Management of Nitrogen Flow in Livestock Waste System Towards an Efficient Circular Economy in Agriculture.

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Abstract

The race is on to achieve high level of efficiency in the attainment of circular economy in Agriculture especially with the aim of sustainable nitrogen management. This cycle in the agricultural sector cuts across livestock farming, agriculture induced waste generation, recycling and utilization, energy generation, crop production, ecosystem protection and environmental management through the mitigation of climate changes. In this work, we access the process and functionalities of livestock waste generated from the piggery farm and the combinations with other by-products such as biochar and ash in comparison with mineral fertilisation (MN) as sources of nitrogen (N) applied in agricultural soil. The experiment was performed in a controlled environment with wheat (*Triticum aestivum* L.) grown in a neutral and an acidic soil. Pig manure was used as the primary feedstock, fed, and processed to biogas and nutrient rich digestate by anaerobic digestion process. The digestate generated were amended with biochar and ash. In the course of the cultivation period, pig manure digestate with other co-amendments showed a positive influence on mobile potassium and phosphorus contents, biomass yield and nitrogen use efficiency. Greenhouse gas (GHG) emissions in the form of methane, carbon dioxide and nitrous oxide released in both soil types from the amendments were significantly lower when compared to mineral nitrogen treatment. The amendments did not have any significant influence on dehydrogenase activity, especially in the acid soil with the pH negatively influencing the enzymatic activities. The pig manure and pig manure digestate treatments showed positive response in the soil microbial biomass-C in the two soil types when compared to other co-amendments. Application of single use amendment application or in combination with biochar and ash as a means of waste management can enhance the N flow to meet up with crop needs, reduce GHG emissions and reduce potential agriculture's negative environmental footprint.

1.0 Introduction

Climate change and environmental degradation resulting from lax nitrogen management remains an empirical problem all over the world. These challenges cut across all sectors, of industry and energy, transport and agriculture, climate and research, hospitality, and environment. In a bid to face these challenges head-on, the EU has set a huge and achievable target through formulating a framework called the Green-deal with a target to ensure a modern, resource-efficient, and competitive economy where there are no net emissions of greenhouse gases (GHG) by the year 2050 and where economic growth is decoupled from resource use [1]. As all these remains not only an EU target but a global issue, international connections and network have been initiated to stem and mitigate the pressing challenges. Agriculture sector remains a focal point and has been included in the EU's overall policy framework to integrating crop and livestock management with different interface such as food production, environmental safety, waste utilization, energy generation from food and non-food crops, soil, and GHG reduction obligations. This realistic target has led to intense drive in sustainably managing the nitrogen (N) flow in livestock farming, food production, organic and inorganic inputs to improve crop yield, productivity and with lesser effect on the soil and the environment[2].

Pig farming production has consistently sought to fill the gap in food/meat production targets on a consistent basis. The consumption of meat to meet nutritional body demands is highly important. The pork meat is the second most consumed meat in the world and with the swine industry striving to continue grow globally [3]. Intensive pig farming produces a lot of waste which is complicated to dispose of and pose environmental risks when not adequately recycled and utilized [4]. An acceptable method or current practices to solve this problem is through digesting the generated waste in a biogas system to reduce the volume and produce bioenergy. The biogas system is an excellent way of using organic waste for energy generation and the recycling of the biodegradable waste [5]. The resulting digestate is a bio-fertilizer, however, there still exist knowledge gaps needed to be filled to enhance the maximization of the composite N nutrients present in this by-product. The generated swine manure contain important micro and macro nutrients, more importantly can act as N sources for soil and plant needs [6]. The selection, application, and management of agricultural activities such as digestate application as sole or co-digested with products as soil amendment promotes carbon sequestration in sustainable fields, provides needed nutrients for plants to grow, and allows for the retention of atmospheric CO_2 to be captured in the soil and stored in the form of organic compounds. As a result, less carbon dioxide is released into the atmosphere and the prospect of climate change mitigation emerges. The application of soil amendment to soil is one of the important agricultural practices undertaken to support plant growth and development, specifically by adding organic and inorganic nutrients to the soil, and improving soil tilth, organic matter, and water holding capacity [2, 6, 7]. Digestates, compost, ash, biochar, mulch, cover crops are examples of soil amendments with each having distinct characteristics geared towards improving soil health [2, 8, 9]. The different products used as soil amendment are generated from anaerobic and aerobic digestion processes, suitable for addressing the challenges of managing different organic waste. Biochar is generated from charred organic matter, made by burning biomass such as wood waste and agricultural residues in the absence of oxygen (pyrolysis) [9]. Biochar amendment has been regarded as a hopeful measure to mitigate climate change contributed by its favorable ability in SOC sequestration and Nitrous oxide (N_2O) emission reduction effects under soil amendment [9–11]. Another soil amendment taken into consideration is ash, generated from the combustion of wood and unbleached wood fiber. Wood ash is an effective liming material aimed at improving soil pH and their beneficial effect on crop growth and yield have been documented from different studies [12].

The application of the different soil amendment in combination with pig manure would pave the way in understanding the complexity of reactive N obtainable in the cycle of pig farming system from waste to utilization. Generally, agricultural management differs considerably between regions in the world, due to different climatic conditions, management technologies and soil types. Hence, the attainment of precision agriculture that is based on optimizing the management of N inputs into agricultural fields would go hand-in hand with a circular agriculture economy where a sustainable path is modelled that adequately recycle and utilize agricultural by-products, minimize the number of external inputs for agricultural production while also reducing their negative impacts on the environment. To have a better understanding of the management strategies for the efficient use of this biological resource in environmental management, we aim to access the opportunities that abound in the use of different organic amendments and combinations as N sources in an agro-system from waste collection to their application and their resulting productivity in two distinct soil types (acid and neutral pH).

2.0 Materials And Methods

The experiment for plant cultivation was conducted at the Agrobiology laboratory of the Institute of Agriculture, Lithuania Research Centre for Agriculture and Forestry and lasted for 69 d. Soil samples used for the pot experiment were randomly sampled and collected from the top layer (0–20 cm) of two different fields from Akademija, Kėdainiai district, Lithuania, each having pH values- acidic (pH = 5.2) and neutral (pH = 6.9) respectively. Stones and plant debris were manually removed from the soil. The soil was air-dried at room temperature and sieved through a 2-mm sieve. The pots were filled with 12 kg of the different soil (acidic and neutral) in 10 L (0.03 m^2) plastic containers after adequate mixing. 30 seeds of spring wheat (*Triticum aestivum*), Collada (Einbeck, Germany), were sown in each pot.

The pots were randomized and for each application, three replicates were tested. Throughout the experiment, 60% of the water holding capacity of soil was maintained using distilled water. The controlled environment parameters were set for a day (16 h) and night (8 h). The temperature was 25 ± 1.0°C during the day, 18 ± 1.0°C during the night, and relative humidity was 65 ± 1%. The experimental treatments were as follows: control (C); mineral N fertilizer (MN); pig manure (PM); pig manure digestate (PMD); pig manure digestate with biochar (PMD+B) and pig manure digestate with ash (PMD+A) applied to the acidic and neutral soil respectively. The rate of fertilizer was calculated based on the maximum permitted N rate of 170 kg ha^{-1}.

2.1 Anaerobic digestion of pig manure

Prepared 500 g were placed daily into the biogas digester with periodic loading using pig manure as the primary feedstock with the procedure as described [13]. The anaerobic digestion experiment was performed using laboratory anaerobic cylindrical continuous type biogas digesters (20 L total volume) intended for specialized preparation of digestates from several complex feedstocks. The study was performed using an organic load of 1.40 kg/(m^3*d) in a mesophilic environment at a temperature of 38 ± 1°C. The biogas produced in the digester was collected at the top and vented through a drum-type biogas flowmeter to a gasholder (Tedlar bag). The collected biogas was analysed using an Awite Bioenergie GmbH AwiFlex gas analyser to determine methane (CH_4), carbon dioxide (CO_2), and hydrogen sulphide (H_2S) concentrations.

2.2 *The physico-chemical parameters of the soil types*

The chemical composition of the soil sampled at the beginning of the pot experiment were determined (Table 1). The content of mobile potassium (K_2O), mobile phosphorus (P_2O_5) in the soil was determined using ammonium lactate-acetic acid extraction by the Egner, Riehm and Domingo (A-L) method. The determination of soil pH was made in 1:5 (vol $^{-1}$) soil suspension in the 1 M KCl solution[14]. The total nitrogen (N_{tot}) was determined using the Kjeldal nitrogen distiller method. Mineral nitrogen (N_{min}) was determined using a spectrometric analyser Fiastar 5000, (C_{org}) using a dry combustion method with a total carbon analyzer Liquid (Elementar. Organic matter and dry matter content was determined gravimetrically using an analytical balance.

Table 1
Soil physico-chemical parameters.

Soil	Mobile P_2O_5	Mobile K_2O	Mineral N	Total N	Organic C	pH
	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	%	%	
Neutral	173	186	21.3	0.15	1.36	6.88
Acidic	135	164	23.0	0.11	1.08	5.22

2.3 *Determination of chemical composition of the amendments*

The chemical analysis of the amendments used in the experiment was investigated, with results shown in Table 2. For each amendment application, the rate of digestate was calculated according to its content of total N.

Table 2
Soil amendment physico-chemical parameters.

Amendment	Mobile P_2O_5	Mobile K_2O	Mineral N	Total N	Organic matter	Dry matter	pH
	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	%	%	%	
Pig manure (PM)	0.28	0.30	0.46	0.61	3.57	8.54	8.10
Pig manure digestate (PMD)	0.05	0.27	0.45	0.64	1.67	4.85	8.33
Pig manure digestate with biochar (PMD+B)	0.07	0.24	0.34	0.44	1.38	4.44	8.27
Pig manure digestate with ash (PMD+A)	0.05	0.34	0.45	0.49	0.89	5.86	9.35

The biochar was produced by pyrolysis in a cylindrical furnace for 5-6 h under anaerobic conditions at a temperature of 550 ^{0}C per minute [15, 16]. Physico-chemical properties of the biochar was analysed by standard laboratory methods. The main chemical composition of the biochar are pH - 7.5, ash content -

32.21%, moisture wt. - 2.52 %, voltiles wt. - 56.73%, residual mass (char formed) wt. - 40.75%, P -18.11%, K- 14.27% and Ca - 75.51%.

The ash was obtained from JSC Mortar Akmene (Venta, Lithuania). The ash was formed by burning wood pellets, all procedures and parameters are as described in details [17].

2.4. *Soil microbial activity analysis*

The soil dehydrogenase activity (DHA) was assayed on freshly sieved samples by the colorimetric assay of 2,3,5 triphenyl formazan (TPF) produced by the microorganism reduction of 2,3,5 triphenyl tetrazolium chloride (TTC) according to the method [18].

The soil microbial biomass carbon (SMB-C) was determined using the fumigation-extraction method [19]. An extraction efficiency coefficient of 0.38 was used to convert the difference in soluble C between the fumigated and unfumigated soils into SMB-C.

2.5 *Greenhouse gas flux measurement*

The GHG fluxes from the soil mainly CO_2, N_2O and CH_4 were measured by the static chamber-gas chromatography technique with slight modifications. The chamber parameters, measurement of fluxes and gas chromatography were as described in previous studies [20, 21]. The flux rate of each GHG was calculated based on the rate of change in GHG concentration within the chamber, estimated as the slope of the linear regression between the GHG concentration and gas sampling time. The CO_2, N_2O and CH_4 fluxes were determined from each plot by the following closed-chamber equation indicated in a previous study.

2.6 *Post harvest analysis*

Harvested plant samples were oven dried at 105°C until constant weight to determine the dry mass of biomass.

2.7. *Calculation of Nitrogen-Use Efficiency*

Nitrogen use efficiency (NUE) represent the fraction of applied nitrogen that is absorbed and utilized by the plant. The efficiency of finding the balance in N flow between the N inputs and outputs is important to prevent excess N and consequent negative influence on the environment in the application of N-sourced amendment. The NUE was determined as N uptake efficiency which represents the ability of the crop to remove N in the form of NO_3-N and NH_4-N from the soil and describes the amount of N absorbed by the plant in proportion to the N supply [22].

2.8 *Statistical analysis*

One way analysis and Two-way analysis of variance (ANOVA) with Duncan's multiple range tests were calculated using the SAS software package, version 9.3 (SAS Institute Inc., USA) ($p \leq 0.05$) to identify the significance and possible interactions of the soil types and factor treatments. Mean ± SE (standard error of the mean) was used to describe the variability of measurements. The normality of the distribution of gas emissions was tested and to verify the normality of the data, we used the Shapiro-Wilk test with significance level $\alpha = 0.05$.

3.0 Results And Discussion

3.1 *Changes in chemical parameters of feedstock after anaerobic digestion*

The pH in the digestate increased when compared to the pig waste feedstock, although the pH of the digestate remained within the alkaline range as with the primary feedstock. The dry matter concentration in the digestate decreased by 40.7%, indicating that almost half of the raw material dry matter was converted to biogas during the anaerobic digestion. Further analysis showed that the nitrogen concentration in digestate decreased by 13.1% compared to that in the feedstock. This implies that with the periodic loading, practically a major percentage of the N that was in the feedstock remained in the digested substrate with negligible N loss as ammonia [23].

Experimental studies showed that the biogas yield from the studied pig manure stabilized at 27.3 ± 0.4 l kg^{-1} of raw material after 25 d. The biogas yield from dry matter was 138.3 ± 1.8 l kg^{-1} and from organic dry matter of pig manure was 160.8 ± 2.2 l kg^{-1}. The average CH_4 concentration in biogas was 64.5 ± 0.5% indicating an optimum biogas production while H_2S concentration in biogas continously increased and peaked to 7210 ± 33 ppm at the stabilisation of the experiment.

3.2 *Effects of amendments on soil properties*

The change in soil pH in the acidic soil was higher in PMD+B with the least pH change in MN fertilizer. It was further observed in the acidic soil that all the amendments had a higher pH change than the MN treatment. For the neutral soil, all the amendments had higher pH change when compared to MN fertilizer. The effect of PMD and the other additives were noticeable with increased pH in the two soil types when compared to MN fertilizer after the experiment (Fig. 1). The alkaline state of the different combination of the soil amendment which ranged from pH of 8.0 – 8.5 is a factor that contributed to the increased pH range. This aligns with previous studies [24] where the pH of individual feedstock that make up an amendment often contribute to pH change in the short to long term.

For the changes in P content in the soil after the experiment, it was observed that the acidic soil had an increased P content in all the treatments associated with pig manure when compared to the control and MN treatment (Fig. 2). However, the highest P content change was observed in the PMD. For the neutral soil, the MN fertilizer had the highest decrease in the P content while the highest P change was observed in PMD+A. Generally, pig manure as the primary feedstock normally has high phosphorus content. This accounts for the increased P contents in all the pig manure amended treatments in the two soil types. Hence, the pig manure digestate can, therefore, be considered a suitable P source for plants.

For the K content, PM and PMD were the only treatments with an increase in the acidic soil (Fig. 2) while PM and MN fertilizer had decrease in their K content in the neutral soil as observed in Fig. 2. The increased K content in both soil types was across all the pig amended treatments resulting from their rich individual composition. Biochar and ash are good source of potassium, phosphorus, and magnesium and in terms of commercial fertilizer, average wood ash would be about 0-1-3 (N-P-K) [25]

3.3 *Effects of amendments on straw composition*

The straw composition is a major consideration in the determination of the influence of amendment on plant productivity [2]. To observe the chemical changes in the harvested plants, the highest N content was observed in the PMD+A in both soil types (Fig. 3a) while the highest C content changed was observed in the PMD+B in the neutral and acidic soil (Fig. 3b). In addition, the PMD had the least N and C change when compared to all the other treatments in the neutral and acidic soil. N content in the straw was high across all the treatments showing a relatively good uptake of N by the root system. Earlier result from our study had showed a well developed root system across both soil types which gives credence to findings where improvement of the uptake of macronutrients with the addition of N is associated with the good development of the root system and the efficient application of N [26]. Furthermore, with respect to C content in straw, lower content observed in the acidic soil showed a lower mineralization rate of organic C, subsequently resulting into slower uptake.

3.4. *Changes in biomass yield after soil amendment*

Aside from the impact of the introduction of the different organic amendment to soil health, the productivity and quality of plants is also considered important. For the biomass yield, all treatments had higher yields when compared to the unamended control, with PMD having the highest yield in both the neutral and acidic soil. It was also observed that the biomass yield was lowest in the PMD+A when compared to other treatments with amendments. (Fig. 4). There were significant differences at $P < 0.05$ in the interaction between the soil types. In relation to the two soil types, the biomass yield was higher in all the amendments than in the control. Some studies have showed the positive influence of digestate application to biomass yield in the short -long term [27–29]. This is supported by the high nutritional composition of the organic amendments which are readily made available for plant uptake.

3.5 *Greenhouse gas emissions from soil amendments*

CH_4 emissions were relatively low from the two soil types with similar outbursts observed during the experimental period in the two soil types. Higher CH_4 peaks at the range of 0.000125 µg ha^{-1} h^{-1} were observed at day 35 in both soils. In the MN treatment from the neutral soil, CH_4 emission was significantly higher at day 5 and day 15 compared to the other treatments while in the acidic soil, there was no significant differences between all the treatments. For the CH_4 flux, our results were similar to previous studies, where emissions were negligible in all the digestate treatments signifying that the soils were CH_4 sink [30, 31]. CH_4 emissions must have been mitigated by the inhibiting effect of oxygen which hindered any potential methanogenation process.

For CO_2 emission in the neutral soil, PM had the highest CO_2 emission at day 5, with the same trend observed in the acidic soil (Fig. 5). CO_2 emission from MN was significantly higher at day 40, when compared to the other treatments from both soils. This emission trend from the MN continued in the neutral soil till the end of the experiment in contrast to the drop observed in day 60 from the acidic soil. The emission of CO_2 increased after application of the amendment in both soil types, with subsequent drop with higher peaks observed in pig manure treatments. The lower CO_2 emissions observed in all the amendments when compared to the PM treatment was due to the earlier digestion of the primary feedstock in the biogas system that had stabilized the digestate, hence making available carbon sources easily utilized by plants. The higher peak in PM fluxes in both soils observed was from the loss of N via volatilization, with the emission occurring over a very short period. The irregular peaks observed in CO_2 emission coincided with the assimilation that is associated with the photosynthesis process during the plant growth.

For N_2O emissions, the highest emission was observed in the PM treatment at the start of the experiment with flux of 0.075 N_2O mg ha^{-1} h^{-1} and 0.55 N_2O mg ha^{-1} h^{-1} in the neutral and acidic soil respectively (Fig. 6). N_2O emissions at the initial stage were significantly greater in all the amended treatments compared to the unamended control in the two soil types. Emissions dropped from both soil types on day 5 and flattened out in all amended soil treatments till the end of the experiment (Fig. 6). The soil N_2O emission were different at the onset of the experiment due to the differences in the N form and composition in the organic amendments despite having the same N application rate. This aligns with previous studies where the differences in N form and content in organic fertilizers can affect the responses of soil N_2O emissions [23, 30].

Furthermore, despite having the rate of amendments calculated according to its content of total N, the higher emission observed in PM can be attributed to high denitrification rate as attested to by Pampillon et al. [32]. In the present study, significant difference was found in the N_2O emissions among the four amendments, which were applied at the same N rate, although emissions in the PM was significantly higher in the two soil types. Johnson et al.[33] reported that the soil pH is an important factor influencing N_2O emissions, because nitrous oxide reductase is inhibited by low pH and in the presence of oxygen. In this study, we assume that an increased pH change in the neutral soil stimulated N_2O emissions in contrast to the lower N_2O emissions observed in the acid soil. Also, the use of biochar and ash can serve as suitable liming agents moderately increasing the soil pH, leading to the enhanced N_2O emissions in the neutral soil. Additionally, the use of N-fertilizers directly influences the amount of $NH4^+$ or NO_3- available in the soil. In this context, the rate of N_2O emissions is related to the N flow applied to the soil. It is expected that the nitrification process would be enhanced based on the greater amount of N-NH_4^+ and easily degradable organic matter in the amendments.

3.6 *Changes in soil microbial activities from the soil amendment*

The effects of the amendments varied across the two soil types with each exhibiting their unique characteristics according to their respective feedstocks. In the neutral soil, increased DHA value was observed after harvest in the control, PM and PMD treatment with the PM treatment having the highest increase of 11 µg TPF g^{-1} dw h^{-1} representing a 69% increase in DHA value (Fig. 7). For the acidic soil, PMD was the only treatment that witnessed in increase in DHA value of 4.7 µg TPF g^{-1} dw h^{-1}. There was statistically significant difference in between the treatments and in the interaction between the amendment and the soil types as presented in Fig. 7. The sensitivity and responsiveness of soil enzymes to different agricultural management practices such as soil amendments makes it a promising tool to induced changes in the soil. The neutral soil had higher enzymatic activities in response to the amendments when compared to the acidic soil. These results confirm other previous reports that acidity suppressed potential enzyme activity due to the effect of destroying ion and hydrogen bonds in enzyme active center [34, 35].

In the neutral soil, there were increase in SMB-C value observed after treatment with PM, PMD, PMD+B and PMD+A when compared to the SMB-C values in MN and control. For the acidic soil, there was increase in SMB-C in all the treatment with the highest SMB-C of 280 µg g^{-1} observed in MN treatment. There were no significant differences in the interaction between the soil types and between the treatments (Fig. 8). The PM and PMD had significant increase in SMB-C based on the abundance and availability of macro- and micronutrients, growth promoters and hormones, provided by the amendments, which could have supported the proliferation of the microbial biomass present in the soil [36]. Although, there have been contrasting reports on the effect of biochar- amended soils with some indicating that there was no effect on soil [37], other studies reported either increased[38] or decreased soil microbial biomass [39]. However, the PMD+B treatment increased soil microbial biomass in our study across the two soil types. The increased SMB-C can be better explained by the biochar increasing decomposition of soil organic matter coupled with the retention of organic C increasing microbial biomass thereby stimulating microbial activity [40]. Furthermore, an increase in SMB-C due to changes in soil pH is primarily related to the increase in soil bacterial activity.

Ash application to soils serve as liming agents which makes it suitable for use in acidic soil. For the amendment combination with ash, both soil types showed similarities to previous studies[41] in which PMD+A resulted in increased DHA and SMB-C after the experiment. The combination of pig manure digestate with ash can be assumed to have a convincing effect by increasing the pH of the acidic soil, indirectly influencing soil C mineralization and SMB-C through changes in the activity of soil microorganisms.

3.6 *Nitrogen Use Efficiency and Sustenance of N management flow*

N uptake is one of the most important NUE components under N-limiting conditions [42] especially from the agronomic standpoint. NUE was highest in synthetic nitrogen fertilizer with the capacity to utilize N as 8.65 % nd the lowest NUE value observed in the control treatment at 4.2 % n the neutral soil. The NUE value was also observed to be significantly higher compared to other treatments in the acidic soil. PMD had a lower NUE value in the acidic soil. The lower NUE efficiency of the other treatments when compared to the synthetic mineral nitrogen highlights the drive to reinvent the nitrogen cycle. Although N losses via leaching of nitrate was not determined in the study, we assumed that the total inorganic N content observed which was the sum of NH_4-N and NO_3-N mg kg $^{-1}$ soil extracted for each soil sample after the incubation and the net N mineralized due to the amendments were higher in comparison to the control soil.

In general, sustainably managing the N based sources and their flows will assist to improve the performance of suitable amendment used as N sources, improve the NUE, increase biodiversity and decrease NH_3 loss with lower environmental consequences. Aside this, there are numerous mitigation options in the agriculture sector that are available for immediate deployment, including increasing the efficiency of nitrogen use both in animal production (through the tuning of feed rations to reduce nitrogen excretion) and in crop production (through precision delivery of nitrogen fertilizers, split applications, and better timing to match nitrogen applications to crop demand [43].

3.7 *Enhancing circular economy in agriculture*

Livestock production is an important sector in agriculture as it provides the desired nutrients for human needs, waste for organic farming, by-products for industries and sources of income to farmers. A dive into analysing and understanding the system to enhance strategic decision making to improve resource efficiency, increase economic gains and reduce potential environmental impacts from agricultural activities is considered necessary. This study was aimed at providing an effective applicability with respect to established agricultural circular economy as defined in earlier studies [44, 45]. The pig manure generated from the animal husbandry is an economically viable resource that aim to drive the optimal use of resources with zero risk to the environment (in terms of N balance, reducing pollution, GHG reduction), biodiversity enhancement and a reduction in natural resource use. Hence, the drive for a productive circular economy in the agriculture sector is a win- win for all participating stakeholders as better interaction is created and assured between the economy (cost reduction), the environment with other key mutual and diversified areas towards a sustainable system

Conclusions

The addition of single organic amendment, with different combination/co-digestion to meet the N demand of soil and plants ensures the maximization of their use towards sustainable N management in the environment. The study showed that the application of different forms of pig waste as N source with either biochar or ash to the soil over a short period of time resulted in higher soil microbial activity. Single use amendment such as pig manure or pig manure digestate other than with other co-amendment produced better positive index in terms of GHG emissions, plant growth characteristics, and biomass yield. The presence of biochar and ash in the mixtures had a complimentary effect on the main amendment (pig manure digestate) especially in the acidic soil, with no negative effect exhibited on the parameters considered in the study. The optimization of livestock production guarantees the generation of waste, effective treatment, and utilization as by-products for organic fertilization, thus enhancing the provision of a suitable cap on manure production, and further providing a balance in the reactive N available in the environment in the quest for a sustainable agriculture.

Declarations

Acknowledgments

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Authors' contributions

MD, KB, KrB, AB and MR collected data and performed data analysis. MD, KB, KrB, and AB collected physical characterization data. KN, KV, SS and VT provided supervision, project administration, and acquisition of funding. Writing and original draft preparation was conducted by MD, KrB, KB and KV. All authors read and approved the final manuscript.

Availability of data and materials

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations of Competing interests

The authors declare they have no competing interests.

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References

1. European Commission. The European Green Deal. European Commission. 2019;53(9):24.

2. Doyeni MO, Stulpinaite U, Baksinskaite A, Suproniene S, Tilvikiene V. The effectiveness of digestate se for fertilization in an agricultural cropping system. Plants. 2021;10(8):1734.

3. Szűcs I, Vida V. Global tendencies in pork meat - production, trade and consumption. Applied Studies in Agribusiness and Commerce. 2017;11(3–4):105–11.

4. Zhang D, Wang X, Zhou Z. Impacts of small-scale industrialized swine farming on local soil, water and crop qualities in a hilly red soil region of subtropical China. International Journal of Environmental Research and Public Health. 2017;14(12).

5. Verdi L, Kuikman PJ, Orlandini S, Mancini M, Napoli M, Dalla Marta A. Does the use of digestate to replace mineral fertilizers have less emissions of N_2O and NH_3? Agricultural and Forest Meteorology. 2019;269–270:112–8.

6. Makdi M, Tomcsik A, Orosz V. Digestate: A New Nutrient Source - Review. In: Biogas. 2012

7. Clements DP, Bihn EA. The impact of food safety training on the adoption of good agricultural practices on farms. Safety and Practice for Organic Food. Elsevier Inc.; 2019. 321–344.

8. Makádi M, Szegi T, Tomócsik A, Orosz V, Michéli E, Ferenczy A, et al. Impact of Digestate Application on Chemical and Microbiological Properties of Two Different Textured Soils. Communications in Soil Science and Plant Analysis. 2016;47(2):167–78.

9. Ayaz M, Feizienė D, Tilvikienė V, Akhtar K, Stulpinaitė U, Iqbal R. Biochar role in the sustainability of agriculture and environment. Sustainability (Switzerland). 2021;13(3):1–22.

10. Martin SL, Clarke ML, Othman M, Ramsden SJ, West HM. Biochar-mediated reductions in greenhouse gas emissions from soil amended with anaerobic digestates. Biomass and Bioenergy. 2014;79:39–49.

11. Xu X, Cheng K, Wu H, Sun J, Yue Q, Pan G. Greenhouse gas mitigation potential in crop production with biochar soil amendment—a carbon footprint assessment for cross-site field experiments from China. GCB Bioenergy. 2019;11(4):592–605.

12. Risse M, Gaskin J. Best management practices for wood ash as agricultural soil amendment. UGA Cooperative Extension Bulletin. 2002;1142:1–4.

13. Tilvikiene V, Venslauskas K, Povilaitis V, Navickas K, Zuperka V, Kadziuliene Z. The effect of digestate and mineral fertilisation of cocksfoot grass on greenhouse gas emissions in a cocksfoot-based biogas production system. Energy, Sustainability and Society. 2020;10(1).

14. Buneviciene K, Drapanauskaite D, Mazeika R, Tilvikiene V. Biofuel ash granules as a source of soil and plant nutrients. Zemdirbyste-Agriculture. 2021;108(1):19–26.

15. Ayaz M, Stulpinaite U, Feiziene D, Tilvikiene V, Akthar K, Baltrėnaitė-Gedienė E, et al. Pig manure digestate-derived biochar for soil management and crop cultivation in heavy metals contaminated soil. Soil Use and Management. 2021.

16. Boostani HR, Najafi-Ghiri M, Mirsoleimani A. The effect of biochars application on reducing the toxic effects of nickel and growth indices of spinach (Spinacia oleracea L.) in a calcareous soil.

17. Buneviciene K, Drapanauskaite D, Mazeika R, Tilvikiene V, Baltrusaitis J. Granulated biofuel ash as a sustainable source of plant nutrients. Waste Management and Research. 2021;39(6):806–17.

18. Casida LE, Klein DA, Santoro T. Soil dehydrogenase activity. Vol. 98, Soil Science. 1964. p. 371–6.

19. Vance ED, Brookes PC, Jenkinson DS. An extraction method for measuring soil microbial biomass C. Soil Biology and Biochemistry. 1987;19(6):703–7.

20. Doyeni MO, Baksinskaite A, Suproniene S, Tilvikiene V. Effect of Animal Waste Based Digestate Fertilization on Soil Microbial Activities, Greenhouse Gas Emissions and Spring Wheat Productivity in Loam and Sandy Loam Soil. Agronomy. 2021;11(7):1281.

21. Kanerva T, Regina K, Rämö K, Ojanperä K, Manninen S. Fluxes of N2O, CH4 and CO2 in a meadow ecosystem exposed to elevated ozone and carbon dioxide for three years. Environmental Pollution. 2007;145(3):818–28.

22. Grahmann K, Verhulst N, Buerkert A, Ortiz-Monasterio I, Govaerts B. Nitrogen use efficiency and optimization of nitrogen fertilization in conservation agriculture. Vol. 8, CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources. 2013. p. 1–19.

23. Möller K, Stinner W. Effects of different manuring systems with and without biogas digestion on soil mineral nitrogen content and on gaseous nitrogen losses (ammonia, nitrous oxides). European Journal of Agronomy. 2009;(1):1–16.

24. Bachmann S, Gropp M, Eichler-Löbermann B. Phosphorus availability and soil microbial activity in a 3 year field experiment amended with digested dairy slurry. Biomass and Bioenergy. 2014;70:429–39.

25. McCaffery K, Dodd R, Cvejic E, Ayre J, Batcup C. What else do I need to know? 2020;

26. Azad MdAK, Ahmed T, Eaton TE-J, Hossain MdM, Haque MdK, Soren EB. Yield of wheat (*Triticum aestivum*) and nutrient uptake in grain and straw as influenced by some macro (S & Mg) and micro (B & Zn) nutrients. Natural Science. 2021;13(09):381–91.

27. Mortola N, Romaniuk R, Cosentino V, Eilza M, Carfagno P, Rizzo P, et al. Potential Use of a poultry manure digestate as a biofertiliser: evaluation of soil properties and *Lactuca sativa* growth. Pedosphere. 2019 Feb;29(1):60–9.

28. Bruhn A, Dahl J, Nielsen HB, Nikolaisen L, Rasmussen MB, Markager S, et al. Bioenergy potential of Ulva lactuca: Biomass yield, methane production and combustion. Bioresource Technology. 2011 Feb;102(3):2595–604.

29. Tilvikiene V, Venslauskas K, Povilaitis V, Navickas K, Zuperka V, Kadziuliene Z. The effect of digestate and mineral fertilisation of cocksfoot grass on greenhouse gas emissions in a cocksfoot-based biogas production system Energy, Sustainability and Society.

30. Sommer SG, Sherlock RR, Khan RZ. Nitrous oxide and methane emissions from pig slurry amended soils. Soil Biology and Biochemistry. 1996;28(10–11):1541–4.

31. Czubaszek R, Wysocka-czubaszek A. Emissions of carbon dioxide and methane from fields fertilized with digestate from an agricultural biogas plant **. 2018;29–37.

32. Pampillon-Gonzalez L, Luna-Guido M, Ruiz-Valdiviezo VM, Franco-Hernandez O, Fernandez-Luqueno F, Paredes-lopez O, et al. Greenhouse gas emissions and growth of wheat cultivated in soil amended with digestate from biogas production. Pedosphere. 2017 Apr;27(2):318–27.

33. Johnson JMF, Franzluebbers AJ, Weyers SL, Reicosky DC. Agricultural opportunities to mitigate greenhouse gas emissions. Vol. 150, Environmental Pollution. 2007. p. 107–24.

34. Wolinska A, Stepniewsk Z. Dehydrogenase Activity in the Soil Environment. Dehydrogenases. 2012;

35. Barčauskaitė K, Drapanauskaitė D, Silva M, Murzin V, Doyeni M, Urbonavicius M, et al. Low concentrations of Cu2+ in synthetic nutrient containing wastewater inhibit MgCO3-to-struvite transformation. Environ Sci: Water Res Technol. 2021;7(3):521–34.

36. Cardelli R, Giussani G, Marchini F, Saviozzi A. Short-term effects on soil of biogas digestate, biochar and their combinations. Soil Research. 2018;56(6):623–31.

37. Kuzyakov Y, Subbotina I, Chen H, Bogomolova I, Xu X. Black carbon decomposition and incorporation into soil microbial biomass estimated by 14 C labeling. Soil Biology and Biochemistry. 2008;41:210–9.

38. Luo Y, Durenkamp M, de Nobili M, Lin Q, Devonshire BJ, Brookes PC. Microbial biomass growth, following incorporation of biochars produced at 350 °C or 700 °C, in a silty-clay loam soil of high and low pH. Soil Biology and Biochemistry. 2013;57:513–23.

39. Dempster DN, Gleeson DB, Solaiman ZM, Jones DL, Murphy D v. Decreased soil microbial biomass and nitrogen mineralisation with Eucalyptus biochar addition to a coarse textured soil.

40. Zhang H, Voroney RP, Price GW. Effects of Biochar Amendments on Soil Microbial Biomass and Activity. Journal of Environmental Quality. 2014;43(6):2104–14.

41. Saidy AR, Hayati A, Septiana M. Different Effects of Ash Application on the Carbon Mineralization and Microbial Biomass Carbon of Reclaimed Mining Soils.

42. Burgos P, Madejón E, Cabrera F. 24: 175 Waste Manag Res Nitrogen mineralization and nitrate leaching of a sandy soil amended with different organic wastes. 2006;

43. Tian H, Xu R, Canadell JG, Thompson RL, Winiwarter W, Suntharalingam P, et al. A comprehensive quantification of global nitrous oxide sources and sinks. 248 | Nature |. 2020;586.

44. Velasco-Muñoz JF, Mendoza JMF, Aznar-Sánchez JA, Gallego-Schmid A. Circular economy implementation in the agricultural sector: Definition, strategies and indicators. Resources, Conservation and Recycling. 2021;170.

45. Stegmann P, Londo M, Junginger M. The circular bioeconomy: Its elements and role in European bioeconomy clusters. Resources, Conservation and Recycling. 2020;6.

Figures

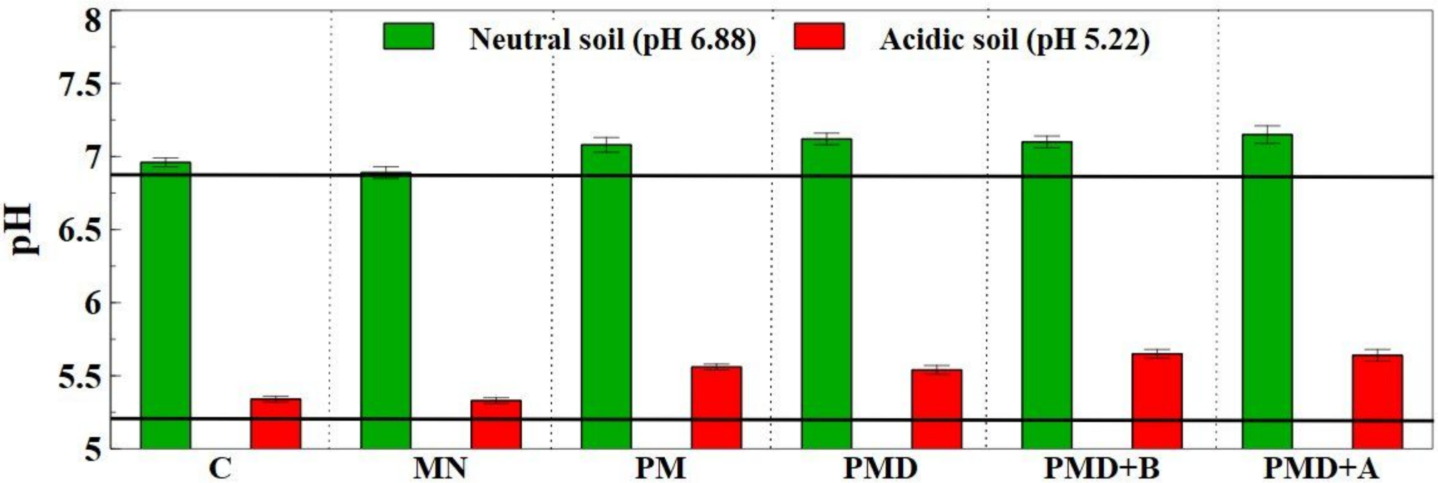

Figure 1

Soil pH change

Note: C – control, MN – mineral N fertilizer, PM – pig manure, PMD – pig manure digestate, PMD+B – pig manure digestate with biochar, PMD+A – pig manure digestate with ash. First line- pH at 5.22 for acidic soil and second line at 6.88 for neutral soil before the experiment.

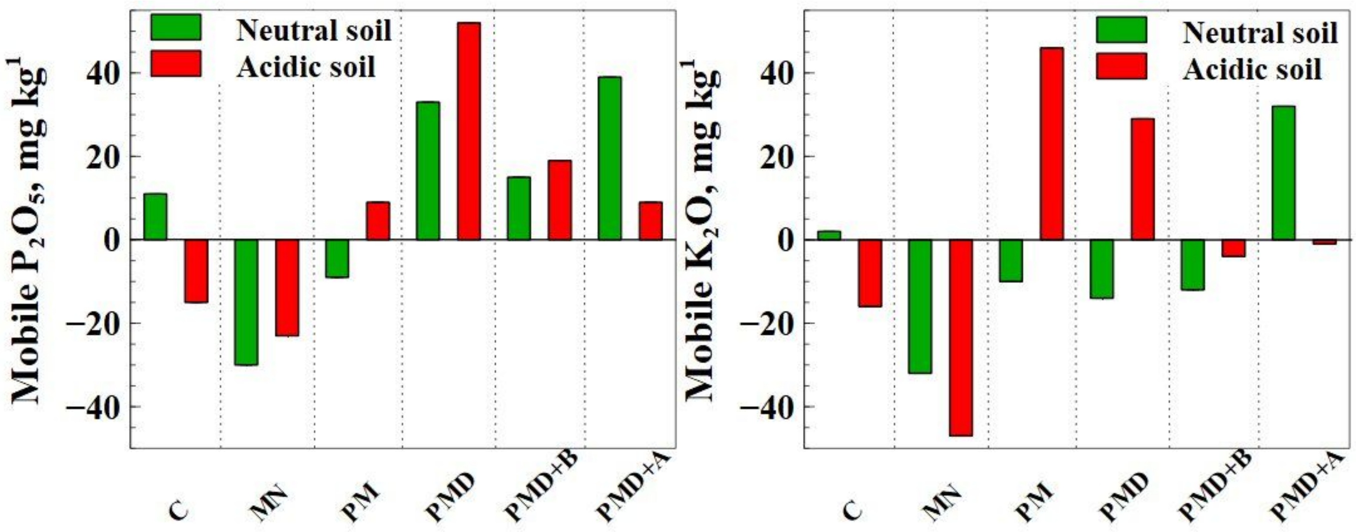

Figure 2

The balance of mobile P_2O_5 and mobile K_2O in the soil

Note: C – control, MN – mineral N fertilizer, PM – pig manure, PMD – pig manure digestate, PMD+B – pig manure digestate with biochar, PMD+A – pig manure digestate with ash.

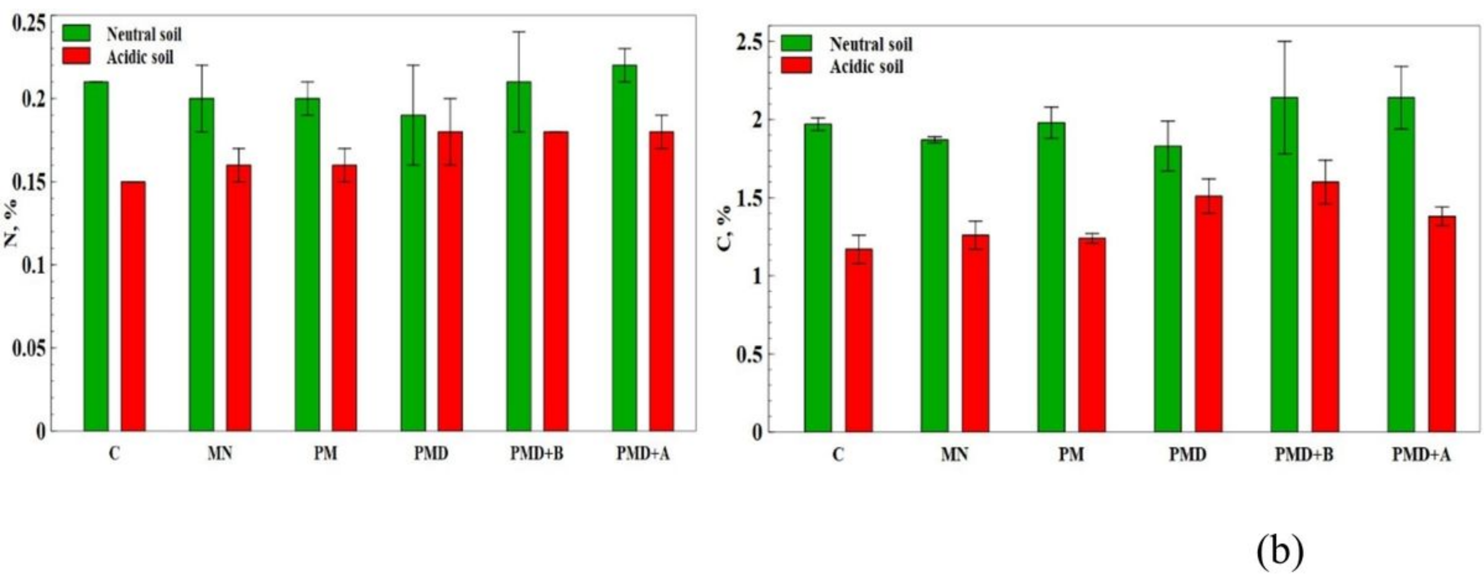

Figure 3

a. Total nitrogen in the spring wheat straw. Figure b. Total carbon in the spring wheat straw*Note:* C – control, MN – mineral N fertilizer, PM – pig manure, PMD – pig manure digestate, PMD+B – pig manure digestate with biochar, PMD+A – pig manure digestate with ash.

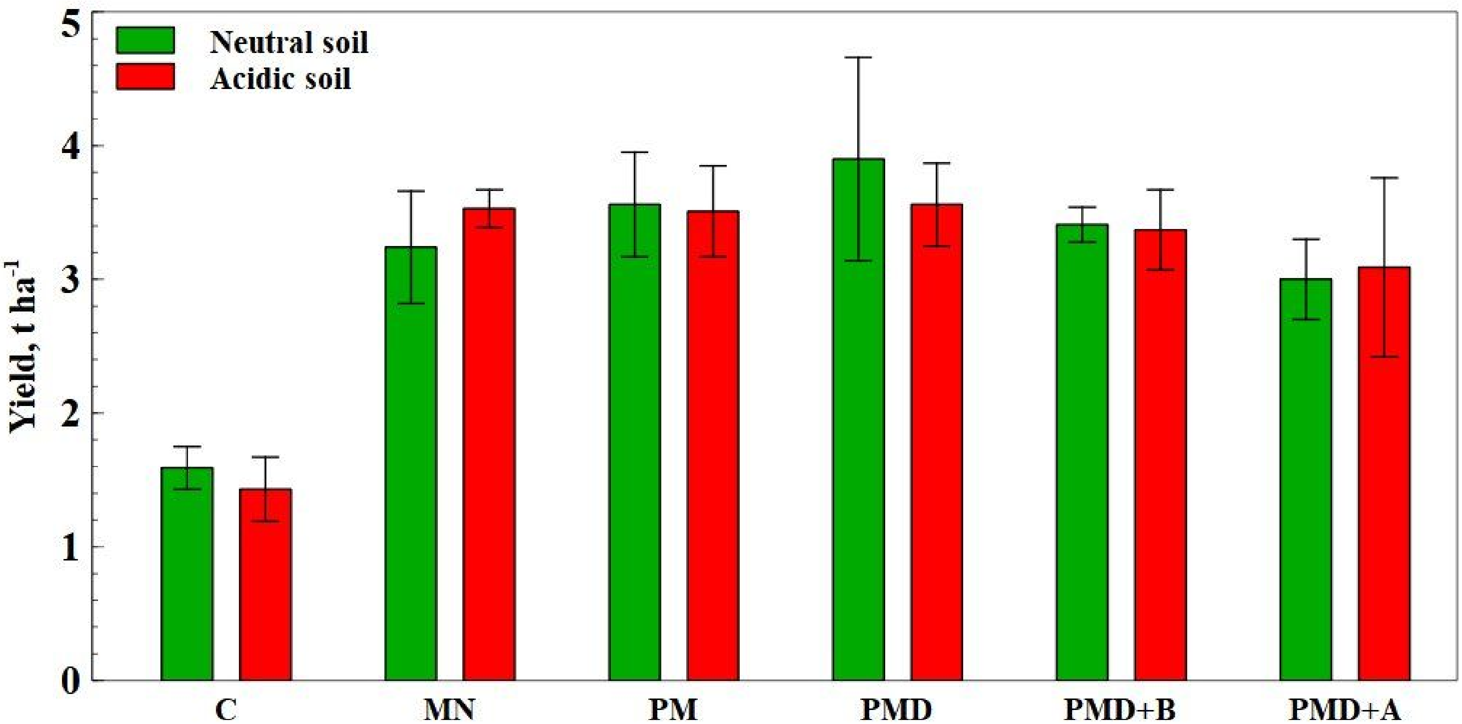

Figure 4

Spring wheat biomass yield

Note: C – control, MN – mineral N fertilizer, PM – pig manure, PMD – pig manure digestate, PMD+B – pig manure digestate with biochar, PMD+A – pig manure digestate with ash.Factor A (soil type) = *, Factor B (amendment) = n.s. AxB = ns,

* Denotes significant differences at p <0.05.

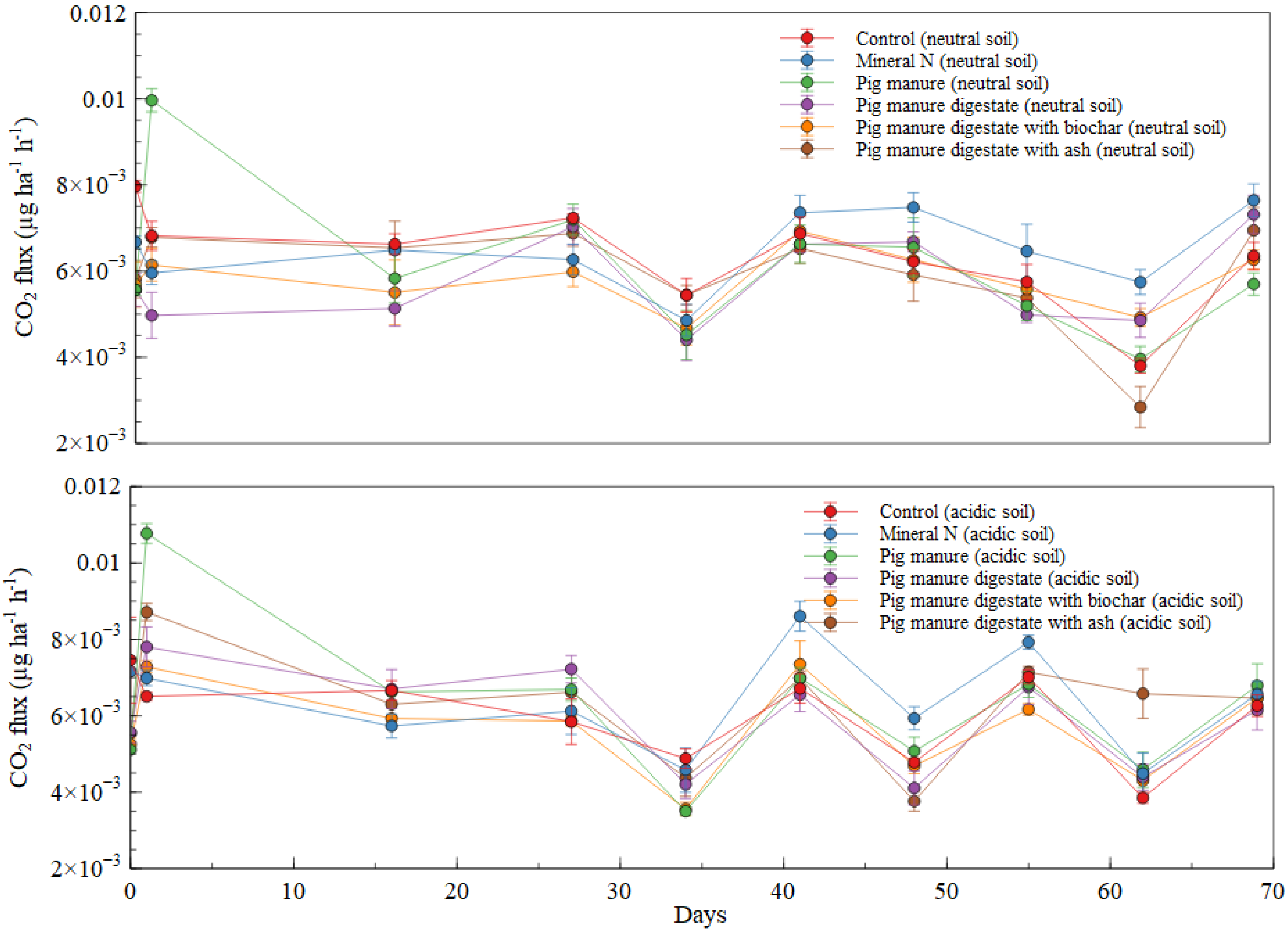

Figure 5

CO_2 emission from the neutral soil and the acidic soil

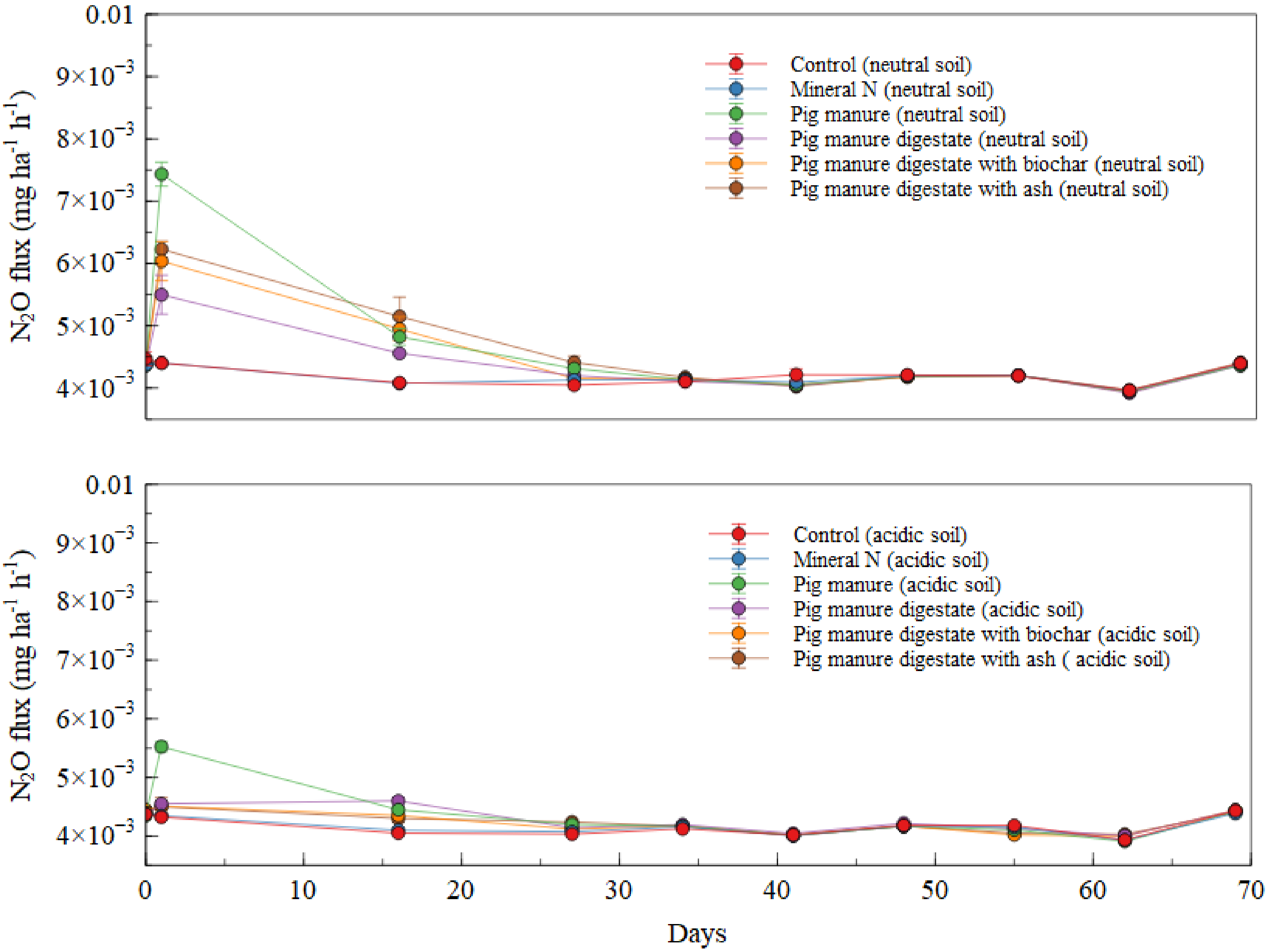

Figure 6

N_2O emission from the neutral and acidic soil.

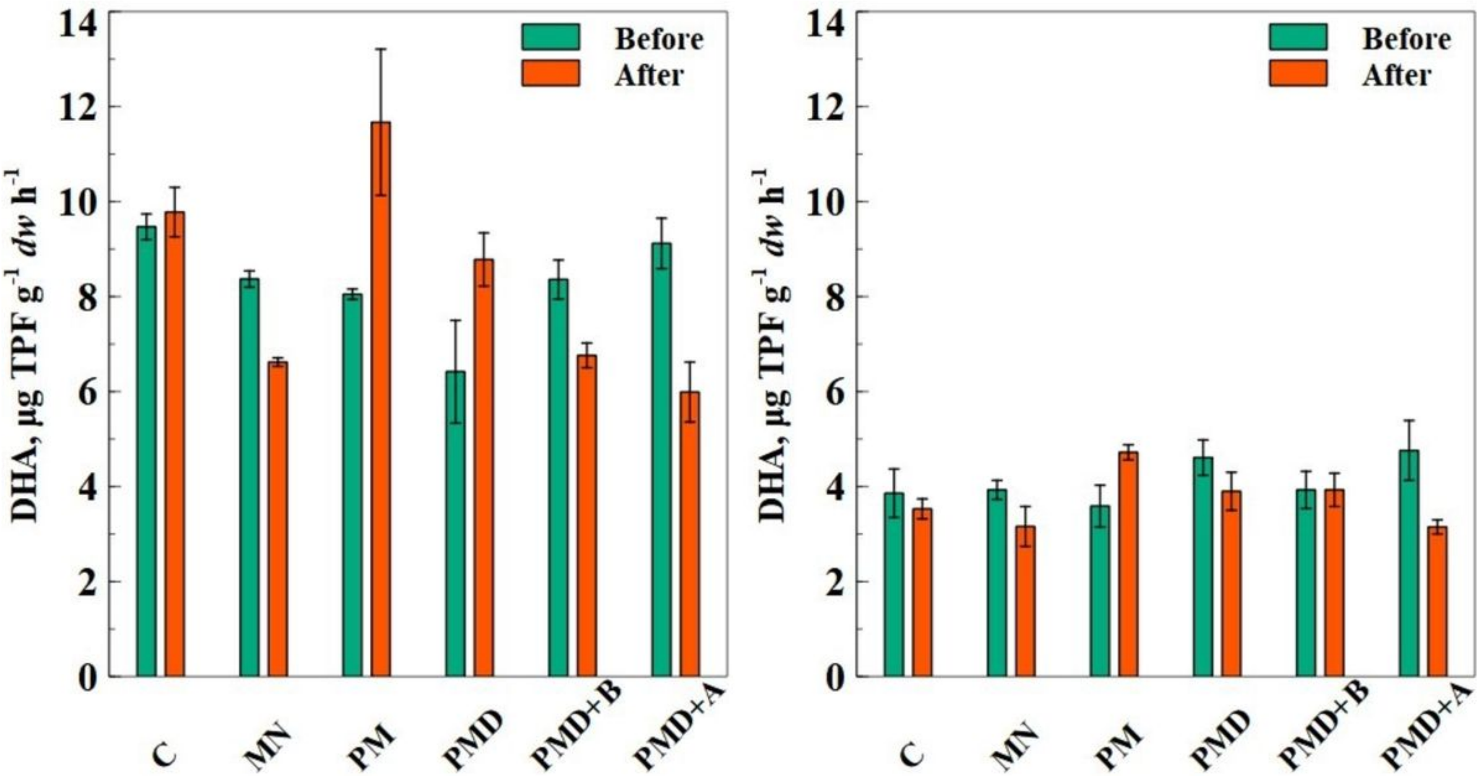

Figure 7

Dehydrogenase (DHA) activity between the amendment and two soil types. (a) – neutral soil, (b) – acidic soil.

	Before	After
A (soil type)	**	**
B (digestate)	ns	**
AxB	ns	**

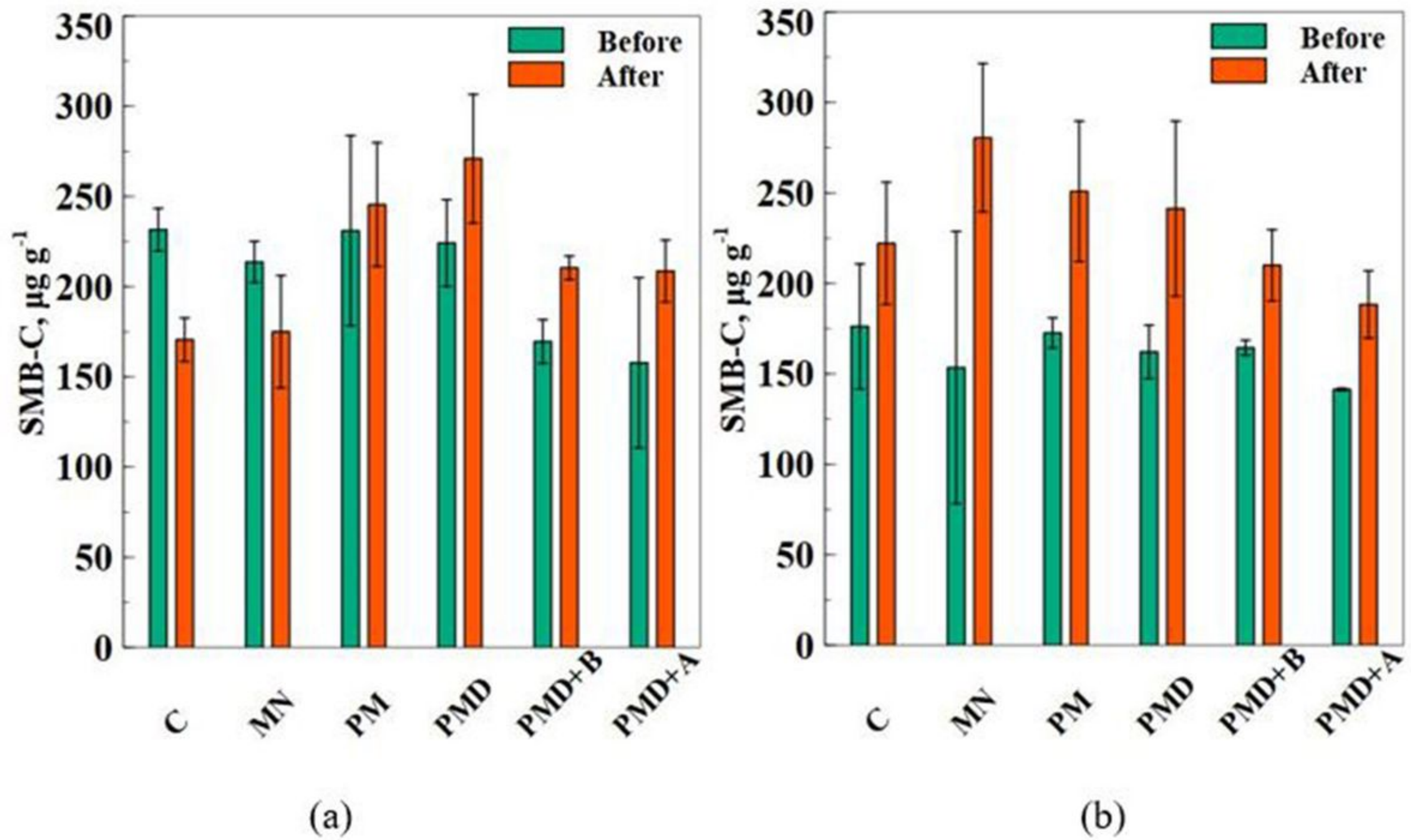

Figure 8

Soil microbial biomass- carbon between the amendment and two soil types. (a) – neutral soil, (b) – acidic soil.

Note: C – control, MN – mineral N fertilizer, PM – pig manure, PMD – pig manure digestate, PMD+B – pig manure digestate with biochar, PMD+A – pig manure digestate with ash. ** denotes significant differences at $p < 0.01$.

Note: C – control, MN – mineral fertilizer, PM – pig manure, PMD – pig manure digestate, PMD+B – pig manure digestate with biochar, PGMD+A– pig manure digestate with ash. NS- neutral soil, AS – acid soil.