Changes in soil physiochemical properties as a result of different land application methods of compost and fresh pig manure

ABSTRACT

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| **Aims:** This study aimed to evaluate the effects of composted and fresh pig manure application via surface and subsurface methods on soil physiochemical properties.**Study design:** A randomized complete block design (RCBD) was used to assess the impact of five different treatments on soil quality parameters.**Place and Duration of Study:** The experiment was conducted in Buea, Cameroon. The duration of the study spanned a single cropping season (April-June, 2024).**Methodology:** Five treatments were evaluated: compose manual surface application (CMSA), compose manure subsurface application (CMSSA), fresh manure surface application (FMSA), fresh manure subsurface application (FMSSA), and the control (CNT) were tested for impact on soil pH, organic matter, organic carbon, nitrogen, phosphorus, potassium, bulk density and moisture content. **Results:** The CMSA treatment significantly improved soil fertility indicators, yielding the highest values for soil pH (6.50), organic carbon (2.25%), phosphorus (68.05 mg/kg) and potassium (1.86 meq/100g). Conversely, CMSSA recorded the lowest values for several nutrients. Surface applied compost outperformed other methods likely due to better nutrient retention in the upper soil layers, enhanced aeration and increased microbial activity. Subsurface application by contrast reduced oxygen exposure and promoted nutrient leaching.**Conclusion:** Surface application of composted pig manure is more effective in enhancing soil health and fertility in tropical agroecosystems than subsurface or fresh manure application methods. The study recommends adopting this method for sustainable soil management in similar environments. |

*Keywords: Pig manure application, soil physiochemical properties, surface vs subsurface application methods, compost*

1. **INTRODUCTION**

According to the Food and Agricultural Organization of the United Nations (FAO), global pig production generates over one billion tons of manure annually (FAO, 2021) from a global pig population estimated to be around 987 million (FAO, 2021). Cameroon ranks first in the Central African region (CEMAC) and second after Nigeria (4.7 million pigs) in West Africa in terms of pig production (Defang *et al*., 2014). Pig manure is a common organic waste generated from pig farming that is often stockpiled (dumped) in open spaces not far from residential areas in most developing countries like Cameroon (Tiku *et al*., 2023).

Organic fertilizer application is an effective agricultural management measure for preventing soil acidification and increasing soil fertility. The long-term application of manure has been shown to prevent and control acidification by increasing the organic matter content and reducing the accumulation of ammonium and nitrate in the soil (Kauer *et al*., 2021). The application of organic fertilizers in acidic soil can enhance the soil pH, improve soil fertility, promote nutrient absorption by crops, and thus, increase crop yields (Yu *et al*., 2020). Long-term application of additional pig manure can prevent red soil acidification and improve phosphorus availability (Li *et al*., 2019).

While the application of manure to improve soil quality has attracted attention, the effect of pig manure application rates on soil acidity remains poorly understood (Luo *et al*., 2023). Several reviews have reported beneficial effects of animal manure application on soil properties and crop production but noted risks for nutrient leaching and runoff from manure if applied at rates above optimum levels (Diacono and Montemurro, [2010](https://acsess.onlinelibrary.wiley.com/doi/full/10.1002/saj2.20359#saj220359-bib-0021); Yost *et al*., 2022). The direct use of untreated manure in the soil at high application rates diminishes its role as soil amendment, and it is often seen as a problem of waste disposal rather than as a valuable source of nutrients
(Goldan *et al*., 2023). Some studies suggest that appropriate management and application rates of organic amendments can significantly reduce associated environmental risks (Sharma *et al*., [2017](https://acsess.onlinelibrary.wiley.com/doi/full/10.1002/saj2.20359#saj220359-bib-0059); Zavattaro *et al*., [2017](https://acsess.onlinelibrary.wiley.com/doi/full/10.1002/saj2.20359#saj220359-bib-0073)).

Several techniques are available for organic fertilizer application that have different emission losses of nutrients, especially N (Brummerloh and Kuka, 2023). Typical techniques are broadcast applications on the soil surface, such as splash plate or band spreading techniques, low trajectory slurry applications, such as trailing shoe or shallow injection methods (Bourdin et al., 2014), and narrow band applications. Brummerloh and Kuka, (2023) found that NH3 losses during slurry application were reduced by up to 74% using shallow injection compared to broadcast application.

As the campaign to improve agricultural soil health has gained momentum among conservationists and researchers worldwide, a comprehensive assemblage of outcomes from manure and soil health–related research studies is important. This research was therefore carried out to assess the changes in soil physiochemical properties as a result of pig manure application using different methods.

1. **MATERIALS AND METHODS**
	1. **Substrate Collection and Treatment**

Fresh pig manure was collected at a pig farm located not more than 1 km from the University of Buea in a 50kg empty rice bag and was transported to the university’s Waste-to-Resource Facility consisting of several composting chambers, each measuring 0.9 x 0.7 x 1m (LxWxH). Only one chamber was used for the composting of the fresh manure. The composting lasted for 40 days, with the mixture turned every 2 days at 9 am to speed up microbial reaction necessary for breaking down the waste into a usable resource.

* 1. **Experimental Design**

The experimental site was cleared manually, and all debris removed from the site. The field experiment was carried out at the Waste-to-Energy Resource project site at the University of Buea, Cameroon. A randomized complete block design (RCBD) was used (Fig 1) covering a total surface area of 182m2 which was divided into 15 blocks each (3m x 2m), five treatments with 3 replicates respectively.



 **Fig 1: Randomized complete block design (RCBD)**

**FMSA** = Fresh manure surface application, **CMSA** = Compost manure surface Application, **CNT** = Control, **FMSSA** = Fresh manure subsurface application, **CMSSA** = Compost manure subsurface application

Fresh and compost pig manure were applied at a rate of 10 tons/ha according to Sanni *et al*., (2021) which correspondent to 6 kg of pig manure per plot. A 1 meter buffer was also kept between plots and 2 meter between the blocks to avoid side interaction. Pig manure was surface applied and roughly mixed with surface soil to prevent ammonium volatilization in the surface application plots while in the subsurface application plots, the manure was buried 5cm into the soil to also reduce ammonium volatilization and nutrient loss.

* 1. **Soil Sampling and Measurement of Physiochemical parameters**

Soil samples at a depth of 0-15cm (Tiwari *et al*., 2023) were collected with the use of a hand trowel at three different locations on the same plot, mixed uniformly to represent the whole. The collected soil samples were air dried, sieved through 2mm sieve, stored in plastic, tagged bags and analyzed for their physical and chemical properties in the Soil Science Lab at the University of Dschang. This was done before and after manure application.

Soil pH in water was determined by the use of glass electrode pH-meter (McLean, 1965). The method of Walkley, (1934) was used for organic carbon determination. Modified KJeldahl distillation method (Landor, 1991) was used to determine soil total nitrogen. The loss on Ignition method (Simon Fraser University, 2011) was used to determine soil organic matter.

Meanwhile, the soil physical properties were assessed at the Waste to Energy Resource project lab of the University of Buea. The soil moisture content was determined by oven drying collected soil samples from each subplot at 105°C for 24 hours (Tran *et al*., 2012). Soil bulk density was determined using a metal ring of known volume following a method described by SDSU Extension (2023). The ring was driven vertically into the soil using a wooden stake and a hammer. Once the ring was filled with soil, it was carefully removed, and it’s content were emptied into labeled plastic bags, then taken to the laboratory and oven dried at 105°C for 24 hours.

* 1. **Statistical Analysis**

Data for the soil physiochemical parameters were analyzed using Excel 2024. A One-Way Anova Test (single factor) was used to the compare means before and after manure application. Additionally, a paired T-test was employed to compare sample means. Results were presented in the form of graphs and tables.

1. results and discussion

**3.1 Pig manure chemical properties**

Table 1 presents the chemical composition of both manure types used in the study. The results indicate that fresh pig manure exhibited higher concentrations of chemical properties compared to composted pig manure.

**Table 1: Pig Manure Chemical Properties**

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| Content Component | Compost pig manure | Fresh pig manure |
| Ca(mg/kg)  | 9040 | 9769 |
| Mg(mg/kg)  | 21680 | 24023 |
| N(mg/kg)  | 21000 | 25200 |
| K(mg/kg)  | 13823 | 18831 |
| Na(mg/kg)  | 1340 | 1707 |
| p(mg/kg)  | 481 | 3157 |

The manure chemical properties for both substrates differed significantly (p=0.02). This is in line with Irshad *et al*., (2013) whose extractability of elements differed significantly (p<0.05) between fresh and composted manure irrespective of the kind of animal manure.

The difference in nutrient concentrations can be as a result of nutrient loss during composting. During composting, microbial activities break down organic matter leading to the loss of certain nutrients, especially nitrogen (N). This is in line with Tran *et al*., (2012) who discovered that, when manure is composted, less manure N will be available compared to fresh manure. This is not unexpected since composting is essentially a process in which C and N are mineralized and lost into the atmosphere in gaseous forms as carbon dioxide and ammonia (Abban-Baidoo *et al*., 2024).

**3.2 Soil Physical and Chemical Properties**

**3.2.1: Bulk Density**

Results in Fig 2, show that surface application of compost manure had the highest bulk density (0.94g/cm3) while subsurface application of compost manure had the lowest bulk density (0.91g/cm3). This highlights the importance of different application methods in influencing soil bulk density. The higher bulk density may be attributed to the filling soil pores with finer organic particles from the compost. This is in line with the findings of Głąb *et al., (*2025), who discovered that applying compost with fine particles (<500µm) increased bulk density. Whereas the lower bulk density observed in the subsurface plot could be due to soil tillage as manure was applied at a depth of 5 cm, potentially breaking up compacted soil layers, hence reducing bulk density. This is consistent with the findings of Orzech  *et al.,*(2021).

Furthermore, all manure treatment plots significantly increased soil bulk density (p=0.00), which could be a result of compaction. This aligns with the studies of Rech *et al*., (2018), who reported an increase in bulk density due to compaction, leading to poor soil porosity caused by manure application. Interestingly, even the control exhibited a bulk density increase. This could be attributed to rainfall during the period of the experiment, which may have broken down soil aggregates, resulting in surface sealing and hence increasing bulk density. This is in line with Yang *et al*., (2020), who reported that aggregate breakdown caused by the impact of raindrops clogs soil pores, reduces soil infiltration, and aggravates the

formation of soil crusts.



 **Fig 2: Bulk Density**

**3.2.2: Moisture Content (MC)**

Soil moisture content was highest in the fresh manure subsurface application treatment plot (32.40%) with the lowest experienced in the compost manure subsurface application treatment plot (32.23%). This could be as a result of higher moisture content initially in the fresh manure used for the experiment compared to compost, which was subsurface applied, and retained its moisture in the soil, leading to higher overall soil moisture content. This is in line with the findings of Khoirunnisak *et al*., (2024), who observed that the application of organic matter, including manure, increased soil moisture content at deeper soil layers over time.

Furthermore, MC between groups increased significantly at p=0.013, and this can be accounted for by consistent rainfall throughout the experiment since measurement was done in the dry season and also in the rainy season. This is in line with Singh *et al*., (2021), who elaborated that soil moisture responses to rainfall are often attributed to storm properties: Storm depths and intensities are often reported as key drivers of soil moisture dynamics (Demand *et al*., 2019).



 **Fig 3: Moisture Content**

**3.2.3: Soil pH (H2O)**

Amongst treatment plots, the compost manure surface application plot had the highest increase in soil pH (6.50) and the lowest observed in the compost manure surface application treatment plot (6.27). The highest pH experienced is likely because the compost manure contains alkaline nutrients like calcium and magnesium, which raise soil pH when applied on the surface. This is in line with the findings of Chen *et al*. (2022), who demonstrated that continuous compost application significantly increased soil pH, attributing this effect to the alkaline characteristic of the compost. The lowest pH experienced in the compost subsurface plot is likely due to limited interaction with soil microorganisms and reduced oxygen availability, which are essential for compost decomposition and subsequent release of alkaline substances. This is in line with the findings of Cooper *et al. (*2020).

Furthermore, all treatment plots showed a significant increase in soil pH (p=0.00) after manure application (Figure 4). This is per the results of Chen *et al*., (2023), who explained that compared to the control, all organic materials increased the soil pH significantly after incubation, and the effect increased with the application rate.



 **Fig 4: Soil pH (H2O)**

**3.2.4: Soil Organic Matter (SOM)**

Amongst treatment plots, the compost manure surface application plot had the highest increase in soil organic matter (3.88%) and the lowest observed in the fresh manure subsurface application treatment plot (2.01%). The highest SOM can be attributed to the fact that compost contains stable organic compounds that resist rapid mineralization and when applied to the surface, promotes aeration and microbial breakdown into humus, enriching SOM levels. This is in accordance with the findings of Adugna (2016). Furthermore, the lowest SOM observed in the fresh manure subsurface application plot ( Figure 5) may be due to the high decomposition rate of the fresh manure. Fresh manure contains readily decomposable organic materials. When applied subsurface, these materials are rapidly broken down by soil microorganisms, leading to quick mineralization and less contribution to long-term SOM. This observation is consistent with the findings of Leuther et al., (2022).

Statistical analysis confirmed that the difference in soil organic matter between groups was not significant (p=0.22). Fresh manure surface application (2.21%), Fresh manure subsurface application (42.90%) and compost manure subsurface application (50.73%) saw reductions after substrate application, indicating a potential loss of organic matter in those treatments, which could be due to climatic conditions such as high temperature in the course of the study. This findings aligns with the results of Shalik (2024), who reported that SOM decomposes faster in warmer climate



 **Fig 5: Soil Organic Matter (SOM)**

**3.2.5: Soil Organic Carbon (SOC)**

Amongst treatment plots, the compost manure surface application plot had the highest increase in soil organic carbon (2.25%) and the lowest observed in the fresh manure subsurface application treatment plot (1.17%). This high increase in SOC plot could be due to the fact that compost applied on soil surface promotes higher microbial activity and better carbon stabilization (Wang *et al.,*2022). The fresh subsurface plot experiencing the lowest SOC can be due to rapid mineralization, resulting in less stable carbon incorporated into the soil. This is against the findings of Gross *et al.* (2021), who reported increased SOC in deeper soils (>20cm) regardless of the tillage intensity.

Furthermore, SOC results showed no significant difference (p=0.23) between treatments after manure application. The results also showed a significant decrease in organic carbon from fresh manure subsurface application (42.65%) and compost manure subsurface application (50.90%) after pig manure application to soil. This maybe due to the fat that both manure types were subsurface applied or buried into the soil, which involved tillage of the soil. This is in line with the findings of Xiao (2015), who stated that management practices such as tillage accelerate the decomposition rate of SOC by making the organic matter more available to soil microorganisms to decompose. Minimum or no tillage with residue retention has shown higher potential to maintain and or reintroduce C into soils, compared to tillage.



 **Fig 6: Soil Organic Carbon (SOC)**

**3.2.6: Soil Nitrogen**

All treatment plots showed significant increase in Figure 7 after manure application (p=0.00), with the fresh manure surface application plot having the highest increase (0.24%) in soil nitrogen and the lowest observed in the fresh manure subsurface application plot (0.20%) after application. The elevated level of soil nitrogen observed in the fresh manure substrate may be attributed to the high nitrogen content in the fresh manure used for this experiment (Table 1), which was likely influenced by the nitrogen-rich diet fed to the pigs. This is in line with of Kerr *et al.* (2020), who discovered that diets higher in fiber content increased manure nitrogen (N). Also, the surface application had the highest soil nitrogen increase and could be as a result of greater microbial activity and oxygen exposure. This is in accordance with the findings of Illarze *et al.* (2023), who investigated the effects of dairy effluent application on pastures and discovered that surface application of dairy effluents significantly increased soil nitrogen availability. This increase was stimulated by microbial activity, attributed to enhanced oxygen exposure at the soil surface.

Furthermore, the subsurface application plot from the fresh manure substrate also experienced the lowest soil nitrogen increase after application, as this could be due to an increase in denitrification losses of nitrous oxide in the soil, hence nitrogen reduction. Smith and Mukhtar (2015) reported similar findings, as nitrogen in the soil is lost in the form of N2O + N2 when slurry was injected (closed slot) compared to surface broadcast application.



 **Fig 7: Soil Total Nitrogen (STN)**

**3.2.7: Soil Phosphorus**

Soil phosphorus had the highest increase in the compost manure surface application plot (68.05 mg/kg) while the lowest was observed in the fresh manure subsurface application plot (50.06 mg/kg) after manure treatment (Fig 8), and there was no significant difference between treatments (p=0.18). The higher phosphorus increase can be attributed to the fact that surface applied manure promotes aerobic conditions, fostering microbial communities that mineralize organic phosphorus into inorganic forms, thereby increasing the labile phosphorus pool in the soil. Similar findings were reported by Islam *et al*. (2021). Furthermore, the lowest soil phosphorus after manure application may be attributed to limited decomposition and phosphorus release.

Fresh manure contains phosphorus in organic form which requires microbial decomposition to become available to plants. Subsurface application creates anaerobic conditions, slowing down microbial activity and phosphorus mineralization. This result supports the findings of Islam *et al*. (2021), who discovered that phosphorus release from fresh poultry manure was significantly delayed under anaerobic conditions compared to aerobic ones



 **Fig 8: Soil Phosphorus**

**3.2.8: Soil Potassium**

The highest soil potassium was observed in the compost manure surface application plot (1.86 meq/100g) while the lowest occurred in the compost manure subsurface application plot (1.44 meq/100g) after manure treatment (Fig 9) showing significance between treatment plots (P=0.00). The highest soil potassium levels observed in CMSA is likely due to the initial nutrient concentration in the compost use (Table 1) and also the method of application as this retained the nutrient at the top soil where root activity and microbial populations are typically higher. This is in line with the findings of Khalsa *et al.* (2022), who in his study highlighted that higher soluble potassium as a proportion of total potassium in organic amendments resulted in increased soil availability. Conversely, the low soil potassium experienced in the CMSSA maybe as a result of potassium leaching in the soil subsurface, reduced microbial activity, and soil compaction all of which limit potassium availability in soil. This finding is similar to that of Agegnehu *et al. (*2015).



 **Fig 9: Soil Potassium**

4. Conclusion

The results of this study demonstrate that the method of pig manure application significantly affects soil chemical properties. Among all treatments, compost manure surface application (CMSA) recorded the highest improvement across several parameters. Notably, CMSA achieved the highest soil potassium, phosphorus, organic carbon, organic matter, and pH after manure application. These improvements are attributed to enhanced nutrient retention and greater microbial activity at the surface. In contrast, compost manure sub-surface application consistently showed the lowest values, including the lowest soil potassium and pH. This was likely due to limited microbial decomposition under anaerobic conditions, increased potential for nutrient leaching, and reduced root interaction at depth. Similarly, fresh manure treatments showed valuable effects, with the fresh manure surface application (FMSA) outperforming fresh manure subsurface application in nitrogen, pH, and organic matter content, although both were generally less effective than compost treatment.

Overall, the surface application of compost manure emerges as the most effective method for improving soil fertility indicators. These findings support the promotion of CMSA in agricultural practices for its superior impact on soil nutrient enhancement and potential for sustainable soil management in tropical regions.

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References

Abban-Baidoo, E., Manka'abusi, D., Apuri, L., Marschner, B., & Frimpong, KA (2024). Biochar addition influences C and N dynamics during biochar co-composting and the nutrient content of the biochar co-compost. *Scientific Reports* , *14* (1), 23781.

Adugna, G. (2016). A review on impact of compost on soil properties, water use and crop productivity. *Academic Research Journal of Agricultural Science and Research* , *4* (3), 93-104.

Agegnehu, G., Bird, MI, Nelson, PN, & Bass, AM (2015). The ameliorating effects of biochar and compost on soil quality and plant growth on a Ferralsol. *Soil Research* , *53* (1), 1-12.

Bourdin, F., Sakrabani, R., Kibblewhite, M. G., & Lanigan, G. J. (2014). Effect of slurry dry matter content, application technique and timing on emissions of ammonia and greenhouse gas from cattle slurry applied to grassland soils in Ireland. *Agriculture, ecosystems & environment*, *188*, 122-133.

Brummerloh, A., & Kuka, K. (2023). The Effects of Manure Application and Herbivore Excreta on Plant and Soil Properties of Temperate Grasslands—A Review. *Agronomy*, *13*(12), 3010.

Chen, D., Ye, X., Jiang, Y., Xiao, W., Zhang, Q., Zhao, S., ... & Hu, J. (2022). Continuously applying compost for three years alleviated soil acidity and heavy metal bioavailability in a soil-asparagus lettuce system. *Frontiers in Plant Science* , *13* , 972789.

Chen, J., Yu, J., Li, Z., Zhou, J., & Zhan, L. (2023). Ameliorating effects of biochar, sheep manure and chicken manure on acidified purple soil. *Agronomy*, *13*(4), 1142.

Cooper, J., Greenberg, I., Ludwig, B., Hippich, L., Fischer, D., Glaser, B., & Kaiser, M. (2020). Effect of biochar and compost on soil properties and organic matter in aggregate size fractions under field conditions. *Agriculture, Ecosystems & Environment*, *295*, 106882.

Defang HF, Kana JR, Bime MJ, Ndebi G, Yemele F, Zoli PA, Manjeli Y, Teguia A, Tchoumboue J. (2014). Socioeconomic and technical characteristics of pig farming in the urban and peri - urban zone of Dschang - West region of Cameroon. Discourse Journal of Agriculture and Food Sciences, www.resjournals.org/JAFS, 2(1): 11-20Doran, J. W. (1996). Soil health and global sustainability. *Soil Quality is in the Hands of the Land Manager*, *45*.

Demand, D., Blume, T., & Weiler, M. (2019). Spatio-temporal relevance and controls of preferential flow at the landscape scale. *Hydrology and Earth System Sciences*, **23**, 4869–4889. [**https://doi.org/10.5194/hess-23-4869-2019**](https://doi.org/10.5194/hess-23-4869-2019)

Diacono, M., & Montemurro, F. (2010). Long-term effects of organic amendments on soil fertility: A review. *Agronomy for Sustainable Development*, **30**, 401–422. [**https://doi.org/10.1051/agro/2009040**](https://doi.org/10.1051/agro/2009040)

FAO. (2021). Pigs Livestock Systems. http://www.fao.org/livestock-systems/global-distributions/pigs/en/

Głąb, T., Gondek, K., & Mierzwa-Hersztek, M. (2025). Enhancing Soil Physical Quality with Compost Amendments: Effects of Particle Size and Additives. *Agronomy*, *15*(2), 458.

Goldan, E., Nedeff, V., Barsan, N., Culea, M., Panainte-Lehadus, M., Mosnegutu, E., ... & Irimia, O. (2023). Assessment of manure compost used as soil amendment—A review. *Processes*, *11*(4), 1167.

Gross, A., & Glaser, B. (2021). Meta-analysis on how manure application changes soil organic carbon storage. *Scientific reports* , *11* (1), 5516.

Illarze, G., del Pino, A., Rodríguez-Blanco, A., & Irisarri, P. (2023). Application of dairy effluents to pastures affects soil nitrogen dynamics and microbial activity. *Agronomy* , *13* (2), 470.

Irshad, M., Eneji, A. E., Hussain, Z., & Ashraf, M. (2013). Chemical characterization of fresh and composted livestock manures. *Journal of soil science and plant nutrition*, *13*(1), 115-121.

Islam, M. R., Bilkis, S., Hoque, T. S., Uddin, S., Jahiruddin, M., Rahman, M. M., ... & Datta, R. (2021). Mineralization of farm manures and slurries under aerobic and anaerobic conditions for subsequent release of phosphorus and sulphur in soil. *Sustainability*, *13*(15), 8605.

Kauer, K.; Pärnpuu, S.; Talgre, L.; Eremeev, V.; Luik, A. Soil particulate and mineral-associated organic matter increases in organic farming under cover cropping and manure addition. Agriculture 2021, 11, 903.

Kerr, BJ, Trabue, SL, Andersen, DS, Van Weelden, MB, & Pepple, LM (2020). *Dietary composition and particle size effects on swine manure characteristics and gas emissions* (Vol. 49, No. 5, pp. 1384-1395).

Khalsa, S. D. S., Hart, S. C., & Brown, P. H. (2022). Nutrient dynamics from surface‐applied organic matter amendments on no‐till orchard soil. *Soil Use and Management*, *38*(1), 649-662.

Khoirunnisak Afifatul, Prijono Sugeng, Nopriani Sri Lenny, Kemeta Tiara, Faisal Moch Andi (2024). Improvement of Soil Pore Distribution and Soil Moisture Content using Organic Matter Addition Technology . Indian Journal of Agricultural Research. 58(6): 1203-1209. doi: 10.18805/IJARe.AF-842.

Landon, J. R. (2014). Booker tropical soil manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Routledge

Landor, S. R., Asobo, P. F., Fomum, Z. T., and Roberts, R. (1991). 5-Amino-3-imino-2, 3-dihydrofurans and 3-amino-5-imino-2, 5-dihydrofurans from 4, 4-dialkyl-4-hydroxybut-2-ynenitriles. *Journal of the Chemical Society, Perkin Transactions 1*, (5), 1201-1204.

Li, D.; Wang, B.; Huang, J.; Zhang, Y.; Xu, M.; Zhang, S.; Zhang, H. Change of phosphorus in red soil and its effect to grain yield under long-term different fertilizations. Sci. Agric. Sin. 2019, 52, 3830–3841
Mar 10 2025].

Luo, P.; Long, Z.; Sun, M.;Feng, Q.; Zeng, X.; Wang, H.; Luo, Z.;Sun, G. Long-Term Application of PigManure to Ameliorate Soil Acidity inRed Upland. Agriculture 2023, 13,1837.

McLean, E. O., Reicosky, D. C., and Lakshmanan, C. (1965). Aluminum in Soils: VII. Interrelationships of Organic Matter, Liming, and Extractable Aluminum with “Permanent Charge” (KCl) and pH‐Dependent Cation‐Exchange Capacity of Surface Soils. *Soil Science Society of America Journal*, *29*(4), 374-378.

Rech, C., Albuquerque, J. A., Corrêa, J. C., Mafra, A. L., and Bortolini, D. (2018). Injection of liquid swine slurry and effects on properties of a Nitossolo Vermelho. *Pesquisa Agropecuária Brasileira*, *53*, 518-521.

Sanni, K. O., Bello, A., & Okedele, N. O. (2021). Effects of pig and goat droppings on soil physiochemical properties and yield of cucumber (Cucumis sativus L.).

SDSU Extension (2023). "Bulk Density is an Indicator of Soil Health." South Dakota State University Extension. Retrieved from SDSU Extension

Shalik, S. S. (2024). *Soil Organic Matter*. In R. Samota, V. R. Senthamizhkumaran, L. P. Verma, K. Kumar, & S. Agarwal (Eds.), *Introduction to Soil Science*. National Press Associates. Retrieved from <https://www.researchgate.net/publication/383430794>

Sharma, B., Sarkar, A., Singh, P., & Singh, R. P. (2017). Agricultural utilization of biosolids: A review on potential effects on soil and plant grown. *Waste Management*, **64**, 117–132. [**https://doi.org/10.1016/j.wasman.2017.03.002**](https://doi.org/10.1016/j.wasman.2017.03.002)

Simon Fraser University (2011). "Direct Estimation of Organic Matter by Loss on Ignition: Methods." Retrieved from Simon Fraser University.

Singh, N. K., Emanuel, R. E., McGlynn, B. L., & Miniat, C. F. (2021). Soil moisture responses to rainfall: Implications for runoff generation. Water Resources Research, 57, e2020WR028827. https://doi. org/10.1029/2020WR028827

Smith, D. W., & Mukhtar, S. (2015). Estimation and attribution of nitrous oxide emissions following subsurface application of animal manure: a review. *Transactions of the ASABE*, *58*(2), 429.

Tiku, D. T., Yengong, F. L., Ngwabie, N. M., & Manga, V. E. (2023). Greenhouse Gas Emissions during Windrow Composting and Open-Air Dumping of Pig Manure with Added Wood Shavings.

Tiwari, A., Thomas, T., Singh, A. K., Rai, A. K., Mohanty, S. R., & Prajapati, P. (2023). Assessment of physico-chemical properties of soil from different villages of Kushinagar District, Uttar Pradesh, India. *Int. J. Plant Soil Sci*, *35*(18), 1312-1320. Orzech, K., Wanic, M., & Załuski, D. (2021). The effects of soil compaction and different tillage systems on the bulk density and moisture content of soil and the yields of winter oilseed rape and cereals. *Agriculture* , *11* (7), 666.

Tran, T. M., Bui, H. H., Luxhøi, J., and Jensen, L. S. (2012). Application rate and composting method affect the immediate and residual manure fertilizer value in a maize–rice–rice–maize cropping sequence on a degraded soil in northern Vietnam. *Soil science and plant nutrition*, *58*(2), 206-223.

Walkley, A., and Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*, *37*(1), 29-38.

Wang, D., Lin, J. Y., Sayre, J. M., Schmidt, R., Fonte, S. J., Rodrigues, J. L., & Scow, K. M. (2022). Compost amendment maintains soil structure and carbon storage by increasing available carbon and microbial biomass in agricultural soil–A six-year field study. *Geoderma*, *427*, 116117.

Xiao, C. (2015). *Soil organic carbon storage (sequestration) principles and management: potential role for recycled organic materials in agricultural soils of Washington State*. Waste 2 Resources Program, Washington Department of Ecology.

Yang, M., Ma, G., Ren, Y., & Li, Z. (2020). Impact of raindrop sizes and intensities on the microcharacteristics of soil aggregates. *Authorea Preprints*.

Yost, J. L., Schmidt, A. M., Koelsch, R., & Schott, L. R. (2022). Effect of swine manure on soil health properties: A systematic review. *Soil Science Society of America Journal*, *86*(2), 450-486.

Yu, Z.; Chen, H.Y.H.; Searle, E.B.; Sardans, J.; Ciais, P.; Peñuelas, J.; Huang, Z. Whole soil acidification and base cation reduction across subtropical China. Geoderma 2020, 361, 114107

Zavattaro, L., Bechini, L., Grignani, C., van Evert, F. K., Mallast, J., Spiegel, H., Sandén, T., Pecio, A., Cervera, J. V. C., Guzmán, G., Vanderlinden, K., D'Hose, T., Ruysschaert, G., & ten Berge, H. F. M. (2017). Agronomic effects of bovine manure: A review of long-term European field experiments. *European Journal of Agronomy*, **90**(August), 127–138. [**https://doi.org/10.1016/j.eja.2017.07.010**](https://doi.org/10.1016/j.eja.2017.07.010)