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Evaluation of Anaerobic Digestate Potential as Organic Fertilizer in Improving Wheat Production and Soil Properties

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Authors' contributions

This work was carried out in collaboration between all authors. Author AM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AM and AN managed the analyses of the study. Authors AHS, SSHS and MOS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Integrated use of synthetic and organic fertilizers is crucial to sustainable crop production and stabilization of depleting soil fertility. Keeping in view these certainties, a three-year field study was undertaken to evaluate the potential of anaerobic digestate alone or in integration with chemical fertilizer for improving wheat production and soil fertility. Six treatments viz; control (with no amendment), recommended dose (RD) of chemical fertilizers (CF), anaerobic digestate (AD) on the

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basis of RD of N, farm manure (FM) on the basis of RD of N, ½ N from CF and ½ N from AD, ½ N from CF and ½ N from FM were applied in Randomized Complete Block Design (RCBD) with three replications. The obtained results revealed that the highest yield (grain and straw), N uptake, NUE, NAE, and NRE were acquired through the utilization of chemical fertilizers which was statistically at par with combined application of anaerobic digestate and chemical fertilizer in all years of study while the minimum was found in control. The integration of digestate not only increase yield but also found to be a monitory feasible strategy. Besides, it was inferred that about half of nitrogenous fertilizer (urea) can be spared with the appropriation of chemical fertilizers and digestate integration.

Keywords: Anaerobic digestate; farm manure; fertilizers; yield; NUE.

1. INTRODUCTION

The sustainability of agricultural productivity is of utmost significance keeping in view the pace of total population growth. It is estimated that the production of food would expand 70% to sustain flourishing populace, which is relied upon to reach up to 9 billion by 2050 [1]. Frequent utilization of chemical fertilizers is practised all through the world to amplify crop production with a specific end goal to satisfy the food needs of growing population [2]. The prolonged utilization of chemical fertilizers and intensive agriculture have prompted deterioration of soil fertility and additionally caused environmental hazards like ground and surface water pollution from nitrate leaching [3]. Lack of appropriate crop management, decrease in addition of fertility restoring inputs and unbalance nutrients application have paved the path for soils to become fragile [4,5].

Under the current scenario, it is indispensable and dire to take suitable measures to check the decrease in soil fertility and profitability. The circumstance immovably emphasis the selection of eco-friendly agricultural practices for keeping up soil fertility and getting crop production on a sustainable basis. For this reason, a sustainable approach is prescribed regarding organic agriculture [6]. Utilization of organic manures would not just be productive in diminishing the unfavourable impacts of synthetic fertilizers, yet in addition will support soil fertility and productivity [7,8]. Organic manures upgrade food quantity and quality by fulfilling crop nutritional requirement with the provision of essential nutrients in a way similar to synthetic fertilizers [9,10,11].

Moreover, the costs of chemical fertilizers are going past the purchasing capacity of normal landholding farmers and furthermore, sole use of either organic or chemical fertilizer is not appropriate [12]. In this way, the present circumstance requests a mix of organic manures with synthetic fertilizers [13]. To get feasible crop production without declining and weakening soil fertility, an appropriate mix of both mineral and organic manure ought to be adopted [14]. Integration of organic and mineral fertilizers will enhance absorption, distribution as well as nutrient and fertilizer use efficiency [15,13].

The digestates generated by anaerobic processing of domesticated animals excrements amid biogas generation are commonly rich in macronutrients, for example, N, P, and K, and micronutrients, for example, Zn, Fe, Mo, and Mn]16]. In like manner, these digestates can possibly be utilized as organic manures and soil amendment in the agricultural land. The advantages of land utilization of digestates include a change in seedling development, crop yield, and fruit/vegetable quality [17,18]. Besides, the physical, chemical and biological properties of soil can likewise be improved [19,20]. Digestate holds significant amounts of organic matter (20 to 30%), which is necessary for our soils with low organic matter (<1%). In this way, digestate can be a good choice to be integrated with chemical fertilizers for getting optimum crop yield and to recharge soil fertility.

Keeping in view the significance of integrated utilization of organic and inorganic manures, the present examination was conducted to study the potential of digestate as organic manure alone and in combination with mineral fertilizers for enhancing wheat yield and soil fertility.

2. MATERIALS AND METHODS

The current field study was conducted at the farm area of Soil Chemistry Section, Institute of Soil Chemistry and Environmental Sciences, Ayub Agricultural Research Institute Faisalabad, Pakistan for three consecutive years. The investigation was performed by utilizing Randomized Complete Block Design having a plot size of 5m × 7m and was replicated thrice. Nitrogen was applied at the rate of 120 kg ha^{-1} as urea, phosphorus 90 kg ha^{-1} as single super phosphate (SSP) and 60 kg ha^{-1} potash as sulfate of potash (SOP). Following six treatments were used in the study;

T_1 = Control (without any fertilizer)
T_2 = Recommended dose (RD) of chemical fertilizer (CF)
T_3 = Anaerobic digestate (AD) on the basis of RD of nitrogen
T_4 = Farm manure (FM) on the basis of RD of nitrogen
T_5 = ½ N from anaerobic digestate (AD) and ½ N from chemical fertilizer (CF)
T_6 = ½ N from farm manure (FM) and ½ N from chemical fertilizer (CF)

A calculated amount of farm manure (on the basis of N contents) was well mixed in the soil at seedbed preparation whereas digestate was applied through fertigation with first irrigation. Wheat cultivar Punjab-2011 was sown following recommended methods with the seed rate of 124 kg ha^{-1} and row to row distance of 22.5 cm × 22.5 cm.

2.1 Soil Sampling and Analysis

For evaluation of the initial fertility status of the field, a soil composite sample was collected. The collected soil samples were air dried, crushed and sieved through a 2 mm stainless steel sieve and before analyzing for physical and chemical characteristics (Table 1). Soil particle distribution was measured by hydrometer method [21]. About 250 g of soil was saturated with distilled water for determining the pH of soil. The paste was allowed to stand for one hour and pH was recorded by pH meter with glass electrodes using a buffer of pH 4.0 and 9.0 as standard [22]. For determining ECe (Electrical conductivity of extract), extract of each soil paste was obtained by using a vacuum pump and ECe was noted with the conductivity meter (Corning 220). Soil organic carbon (SOC) content was estimated TOC analyzer (*Shimadzu TOC analyzer; TOC-VCSH*) [23] and available phosphorus was estimated by Olsen's method [24] using the spectrophotometer. For potassium content, soil extraction was done with ammonium acetate (1 N of pH 7.0) and potassium was determined by using PFP-7 Janway Flame photometer [25]. After each crop harvest, soil samples were taken and analyzed to evaluate improvement in soil physicochemical properties by organic amendments supplementation. Meteoro- logical data for each year of the study is given in Fig. 1.

Table 1. Soil physicochemical properties

Characteristics	Unit	Value
pH	-	8.29
ECe	dSm^{-1}	1.83
Organic matter	%	0.76
Total nitrogen	%	0.038
Available phosphorus	mg kg^{-1}	8.83
Extractable potassium	mg kg^{-1}	200
Sand	%	52.6
Silt	%	21.4
Clay	%	26
Texture textural class	-	Sandy clay loam

2.2 Characterization of Organic Materials

The anaerobic digestate used was collected each year of the study from a biogas plant located at Chak No. 254 RB, Faisalabad, Pakistan. Whereas farm manure was taken from the dairy farm of Ayub Agricultural Research Institute, Faisalabad, Pakistan. Before application, the samples of both fresh slurry and farm manure were collected and analyzed for chemical constituents by following standard methods (Table 2).

2.3 Plant Sampling and Analysis

At harvest, data regarding grain yield (Mg ha^{-1}) and straw yield (Mg ha^{-1}) was collected in each year of study. Area of 9 m^2 was harvested from each experimental unit. The harvest of each experimental unit was labeled, sundried and threshed separately. Grain samples were collected and dried at 70 ℃ for the determination of nitrogen. The dry grain samples were ground and 0.5 g sample was digested with the tri-acid mixture of HNO_3-H_2SO_4-$HClO_4$ for the determination of total nitrogen by Kjeldahl method [24]. Nitrogen uptake, nitrogen use efficiency (NUE), nitrogen recovery efficiency (NRE) and nitrogen agronomic efficiency (NAE) were calculated by using following equations as mentioned by Javid et al. [26].

$$N\ uptake\ (kg\ ha^{-1}) = \frac{N\ content\ (\%) grain\ (dry\ matter) \times Yield\ (kg\ ha^{-1})}{100}$$

Table 2. Chemical composition of organic materials

Year	Anaerobic digestate			Farm manure		
	N	P	K	N	P	K
	-------------------%----------------			---------------------%--------------		
Year 1	0.96±0.09	0.63±0.07	1.10±0.13	0.57±0.05	0.42±0.03	0.98±0.11
Year 2	1.01±0.11	0.58±0.04	0.92±0.11	0.62±0.07	0.44±0.05	0.86±0.09
Year 3	0.94±.13	0.62±0.10	0.94±0.08	0.58±0.06	0.46±0.03	0.91±0.12

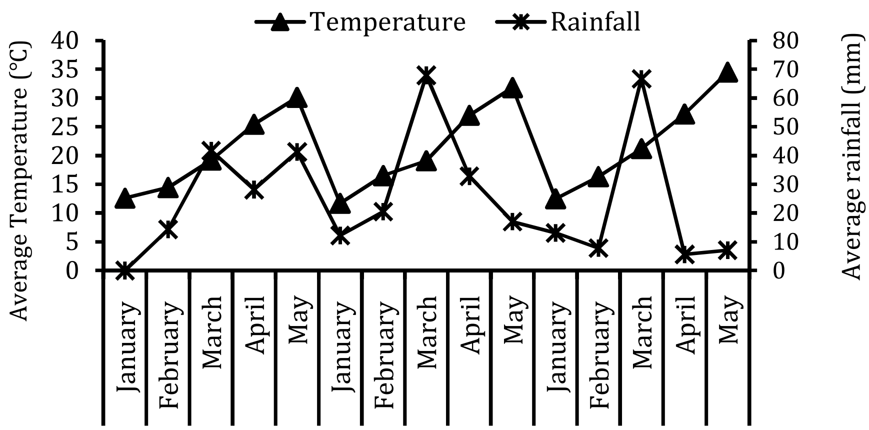

Fig. 1. Meteorological data showing mean monthly temperature and total rainfall during wheat growing period (2014, 2015, 2016)

$$NUE = \frac{Wheat\ grain\ yield\ (kg\ ha^{-1})}{N\ fertilizer\ applied\ (kg\ ha^{-1})}$$

$$NRE = \frac{N\ uptake\ (kg\ ha^{-1}) in\ fertilized\ plot - N\ uptake\ in\ control\ (kg\ ha^{-1})}{N\ fertilizer\ applied\ (kg\ ha^{-1})}$$

$$NAE = \frac{Yield\ in\ fertilized\ plot - yield\ in\ control\ (kg\ ha^{-1})}{N\ fertilizer\ applied\ (kg\ ha^{-1})}$$

2.4 Statistical and Economic Analysis

The data regarding various traits were subjected to analysis of variance to test the significance of treatments using *Statistix 8.1®* (Analytical Software, Tallahassee, USA) and treatment means were compared using least significant difference (LSD) [27]. A benefit-cost analysis was conducted to estimate the economic feasibility of different organic amendments to increase vegetable production and net economic returns as described by *CIMMYT* [28].

3. RESULTS AND DISCUSSION

The present three-year investigation was conducted for the evaluation of anaerobic digestate potential as fertilizer alone and in a mix with chemical fertilizers. The three year pool data in regards to wheat yield (Fig. 2) portrayed that highest yield (4.33 and 7.01 Mg ha^{-1} for grain and straw respectively) was acquired with the use of prescribed quantity of chemical fertilizers which was at par with the yield got in plots accepting digestate in combination with chemical fertilizers in 1:1 ratio (4.16 and 6.46 Mg ha^{-1} for grain and straw separately). Both treatments displayed similar performance in each year of the study period (Tables 3, 4). The treatments with the sole application of either farm manure or digestate on the basis of the recommended dose of N were statistically at par with each other. The highest yield with the application of chemical fertilizer might be attributed to the delivery of nutrients in soluble form in the soil solution, which become available promptly for plants to take up and flourish [29]. The improved nutrient and soil moisture availability could be the reason for a noteworthy increase in yield in response to integration of organic and inorganic fertilizers. The propensity of organic fertilizers for improving soil physicochemical properties as well as nutrient supplying capability might also be the reason for better yield. The lowest yield in case of farm manure or digestate alone compared to

Table 3. Effect of integrated use of organic and inorganic fertilizer on wheat grain yield ($Mg\ ha^{-1}$)

Treatments	Year I	Year II	Year II	Pool
Control	1.64 d	1.68 d	1.75 d	1.69 e
RD of NPK	4.30 a	4.42 a	4.28 a	4.33 a
FS on the basis of RD of N	3.17 c	3.11 c	3.30 c	3.19 d
FYM on the basis of RD of N	3.08 c	2.96 c	3.27 c	3.10 d
½ N from FS + ½ N from CF	4.12 ab	4.28 ab	4.04 ab	4.16 ab
½ N from FYM + ½ N from CF	3.87 b	3.96 b	3.61 bc	3.81 c
LSD	0.36	0.39	0.47	0.22
CV	5.81	5.58	7.70	5.89

* $p<0.05$

Table 4. Effect of integrated use of organic and inorganic fertilizer on wheat straw yield ($Mg\ ha^{-1}$)

Treatments	Year I	Year II	Year II	Pool
Control	3.85 d	3.93 d	3.21 c	3.66 e
RD of NPK	6.22 a	8.12 a	6.68 a	7.01 a
FS on the basis of RD of N	4.86 c	5.65 c	5.23 b	5.25 cd
FYM on the basis of RD of N	4.67 c	4.95 c	5.19 b	4.64 d
½ N from FS + ½ N from CF	5.72 ab	7.63 ab	6.02 a	6.46 ab
½ N from FYM + ½ N from CF	5.52 b	6.89 b	5.67 ab	6.03 bc
LSD	0.63	0.72	0.73	0.84
CV	6.89	7.89	7.67	6.89

* $p<0.05$

that of chemical fertilizers and their integration might be due to slow release of nutrients needed by plants for their growth and development [30]. The findings of the current study are in agreement to the observations of Shaheen et al. [31] who found higher soybean dry matter yield with the application of chemical fertilizers followed by integrated use of inorganic and organic fertilizer, whereas *Noreen and Noreen* [32] found non-significant wheat grain and straw yield with the supplementation of chemical fertilizers alone and combined application of chemical fertilizers (75%) and farm manure (25%). Similarly, *Muhammad* et al. [33] and *Ayoola and Makinde* [34] found the highest corn cob yield with the application of chemical fertilizers followed by a combination of synthetic fertilizers and organic amendments.

3.1 Nitrogen Uptake and Use Efficiency

The data regarding nitrogen uptake and use efficiency (Figure 3) illustrated that maximum nitrogen uptake (85.7 kg ha^{-1}) was obtained in treatment receiving nitrogen from chemical source followed by treatment with an integration of chemical fertilizer and digestate (77.2 kg ha^{-1}). A similar trend was obtained for nitrogen use efficiency, nitrogen agronomic efficiency and nitrogen recovery efficiency with values of 36.1, 19.5 and 57.4 kg kg^{-1} correspondingly. Chemical fertilizers contain nutrients in a readily available form which release instantly upon application for plant uptake [29]. This is the reason why the nitrogen uptakes, as well as use efficiencies, were maximum in case of application of nitrogen from the synthetic source. The greater nitrogen uptake and use efficiency in case of integrated use of organic and inorganic fertilizer than the sole application of organic amendments may be ascribed to the sustainable and prolonged supply of nutrients [35,29]. More so, the application of organic fertilizer alone results in the slow release from their decomposition by soil microbes [36].

The findings of the present study are consistent with the results obtained by Haile et al. [37] who found an increase in the application rate of N resulted in significant improvement in N uptake by wheat crop. Similar results were also found by Shaheen et al. [31] and Islam and Munda [38]. However, findings that differ from this study were obtained by Naing et al. [39] who reported significantly higher agro-physiological N and P use efficiencies for rice with organic-inorganic mixed fertilizers compared to chemical fertilizers or organic fertilizer alone. Whereas *Hossain* et al. [40] found higher nutrient uptake with the application of farmyard manure alone compared to that of no fertilizer and inorganic fertilizers application.

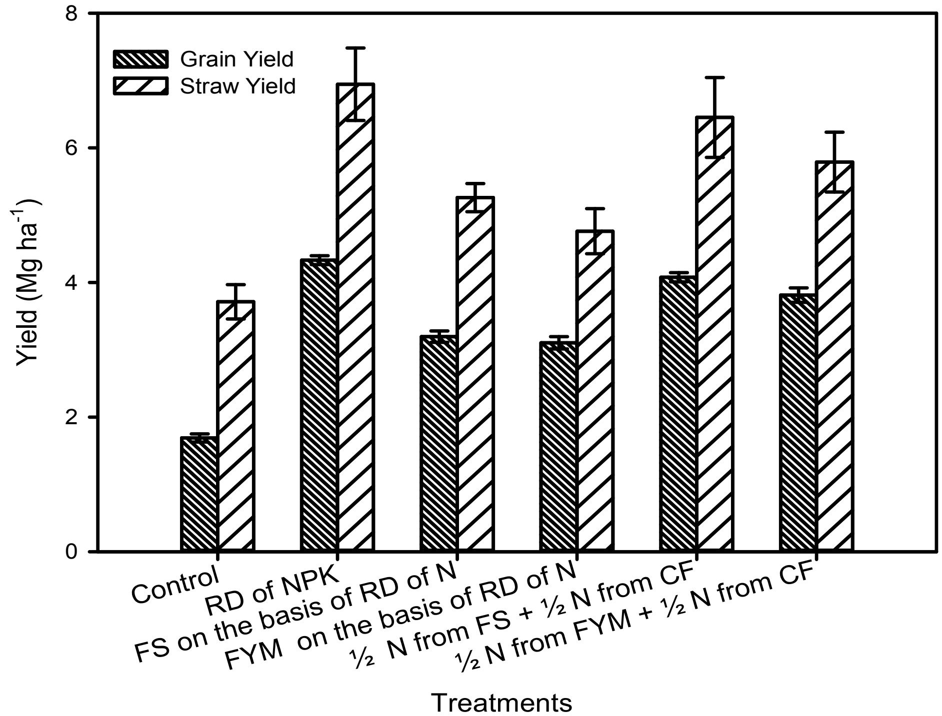

Fig. 2. Three-year pool grain and straw yield (Mg ha^{-1}) of wheat in response to digestate and chemical fertilizers application

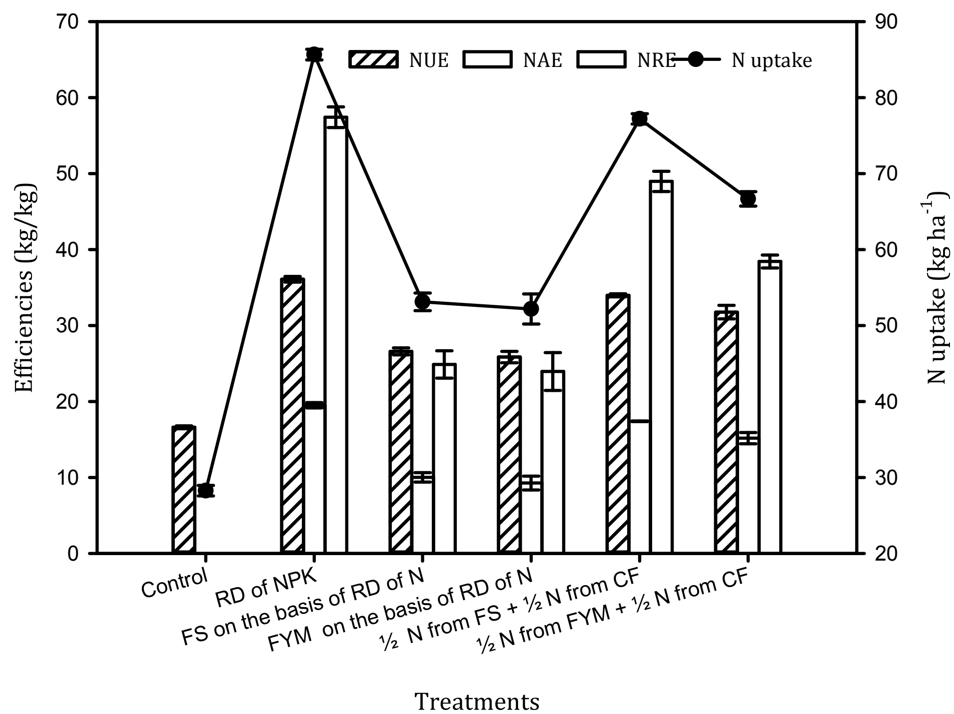

Fig. 3. N uptake and use efficiencies as affected by digestate and chemical fertilizer application

Table 5. Post-harvest soil properties

Treatment	pH	ECe	O.M	P	K
		dSm^{-1}	%	--------mg kg^{-1}-------	
Control	8.13^{NS}	1.74^{NS}	0.51 e	7.17 d	170 d
RD of NPK	8.18	1.77	0.68 d	11.06 c	196.7 bc
FS on the basis of RD of N	8.19	1.76	0.82 c	12.87 bc	230 ab
FYM on the basis of RD of N	8.19	1.80	0.86 bc	13.63 bc	215 bc
½ N from FS + ½ N from CF	8.19	1.71	0.96 a	14.93 a	245 a
½ N from FYM + ½ N from CF	8.18	1.74	0.93 ab	14.63 bc	220 b
LSD	0.10	0.08	0.07	0.84	19.6

* $p<0.05$

Table 6. Economic analysis of the study (Benefit-cost ratio; BCR)

Treatments	Total expenditure(Rs.)	Gross income (Rs.)	Net income (Rs.)	Benefit-cost ratio (BCR)
Control	24595	50700	26105	2.06
RD of NPK	55986	129967	73981	2.32
FS on the basis of RD of N	35595	95800	60205	2.69
FYM on the basis of RD of N	35595	93100	57505	2.62
½ N from FS + ½ N from CF	40290	122367	82077	3.04
½ N from FYM + ½ N from CF	40290	114400	74110	2.84

3.2 Improvement in Soil Chemical Properties

The findings regarding post-harvest soil chemical analysis (Table 5) depicted that there is a little variation in soil pH and ECe during the studied period. The contents of organic matter improved significantly with the addition of organic fertilizer either alone or in combination with chemical fertilizers. The maximum contents (0.96%) were seen in the treatment receiving the combined application of organic and inorganic fertilizer while the minimum was observed in control without any amendment. Similarly, significant improvements were observed for phosphorus and potassium contents in the current study. The highest amount of P and K (14.63 and 245 mg kg^{-1} respectively) were obtained with the application of digestate and chemical fertilizer together.

The non-significant change in soil pH and ECe in this study might be due to the highest buffering capacity of the soil. Similar to the current study, Yadav et al. [41] found no appraisable change in pH and ECe in response to the application of organic amendments. The improved contents of organic matter, phosphorus and potassium contents could be attributed to the sustained supplementation of organic amendments over the studied period and their subsequent residual effects on the soil properties that last for several years after their application due to their slow mineralization. The findings of our study are in accordance with the results obtained by *Enujeke* et al. [42] in a study undertaken for evaluation of the residual effect of organic manure and chemical fertilizer on soil properties. Likewise, Zahariev et al. [43] and Aladjadjiyan et al. [44] also concluded that the application of composted and anaerobically digested manures in the field could improve soil physicochemical characteristics.

3.3 Economic Analysis

The economic analysis (Table 6) depicted that the maximum cost-benefit ratio was obtained with the combined application of chemical fertilizer and digestate followed by the integration of chemical fertilizers and farm manure while the minimum was in case of the recommended dose of chemical fertilizer among all treatments except control.

4. CONCLUSIONS

The discoveries of the present investigation uncovered that anaerobic digestate can possibly enhance crop production and soil fertility. Wheat yield, nutrient uptake, and soil chemical properties portrayed critical contrasts with the application of various blends of organic and inorganic fertilizers. In any case, the best mix was anaerobic digestate alongside inorganic fertilizers. It not only brought about a significant increase in nutrient uptake and yield of wheat but also proved to be cost-effective and monetary feasible. Furthermore, it was concluded that about half of nitrogenous fertilizer can be saved with the adoption of chemical fertilizer and digestate integration.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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