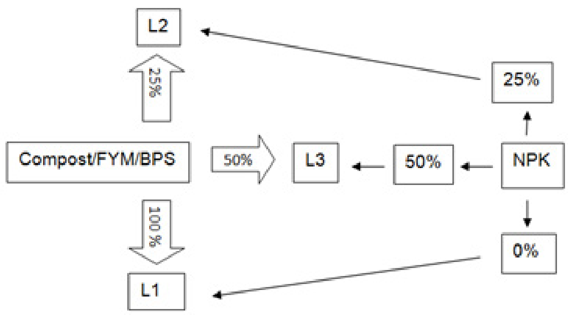

Figure 2: *Flow chart of the research treatments*

Data were analyzed according standard procedures of two-way ANOVA and least significant difference test at 95% level of significance was used to compare treatment means. Statistix 8.1 software was used for data analysis. The meteorological data, i.e. average temperature (°C), precipitation (mm), wind speed (km.hr^{-1}) and humidity (%) for each season (as Pakistan has four seasons per year) was collected from Meteorological Regional Center Peshawar as shown in Figure 1.

Results

Thousand-grain weight and plant height were significantly affected by organic sources (OS), their levels and interaction of OS with their levels and comparison of control with organic sources (Table 2). The highest thousand grains weight (46.8 g) was found in the biogas plant slurry (BPS) followed by 45.5g in compost while lowest grain weight 40.2g in farm yard manure (FYM). In levels of OS, L3 (50% N from organic source + 50% N from urea) had highest thousand grains weight (47 g) followed by 43.5g in L2 (75% N from organic source + 25% N from urea) while the lowest thousand grains weight (41.9 g) was found in L1 (100% N from organic source). The lowest plant height (92.39 cm) was found in the FYM while BPS and compost had statistically higher (96 cm) and similar effect. In levels of OS, L3 (50% N from organic source + 50% N from urea) had highest plant height (96.84 cm) while L2 and L1 had statistically similar results. The mean of both years showed that BPS and compost resulted in higher plant height than the FYM. L3 (50% N from organic source + 50% N from urea) had highest plant height than L1 and L2.

Thousand grains weight of wheat was significantly affected by OS level because grains weight directly dependent on amount of available nitrogen in the soil. The urea is rich in nitrogen therefore urea provides more nitrogen content to the soil than the other sources. The results are similar to the Ghimire *et al.* (2023) the combination of urea and organic sources resulted in higher thousand grains weight because of presence of essential nutrients. The increase in grains weight might be due to the balance supply of essential nutrients to the plants during growing season (Tang *et al.*, 2020). The application of compost and BPS enhanced the grain weight and wheat growth. The reason is that the compost and BPS are completely changed into porous materials and its addition to the soil increases the soil porosity, water holding capacity and nutrients holding capacity of the soil particles. The results are in line with França *et al.* (2021) stated that the compost and BPS provide more nutrients than the other sources for producing fruits. The plant growth is reliant to nitrogen availability to the plants. The BPS and compost had higher nitrogen content than the FYM and OS level L3 (50% N from organic source and 50% N from urea) had higher nitrogen

Table 2: *Thousand grain weight (g) and Plant height (cm) of wheat crop as affected by different organic sources and their levels and inorganic fertilization.*

Organic source (OS)	Thousand grain weight (g)			Plant height (cm)		
	2019-20	2020-21	Mean	2019-20	2020-21	Mean
Biogas plant slurry	46.1 a	47.5 a	46.8 a	100.13 a	92.12 a	96.13a
Compost	45.1 a	45.8 b	45.5 b	100.60 a	92.55 a	96.57a
FYM	39.8 b	40.5 c	40.2 c	96.12 b	88.65 b	92.39b
$LSD_{0.05}$	1.40	1.74	1.08	1.867	2.181	1.386
Levels (L)						
L1	41.2 c	42.7 c	41.9 c	97.59 b	89.78 b	93.68 b
L2	43.1 b	43.9 b	43.5 b	98.45 b	90.68 b	94.56 b
L3	46.7 a	47.3 a	47.0 a	100.82 a	92.86 a	96.84 a
$LSD_{0.05}$	1.40	1.74	1.08	1.867	2.181	1.386
Year (Y)						
2019-20			43.7			98.95 a
2020-21			44.6			91.11 b
LSD			NS			1.423
Contrast						
Control	46.2	46.4	46.3	97.19	92.74	94.97
Organic Source	43.7	44.6	44.1	98.95	91.11	95.03
$LSD_{0.05}$	**	NS	**	NS	NS	NS
Interaction		Level of significance				
OS x L	*	*	***	NS	NS	**
Y x OS			NS			NS
Y x L			NS			NS
Y x OS x L			NS			NS

*L1= 100% N from OS, L2 = 75% N from OS + 25% N from urea, L3 = 50% N from OS + 50% N from urea, NS = Non-significant and *, *** = significant at 5% and 0.1% level of probability, respectively*

content than the other levels. Therefore, BPS and compost should be selected for enhancing plant height of wheat. The results are in line with (Tang *et al*., 2020; Chen *et al*., 2022; Jiang *et al*., 2024) also found same results and declared that organic and inorganic amendments for N had resulted taller plants with greater spike length.

Organic sources factors and their levels, year and interaction of OS with their levels showed a significant effect on biological yield and grain yield of wheat (Table 3). Highest biological yield (12.30 T ha^{-1}) was found in the compost followed by BPS (11.80 T ha^{-1}) while FYM produced lowest biological yield (10.57 T ha^{-1}). In the OS levels, L3 (50% N from organic source + 50% N from urea) had highest biological yield (12.07 T ha^{-1}) followed by (11.50 T ha^{-1}) in L2 while L1 had lowest biological yield of (11.1 T ha^{-1}). The mean of both years showed that compost resulted in higher biological yield than the BPS and FYM. L3 had highest biological yield than L1 and L2. In 2019-2020, BPS had highest grain yield (4.4 T ha^{-1}) followed by compost (4.25 T ha^{-1}) while FYM had lowest grain yield of 3.5 T ha^{-1}. L3 (50% N from organic source + 50% N from urea) had highest grain yield (4.4 T ha^{-1}) followed by L2 (4 T ha^{-1}) while L1 had lowest result of 3.8 T ha^{-1}. In 2020-2021, highest grain yield of 4.4 T ha^{-1} was recorded in BPS followed by compost (4.15 T ha^{-1}) while FYM had lowest grain yield (3.4 T ha^{-1}). L3 (50% N from organic source + 50% N from urea) had highest grain yield (4.3 T ha^{-1}) followed by L2 (3.9 T ha^{-1}) and L1 had lowest result of 3.7 T ha^{-1}. The mean of both years showed that BPS resulted in higher grain yield than the FYM. L3 (50% N from organic source + 50% N from urea) had highest grain yield than L1 and L2.

Table 3: *Biological yield (T ha^{-1}) and grain yield (T ha^{-1}) of wheat crop as affected by different organic sources and their levels and inorganic fertilization.*

Organic source (OS)	Biological yield (T ha^{-1})			Grain yield (T ha^{-1})		
	2019-20	2020-21	Mean	2019-20	2020-21	Mean
Biogas plant slurry	11.94 b	11.67 b	11.80 b	4.46 a	4.36 a	4.41 a
Compost	12.43 a	12.17 a	12.30 a	4.25 b	4.16 b	4.20 b
FYM	10.69 c	10.45 c	10.57 c	3.52 c	3.44c	3.48 c
$LSD_{0.05}$	0.329	0.308	0.218	0.144	0.138	0.096
Levels (L)						
L1	11.23 c	10.98 c	11.10 c	3.83 c	3.74 c	3.78 c
L2	11.63 b	11.37 b	11.50 b	4.02 b	3.94 b	3.98 b
L3	12.20 a	11.94 a	12.07 a	4.38 a	4.28 a	4.33 a
$LSD_{0.05}$	0.329	0.308	0.218	0.144	0.138	0.096
Year (Y)						
2019-20			11.68 a			4.08 a
2020-21			11.43 b			3.99 b
LSD			0.202		-	0.066
Contrast						
Control	11.68	11.63	11.65	4.19	4.17	4.18
Organic Source	11.68	11.43	11.56	4.08	3.99	4.03
$LSD_{0.05}$	NS	NS	NS	NS	*	*
Interaction		Level of significance				
OS x L	**	**	***	**	**	***
Y x OS			NS			NS
Y x L			NS			NS
Y x OS x L			NS			NS

*L1= 100% N from OS, L2 = 75% N from OS + 25% N from urea, L3 = 50% N from OS + 50% N from urea, NS = Non-significant and *, *** = significant at 5% and 0.1% level of probability, respectively*

Compost resulted in highest biological yield of wheat and BPS resulted in highest grain yield and harvest index. In the same way, L3 (50% N from OS + 50% N from urea) had highest biological and grain yield. The increased in biological yield and grain yield by BPS and compost had proper nitrogen and other essential nutrients. This may be due to the fact that these organic sources improve soil structure, enhance chemical characteristics, water and nutrient holding capacity and nutrients availability to the plants (Tang *et al*., 2020). The results showed that compost enhance vegetative growth and dry matter content within the vegetative parts of the plants but BPS help in increasing yield of the crop. The results are similar to the Ghimire *et al*. (2023), stated that OS provide essential nutrients but its ratio depends on the source and quality of OS. Rapid mineralization in the OS results in availability of nutrients to plant on time.

Harvest index and benefit cost ratio of wheat is significantly affected by organic sources and interaction of organic source with their levels while years and levels of OS had no significant effect (Table 4). In 2019-2020, BPS had highest harvest index (37.3) followed by compost (34.2) while FYM had lowest harvest index of 32.9. In 2020-2021, highest harvest index of (37.4) was recorded in BPS followed by compost (34.1) while FYM had lowest harvest index (32.9). The mean of both years showed that BPS resulted in higher harvest index than the compost and FYM. L3 (50% N from organic source + 50% N from urea) had slightly higher harvest index than L1 and L2.

In 2019-2020, lower benefit cost ratio (3.73) was found in the compost than FYM and BPS. In the OS levels, L1 had lowest benefit cost ratio (3.99) followed by (4.17) in L2 while L3 had highest benefit cost ratio of (4.47). In 2020-2021, lowest benefit cost ratio of (5.02) was recorded in compost followed by (5.23) in FYM while BPS statistically highest benefit cost ratio of (6.47). L3 (50% N from organic source + 50% N from urea) had highest benefit cost ratio (5.97) followed by (5.51) by L2 while L3 had lowest result (5.24).

Table 4:

Organic Source (OS)	Harvest Index (%)			Benefit Cost Ratio		
	2019-20	2020-21	Mean	2019-20	2020-21	Mean
Biogas plant slurry	37.3 a	37.4 a	37.4 a	4.91 a	6.47 a	5.69 a
Compost	34.2 b	34.1 b	34.2 b	3.73 c	5.02 c	4.37 c
FYM	32.9 c	32.9 c	32.9 c	3.99 b	5.23 b	4.61 b
$LSD_{0.05}$	1.62	1.62	1.11	0.09	0.11	0.07
Levels (L)						
L1	34.1	34.1	34.1 b	3.99 c	5.24 c	4.62 c
L2	34.5	34.5	34.5 b	4.17 b	5.51 b	4.84 b
L3	35.9	35.9	35.9 a	4.47 a	5.97 a	5.22 a
$LSD_{0.05}$	NS	NS	1.11	0.09	0.11	0.07
Year (Y)						
2019-20			34.8			4.21 b
2020-21			34.8			5.57 a
LSD			NS			0.07
Contrast						
Control	36.0	35.9	35.9	4.38	6.01	5.20
Organic Source	34.8	34.8	34.8	4.21	5.57	4.89
$LSD_{0.05}$	NS	NS	NS	**	***	***
Interaction		Level of significance				
OS x L	NS	NS	**	***	***	***
Y x OS			NS			***
Y x L			NS			*
Y x OS x L			NS			NS

*L1= 100% N from OS, L2 = 75% N from OS + 25% N from urea, L3 = 50% N from OS + 50% N from urea, NS = Non-significant and *, *** = significant at 5% and 0.1% level of probability, respectively*

The mean of both years showed that compost resulted in lower benefit cost ratio than the FYM and BPS. L1 had lowest benefit cost ratio than L2 and L3.Table 4. Harvest Index (%) and benefit cost ratio of wheat crop as affected by different organic sources and their levels and inorganic fertilization.

Discussion

The two-year field results demonstrate that nitrogen source and the organic–inorganic split markedly influence wheat growth, yield formation, and profitability under the study conditions. Across sources, biogas plant slurry (BPS) consistently delivered the highest grain yield (mean ≈ 4.41 t ha^{-1}) and harvest index (≈ 37.4%), with the 50:50 organic–urea split (L3) performing best among levels (grain ≈4.33 t ha^{-1}). Compost maximized biological yield (≈ 12.30 t ha^{-1}), suggesting greater vegetative biomass accumulation, whereas FYM trailed on most traits. Economically, BPS yielded the highest benefit–cost ratio (mean ≈ 5.69), indicating superior return per unit input. Together, these data support integrated N management, particularly BPS:urea at 50:50, as a pragmatic strategy for semi-arid wheat systems.

Why BPS excelled. BPS likely supplied a more plant-available N pool (ammoniacal N) and readily mineralizable organic fractions, improving early vigor and spike fertility relative to compost and FYM. The synchrony between N release from BPS and crop demand is consistent with the observed improvements in thousand-grain weight and plant height under BPS and under the L3 split, where urea buffered in-season demand peaks. In contrast, FYM, with a typically higher C:N and slower mineralization, likely lagged in in-season N release, limiting grain set and fill. Compost improved canopy growth and total biomass (highest biological yield) but, without sufficient in-season mineral N, partitioning to grain was comparatively lower than with BPS, explaining the lower harvest index.

Conclusions

The L3 strategy appears to balance the short-term N availability of urea with the stability and co-benefits of organic sources (improved porosity, water-holding capacity, and cation exchange). This likely reduced temporal N gaps around stem elongation and grain filling, evidenced by consistently higher thousand-grain weight and plant height at L3. By contrast, 100% organic (L1) under-supplied readily available N at critical stages, while 75:25 (L2) only partly closed that gap.

Economic significance. The BCR advantage of BPS—especially under L3—indicates strong profitability even before accounting for potential savings from reduced synthetic N purchase and on-farm availability of slurry. These findings align with farmer-adoptable recommendations: where BPS is accessible, a 50% substitution of urea-N can maintain or raise yield while improving economic returns.

Environmental and soil implications. Although the study did not directly measure soil carbon or N losses, the performance pattern suggests that integrated strategies may also lower fertilizer N demand and support soil physical improvement (structure, moisture retention) attributed to organic inputs. Compost's higher biomass points to greater residue returns and potential soil-C accrual, whereas BPS's yield advantage implies better N use efficiency during the crop cycle. Future work should quantify soil organic C changes, mineral N dynamics (NH_4^+/ NO_3^-), and N_2O emissions to capture environmental co-benefits.

Year effects and robustness. Modest year-to-year variation in plant height and yields underscores the robustness of the BPS × L3 effect across typical seasonal fluctuations. Nevertheless, confirming performance across more sites and soil textures would strengthen external validity and guide region-wide scaling.

Use ofBPS:urea 50:50 of total N to raise wheat yield and BCR; compost:urea 50:50 to maximize biomass and residue return.

Limitations

The trial lacked chemical characterization of BPS/ compost/FYM batches in the manuscript and did not measure soil mineral N kinetics or post-harvest soil health indicators—metrics that would refine mechanistic interpretation and support life-cycle claims. Economic analysis assumptions (input prices, transport costs for organic sources) should be explicitly tabulated for replication.

Recommendations

For semi-arid wheat on silt-clay loams of Khyber Pakhtunkhwa, adopt BPS: urea at 50:50 of total N; where BPS is scarce, compost:urea 50:50 can maximize biomass and maintain competitive grain yields. Include basic slurry analysis (TN, NH_4-N, P, K, EC, pH) each season to standardize rates; pair with two-split urea (e.g., at tillering and booting) to secure grain fill.

Acknowledgements

The author thanks the Department of Agricultural Mechanization and Renewable Energy Technologies, the University of Agriculture, Peshawar-Pakistan for guiding the research process. Special thanks are extended to Prof. Dr. Mansoor Khan Khattak and Dr. Muhammad Ramzan for their invaluable contributions as supervisors.

Novelty Statement

This study proposes bio fertilizer as novel selection methods for increase wheat crop yield and the combination of 50% N from OS has the potential to reduce the cost of inorganic fertilizers by up to 50%.

Author's Contribution

Rafi Ud Din: Designed and conducted the experiments, performed the calculations, and wrote the manuscript.
Mansoor Khan Khattak, Muhammad Ramzan, Sohail Ahmad and Iftikhar Ahmad: Supervised the research, performed simulations, analyzed the data, and contributed to the final version of the manuscript.
Muhammad Hanif and Inam Ul Haq: Collected and analyzed the field data, and performed statistical analysis.

Generative AI or AI assisted technology statement
The authors declared that no gnerative AI was used in the creation of this manuscrpt.

Conflict of interest
The authors confirm that they have no conflicts of interest in publishing this manuscript in SJA.

Project Details

This research was conducted as a part of the Higher Education Commission (HEC) Pakistan project "Development of Efficient Digester for Production of Purified Biogas from Biomass. "The project was assigned the number 20-4825/NRPU/R&D/HEC 2014/636 and had a total cost of Rs. 2,261,477. The project was expected to be completed on January 31, 2020.

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