Journal of Arid Agriculture

J. Arid Agric. 2025, Vol. 26 (3): 91 - 98
Copyright © 2014 Faculty of Agriculture
University of Maiduguri, Maiduguri, Nigeria
https://jaaunimaid.ng/index.php/home
Printed in Nigeria. All rights of reproduction in any form reserved
0189-7551
https://doi.org/10.63659/jaa.v26i3.112

MINERALIZATION OF NITROGEN, PHOSPHORUS AND POTASSIUM IN SOIL AMENDED WITH DIFFERENT TYPES OF ANIMAL MANURE

J.D. Kwari[1], Y.H. Musa[2*], A.M. Zubairu[1] and S.J Kwari[1]

[1]Department of Soil Science, Faculty of Agriculture, University of Maiduguri, PMB 1069, Maiduguri, Borno State
[2]International Crops Research Institute for Semi-Arid Tropics (ICRISAT)

*Correspondence: yusufh.m@yahoo.com +2349062375671

ABSTRACT: An incubation experiment was conducted in the Soil Chemistry Laboratory, Department of Soil Science, Faculty of Agriculture, University of Maiduguri. The objective was to determine the pattern of release of Ammonium and Nitrate, Phosphorus and Potassium from soil amended with three types of animal manure for better synchrony with plants growth. There were Four treatments; control, poultry manure, Sheep/goat manure, and cattle manure. The soil amended with three types of animal manure were incubated for 8 weeks and ammonium, phosphorus and potassium mineralized were determined at 2 weeks intervals. Soil amended with poultry manure recorded higher NH_4^+-N at 2-6 weeks. But soil amended with animal manure did not affect P mineralization at 2-8weeks while soil amended with cattle manure recorded higher mineralization of K at 2-8 weeks. The trend of mineralization was in the order of poultry manure>sheep/goat manure> cattle manure. For better synchrony of nutrients release with crop growth, poultry manure should be applied at least 2-4weeks before planting while sheep/goat and cattle manure may be applied at least 6 weeks before planting.

Keywords: Manure, Mineralization, Nitrogen, Ammonium, Nitrate, Incubation

INTRODUCTION

Manure mineralization involves the decomposition of organic matter in manure by soil microorganisms, leading to the release of inorganic nutrients (Watts and Torbert, 2014). Soil moisture (Kaneda and Kaneko, 2011), temperature (Boczulak et al., 2015), and aeration (Visconti-Moreno and Valenzuela-Balcázar, 2023) regulate soil microbial activity and thus, are factors that influence the rate of manure mineralization. Therefore, soil that are warm, moist, and well aerated have the highest potential rate of organic manure mineralization. Lower potential rates should be expected when the soil is dry, cold, or saturated with water.

Mineralization of organic matter has predominantly been investigated in laboratory incubations using sieved soil samples (Stenger *et al*., 2002). Carbon (C) and nitrogen (N) mineralization flushes frequently observed after sieving are thought to result from physically protected pools of organic matter becoming accessible for microbial degradation (Cabrera and Kisse, 1988).

However, patterns of mineralization under field conditions are influenced by the organization of the physical, chemical, and biological components of the soil matrix at the micro scale (Strong *et al*., 1998). Organic manure from animals provides nutrients to crops for several years. According to Joseph and Babu (2024), manure contains essential nutrients like nitrogen (N), phosphorus (P), and potassium (K), which are released slowly over time, providing a long-term nutrient supply to crops. Pratt *et al*. (1973) developed a decay series (based on best judgments and some laboratory

How to cite this Article: Kwari, J.D., Musa, Y.H., Zubairu, A.M. and Kwari, S.J. (2025). Mineralization of Nitrogen, Phosphorus and Potassium in Soil Amended with Different Types of Animal Manure. *Journal of Arid Agriculture*, *26*(3), 91–98. https://doi.org/10.63659/jaa.v26i3.112
Retrieved from https://jaaunimaid.ng/index.php/home/article/view/112

data) to estimate N availability in the first, second, third, and fourth year after animal manure application. The decay series was different for each manure type. For example, the decay series for beef cattle manure (15 g kg^{-1} N) (1.5% N) was 0.35, 0.10, 0.05, and 0.02, indicating that 35% of total manure N was available in the first year and 10, 5, and 2% of the original N was available in the second, third, and fourth year after application, respectively. The decay series for poultry manure was 0.90 and 0.01, while for swine manure it was 0.75,0.04. and 0.01. Klausner *et al*. (1994) developed an N decay series of 0.21, 0.09, 0.03, and 0.03 for dairy manure based on corn (*Zea mays* L.) uptake. In addition to N, residual amounts of other nutrients can remain in the soil for several years. It should be noted that manure application increases SOC and nutrient contents (nitrogen (N), and phosphorus (P) as reported by (Zhang *et al*., 2015).

Animal waste or other organic waste can be used as a single or complementary organic nutrient source to annual crops (Ciancio *et al*., 2014) which is desirable, since it reduced the potential of nutrient transfer through surface runoff and leaching, potentiating nutrient cycling and nutrient concentration in grains (Doneda *et al*., 2012). According to Fulhage (2000), manure contains the three major plant nutrients which are nitrogen, phosphorus and potassium (NPK) as well as many essential nutrients such as calcium, magnesium, sulphur, zinc, boron, cupper, and manganese. Nitrogen (N) availability from applied manure includes the inorganic N (NO_3-N and NH_4-N) in manure plus the amount of organic N mineralized following application. Nutrient mineralization from applied manure depends on temperature, soil moisture, soil properties, manure characteristics, and microbial activity. Since these factors cannot be accurately predicted, nutrient mineralization from applied manure can only be approximated.

In order to apply manure to fulfill the nutrient requirements of a crop, knowledge of the amount of nutrients mineralized following application is needed. Therefore, the objective of this study was to determine the pattern of release of NPK from poultry, cattle and sheep/goat manures and establish a better synchrony between the availability of nutrients in manure and crop growth.

MATERIALS AND METHOD

Soil and Manure Collection

Composite soil samples at depth of 0-15 cm for the experiment was collected at Research and Demonstration Farm, Faculty of Agriculture University of Maiduguri while animal manures were collected from the Department of Animal Science Research and Teaching Farm Faculty of Agriculture University of Maiduguri and were analysed at Soil Science laboratory, University of Maiduguri.

Three types of animal manure were collected for the experiment, poultry manure, sheep/goat manure and cattle manure. The soil and manure samples were brought to Soil Chemistry Laboratory, Department of Soil Science, Faculty of Agriculture, University of Maiduguri and prepared for further analysis and experiment.

Incubation Studies

The incubation studies were done according to the incubation technique of Sommers *et al*., 1980. Five hundred (500) grams of soil was weighed into 1liter conical flask and mixed with 2.5g of each type of manure, to give the field application rate of 5 tons per hectare, a control without manure was included. The four treatments were replicated three times in a completely randomized block design. Water was added to bring the soil to field capacity, the conical flask was tightly closed and incubated in order to aid mineralization. Every day the flasks were untightened for atleast 1 hour. Seventy-three (73) mls of water was added to bring the soil back to field capacity for effective mineralization for the duration of 8 weeks. Ten (10) g from each treatment were taken from each flask at 2 weeks interval and then analyzed for available N, P and K.

Determination of Available Nitrogen

Ammonium nitrogen was determined using the classical Kjeldahl method, introduced in 1883, widely used technique for determining nitrogen content in various samples, including food, feed, soil, and water (Sáez-Plaza et al., 2013). Five (5) ml boric acid indicator solution was added to a 50ml Erlenmeyer flask marked to indicate a volume of 30ml. The flask was placed under the condenser tip of the distiller so that the tip is about 4cm above the surface of the HBO_3. Twenty (20) ml of the extract was pipetted into a distillation flask and 0.2g of MgO was added through a dry powder funnel having a long stem that reaches down into the bottom of the flask. The flask was fixed to the distillers and commenced distillation until about 30ml of distillate is collected. The flask was removed from the distiller, the condenser tip rinsed, and the distillates titrated with 0.005N HCl until colour changed from green to pink.

Procedure: 2.5g soil was weighed 250ml wide polythene container, 100ml of KCl was added and shake for 1 hour on a shaker and filtered. Determination of NH_4, and NO_3, -N was done by steam distillation.

Determination of Available Phosphorus

Procedure for extraction: ammonium fluoride (0.03N NHF) in 0.025HCl was used to extract phosphorus from the soil sample using Bray II method as described by Olsen and Sommers (1982). Two (2) g of air-dried soil sample were weighed into 120ml plastic bottle. 14ml of extracting solution was added and shake on a mechanical shaker for 1 minute. The content was filtered through filter paper to get a clear supernatant solution. The 2ml filtrate was pipetted into a 20ml test tube, 5ml of distilled water and 2ml of ammonium molybdate solution was then added and mixed thoroughly. One (1) ml of stannous chloride solution ($SnCl_2$) was added and thoroughly mixed again. After 5 minutes the percentage transmittance of the sample was measured in the flask spectrophotometer at the wavelength of 600mn. The phosphorus content of each sample was extrapolated.

Determination of Exchangeable Potassium

Widely accepted and well-documented ammonium acetate (NH_4OAc) method was used as an extractant for exchangeable soil potassium as described by Brown and Warncke, 1988 and common flame photometry technique was used for quantifying the exchangeable potassium in the soil extracts.

Procedures for extraction:100ml of ammonium acetate solution was added to 5g air dried soil (1-2mm sieve) in a plastic bottle. The bottle was placed on a shaker and shaken for 1 hour and filtered.

Procedure for determination: an aliquot of the solution to be analyzed was pipetted into 50ml volumetric flask, the potassium concentration was determined by the flame photometer and the appropriate calibration curve. The amount of potassium in the sample k(meq) was calculated.

RESULT AND DISCUSSION

Mineralization of NH_4^+ (mg/kg) in Soil Amended with Different Types of Animal Manure

The results in Figure 1 and Table 1 show the mineralization of NH_4-N in soil amended with different types of animal manure. The highest value obtained was 1.54mg/kg under poultry manure and the lowest value obtained was 0.48mg/kg under control both at 2 Weeks. There was no significant ($P>0.05$) difference among the treatments except in poultry manure and control. At 4weeks highest value obtained was 1.21mg/kg under poultry manure and the lowest value was 0.51mg/kg under control. There was no significant ($P>0.05$) difference among treatments except in poultry manure, sheep/goat manure and control. At 6 weeks the maximum value was 1.28mg/kg under sheep/goat manure and the minimum value was 0.78mg/kg under control. The rise of release of nitrogen in goat and sheep manures at 6 weeks is typically due to higher carbon to nitrogen ratios which slows down the mineralization process, leading to a more gradual release of nutrients over time (Azeez and Van Averbeke, 2010) compared to poultry manure which releases nitrogen more rapidly due to its lower C ratio and higher initial mineralization rates (Dalias and Christou, 2020).

There was no significant difference among the treatments but there was significant differences between control and other treatments. At 8weeks the highest value was 0.98mg/kg under cattle manure and the lowest value was 0.64mg/kg under control. There were no significant differences between poultry manure, sheep/goat and cattle manure but there was significant ($P<0.05$) difference between control and other treatments. The result suggests that mineralization of NH_4-N was enhanced in soil amended with poultry manure, sheep/goat manure and cattle manure but low in control throughout the duration of experiment. Mineralization of NH_4-N was enhanced in soil amended with poultry manure followed by sheep/goat manure then cattle manure because high nitrogen content in poultry leads to a greater and more rapid release of NH_4-N upon decomposition (Shen et al., 2021) meanwhile sheep and goat manure have a moderate nitrogen content and cattle manure has a lower nitrogen content and a slower mineralization rate which results in a more gradual release of NH_4-N (Dalias and Christou, 2020). The result is similar to the findings of Mlowe (2009), who reported that mineralized N increased in soil amended with poultry, pig, goat and cattle manure. Mineralized N of the four animal manure types differed from control suggesting increased nutrition for the mineralization microorganisms.

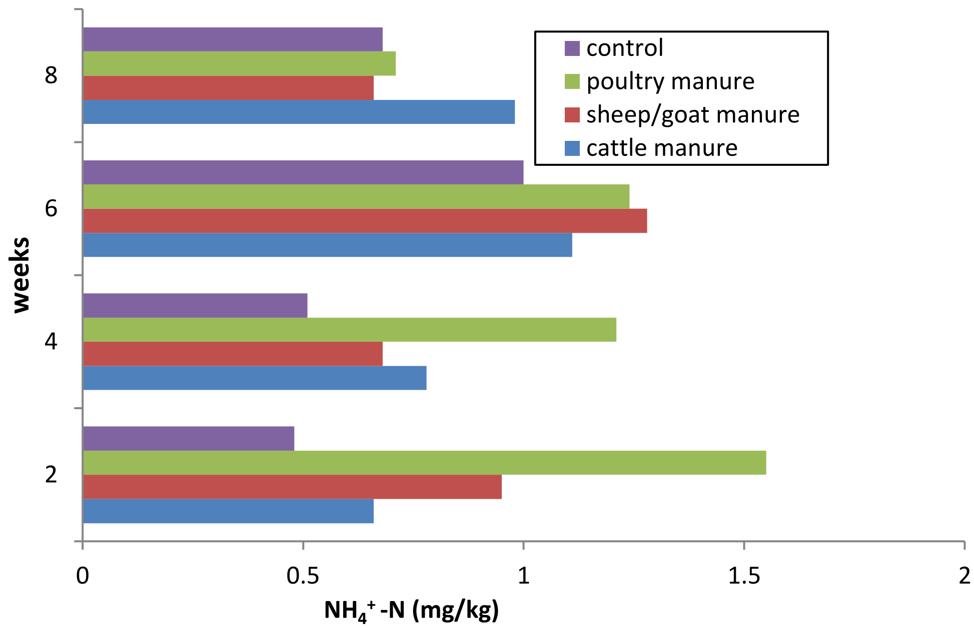

Fig 1: Mineralization of NH_4^+-N in soil amended with different types of animal manure (mg/kg).

Table 1: Mineralization of NH_4^+-N in soil amended with different types of animal manure (mg/kg)

Treatments	Week 2	Week 4	Week 6	Week 8
Control (T1)	0.45^a	0.51^b	0.78^b	0.64^a
Poultry (T2)	1.54^a	1.21^a	1.24^a	0.71^a
Sheep/Goat (T3)	0.94^a	0.78^b	1.28^a	0.64^a
Cattle (T4)	0.66^a	0.78^b	1.11^{ab}	0.98^a
Mean	0.90	0.79	1.10	0.77
SE ±	0.54 NS	0.16*	0.17*	0.19 NS

Mean in the column followed by letters of different animal manure within the same column differ significantly ($p<0.05$).

Mineralization of P (mg/kg) in Soil Amended with Different Types of Animal Manure

Figure 2 and Table 2 shows the result of the mineralization of P in soil amended with different types of animal manure. At 2 weeks the highest value was 13.00 mg/kg under poultry manure and the lowest value was 5.13mg/kg under control. There was no significant difference between the treatments. At 4 weeks the highest value was 15.80 mg/kg under sheep/goat manure and the lowest value was 4.06mg/kg under control. There was no significant difference between the treatments. At 6weeks the highest value was 17.66 mg/kg under poultry manure and the lowest value was 6.90mg/kg under control. There was no significant difference between the treatments. At 8weeks the highest value was 17.86 mg/kg under cattle manure and the lowest value was 9.20mg/kg under control with no significant difference among the treatments. The result suggests that the application of animal manures did not enhance P mineralization throughout the incubation period. However, soils amended with the three animal manure types exhibited slightly higher phosphorus (P) mineralization compared to the control, aligning with Larney and Janzan (1996) findings of increased soil P concentration at higher application rates of poultry and cattle manure.

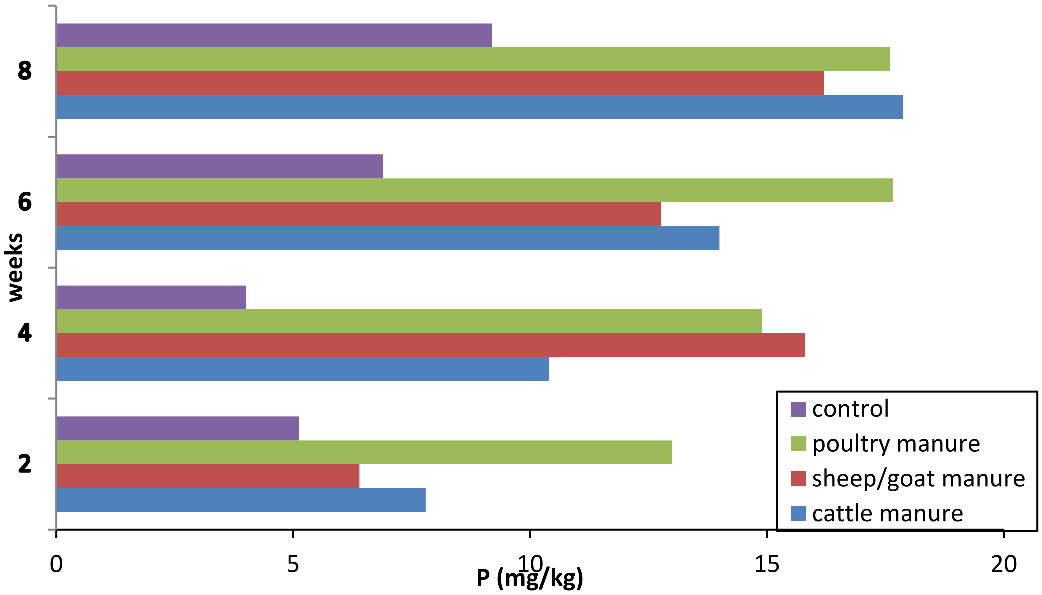

Fig. 2: Mineralization of P (mg/kg) in soil amended with different types of animal manure

Table 2: Mineralization of P (mg/kg) in soil amended with different types of animal manure

Treatments	Week 2	Week 4	Week 6	Week 8
Control (T1)	5.13^{b}	4.06^{b}	7.20^{c}	9.20^{b}
Poultry (T2)	13.00^{a}	14.90^{a}	17.66^{a}	17.60^{a}
Sheep/Goat (T3)	6.40^{b}	15.80^{a}	12.76^{b}	16.20^{a}
Cattle (T4)	7.80^{b}	10.40^{b}	7.20^{c}	17.86^{a}
Mean	8.08	11.29	12.90	15.21
SE ±	1.36**	1.74**	1.98*	2.18*

Mean in the column followed by letters of different animal manure within the same column differ significantly ($p<0.05$).

Mineralization of K (Cmol/kg) in Soil Amended with Different types of Animal Manure

The result in Figure 3 and Table 3 shows the mineralization of K in soil amended with different types of animal manure. At 2weeks the highest value was 0.27 Cmol/kg under sheep/goat manure and the lowest value was 0.22 Cmol/kg under control. There was no significant ($P>0.05$) difference among treatments except between cattle manure and control. At 4weeks the highest value was 0.39 Cmol/kg under cattle manure and the lowest value was 0.25 Cmol/kg under control. There was no significant difference among treatments except between control and other treatments. At 6weeks the highest value was 0.46 Cmol/kg under cattle manure and the lowest value was 0.35 Cmol/kg under control. There was no significant ($P>0.05$) difference among treatments except between control and cattle manure. At 8weeks the highest value was 0.59 Cmol/kg under cattle manure and the lowest value was 0.37 Cmol/kg under control and there was no significant difference among treatments except between control and cattle manure. Throughout the incubation period the highest value was recorded from cattle manure and the lowest from control followed by poultry manure. Reports by Schoenau and Davis (2006) noted a similar trend in plant available K with the application of animal manure. The higher amount of K mineralized in soil amended with cattle manure may be explained by the higher K content of cattle manure (Shao *et al*., 2024). which contributes to the increased availability of this nutrient in the soil when the manure is applied.

Journal of Arid Agriculture. 2025, Vol. 26 (3): 91 - 98

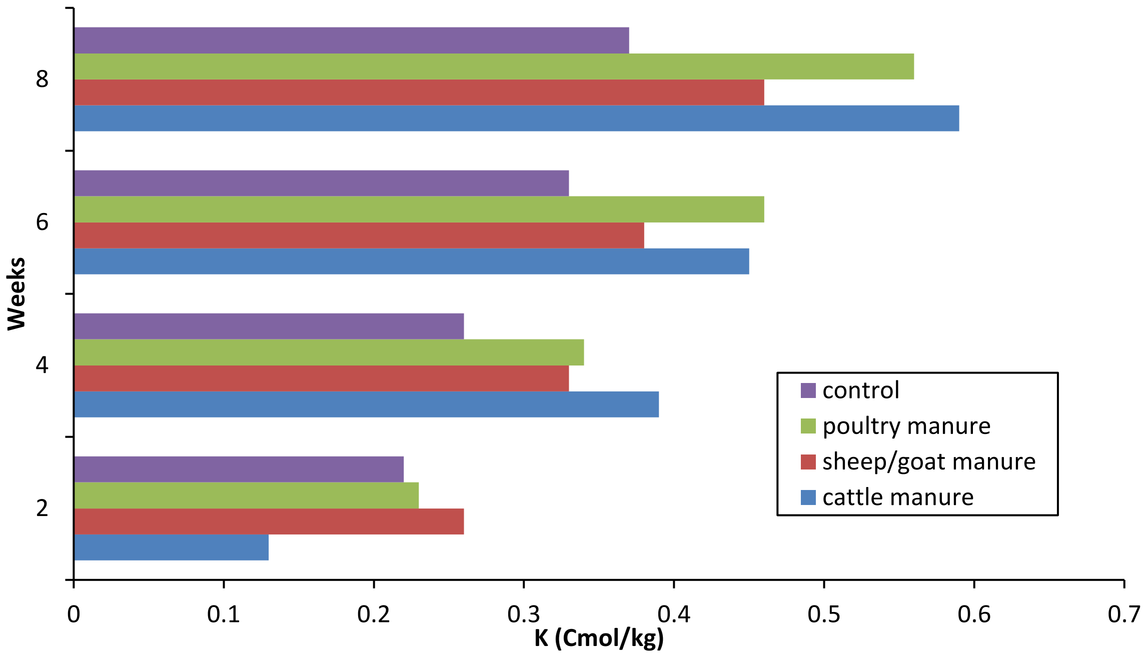

Fig. 3: Mineralization of K (Cmol/kg) in soil amended with different types of animal manure

Table 3: Mineralization of K (Cmol/kg) in soil amended with different types of animal manure

Treatments	Week 2	Week 4	Week 6	Week 8
Control (T1)	0.22^{a}	0.25^{b}	0.35^{c}	0.37^{b}
Poultry (T2)	0.25^{a}	0.34^{a}	0.44^{ab}	0.56^{ab}
Sheep/Goat (T3)	0.27^{a}	0.33^{a}	0.38^{bc}	0.46^{ab}
Cattle (T4)	0.13^{a}	0.39^{a}	0.46^{a}	0.59^{a}
Mean	0.22	0.33	0.41	0.49
SE ±	0.10NS	0.03*	0.03*	0.08*

Mean in the column followed by letters of different animal manure within the same column differ significantly ($p<0.05$).

DISCUSSION

The result demonstrates that at 2-4 weeks release of NH_4-N and P was higher in soil amended with poultry manure. The trend of mineralization was in the order poultry > sheep/goat > cattle manure. But in 6-8weeks cattle manures gave a higher value than poultry and sheep/goat manures. The result of NH-N indicates that from 2-6 weeks these were higher in soil amended with poultry manure, but at 8 week is higher in sheep/goat manure similar to findings of Kaleem Abbasi *et al*., 2007; Rasouli-Sadaghiani and Moradi, 2014 and Saka *et al*., 2017. The result indicates that from 2-8weeks P mineralized was higher in soil amended with poultry manure except at 6weeks where cattle manure gave higher P mineralized. The result indicates that from 2-8weeks and K mineralized was higher in soil amended with cattle manure. It could be concluded that soil amendment with poultry manure recorded higher NH_4-N between 2-6 weeks. Soil amended with animal manure did not affect P mineralization at 2-8 weeks. Soil amended with cattle manure recorded higher mineralization of K at 2-8 weeks. For better synchrony of nutrient release with plant growth, poultry manure may be applied at least 2 weeks before planting, while sheep/goat and cattle manure may be applied at least 6 weeks before planting.

CONCLUSION AND SUMMARY

The findings reveal clear trends in nutrient mineralization in soils modified with manure. Manure kind and timing have demonstrated an important impact on nutrient availability, hence improving agronomic efficiency. Poultry manure-amended soils had increased NH_4-N (2-6 weeks) and P mineralization (2-8 weeks, except at 6 weeks), but cattle manure performed well in sustained K release at 6-8 weeks. NH_4-N levels in sheep/goat manure reached their peak by week 8. To achieve nutrient-plant synchronization, use poultry manure at least 2 weeks before planting and cattle/sheep-goat manure at least 6 weeks before planting.

Conflict of Interest

The authors had no conflict of interest to declare.

REFERENCE

Azeez, J. O., and Van Averbeke, W. (2010). Fate of manure phosphorus in a weathered sandy clay loam soil amended with three animal manures. *Bioresource technology*, *101*(16), 6584-6588.

Boczulak, S. A., Hawkins, B. J., Maynard, D. G., and Roy, R. (2015). Long-and short-term temperature differences affect organic and inorganic nitrogen availability in forest soils. *Canadian Journal of Soil Science*, *95*(2), 77-86.

Brown, J. R., and Warncke, D. (1988). Recommended cation tests and measures of cation exchange capacity. *Recommended chemical soil test procedures for North Central Region*, 15-16.

Cabrera ML, Kissel DE (1988) Potentially mineralizable nitrogen in disturbed and undisturbed soil samples. *Soil Science Society of America Journal 52, 1010–1015.*

Ciancio, N. R., Ceretta, C. A., Lourenzi, C. R., Ferreira, P. A. A., Trentin, G., Lorensini, F. and Brunetto, G. (2014). Crop response to organic fertilization with supplementary mineral nitrogen. *Revista Brasileira de Ciência do Solo*, *38*, 912-922.

Dalias, P., and Christou, A. (2020). Nitrogen supplying capacity of animal manures to the soil in relation to the length of their storage. *Nitrogen*, *1*(01), 6.

Dalias, P., and Christou, A. (2020). Nitrogen supplying capacity of animal manures to the soil in relation to the length of their storage. *Nitrogen*, *1*(01), 6.

Doneda, A., Aita, C., Giacomini, S. J., Miola, E. C. C., Giacomini, D. A., Schirmann, J., and Gonzatto, R. (2012). Phytomass and decomposition of pure and intercropped cover crop residues. *Brazilian Journal of Soil Science*, *36*, 1714-1723.

Fulhage, C.D. (2000). Reduce environmental problems with proper land application of animal manure. University of Missouri Extension. USA. | Gamiliel, A., Austerweil, M. and Krizman, G. 2000.

Joseph, B., and Babu, S. (2024). Microbiome and nutrient dynamics of organic manures for precision NPK management in sunflower (Helianthus annuus L.). *Annals of Applied Biology*.

Kaleem Abbasi, M., Hina, M., Khalique, A., and Razaq Khan, S. (2007). Mineralization of three organic manures used as nitrogen source in a soil incubated under laboratory conditions. *Communications in soil science and plant analysis*, *38*(13-14), 1691-1711.

Kaneda, S., and Kaneko, N. (2011). Influence of Collembola on nitrogen mineralization varies with soil moisture content. *Soil Science and Plant Nutrition*, *57*(1), 40-49.

Klausner, S. D., Kanneganti, V. R., and Bouldin, D. R. (1994). An approach for estimating a decay series for organic nitrogen in animal manure. *Agronomy Journal*, *86*(5), 897-903.

Larney, V.and Jazan, S. (1996). Physical and Chemical Change during decomposition of poultry, sheep, goat and beef cattle feedlot manure. *Journal of Environment Quality. 37:725-735.*

Mlowe, F.C.(2009). Mineralization of Nitrogen from Animal Manure Resource *Journal of agriculture 33-35pp.*

Olsen, S. R. and Sommers, L. E. (1982). Phosphorus In: methods of soil Analysis. Part 2. 2nd edition, chemical and microbiological props A.L page, R.H. Miller, D.R. Keeney, D.E (eds) Agronomy No: 9 American Society of Agronomy Madison Wisconsin pp 403- 430.

Pratt, P., Broadbent, F., and Martin, J. (1973). Using organic wastes as nitrogen fertilizers. *California Agriculture*, *27*(6), 10-13.

Rasouli-Sadaghiani, M. H., and Moradi, N. (2014). Effect of poultry, cattle, sheep manures and sewage sludge on N mineralisation. *Chemistry and Ecology*, *30*(7), 666-675.

Sáez-Plaza, P., Michałowski, T., Navas, M. J., Asuero, A. G., and Wybraniec, S. (2013). An overview of the Kjeldahl method of nitrogen determination. Part I. Early history, chemistry of the procedure, and titrimetric finish. *Critical Reviews in Analytical Chemistry*, *43*(4), 178-223.

Journal of Arid Agriculture. 2025, Vol. 26 (3): 91 - 98

Saka, H. A., Azeez, J. O., Odedina, J. N., and Akinsete, S. J. (2017). Dynamics of soil nitrogen availability indices in a sandy clay loam soil amended with animal manures. *International Journal of Recycling of Organic Waste in Agriculture*, *6*, 167-178.

Schoenau, J. J., and Davis, J. G. (2006). Optimizing soil and plant responses to land-applied manure nutrients in the Great Plains of North America. *Canadian Journal of Soil Science*, *86*(4), 587-595.

Shao, Z., Zhang, X., Nasar, J., and Gitari, H. (2024). Synergetic Effect of Potassium, Biochar and Cattle Manure on the Growth and Yield of Maize, and Soil Physio-Chemical Characteristics. *Plants*, *13*(23), 3345.

Shen, S. Z., Wan, C., Ma, Y. J., Hu, Y. K., Wang, F., and Zhang, K. Q. (2021). The nitrogen mineralization characteristics of organic fertilizer for livestock and poultry under paddy upland rotation.

Sommers, L.E., D.W. Nelson, C. Parker and J. Graveel, 1980. Optimum Utilization of Sewage Sludge on Agricultural Land. Annual Report from Purdue Agriculture Experimental Station to Regional Project W-124. Agricultural Experiment Station, Purdue Univ., West Lafayette, IN

Stenger, R., Barkle, G. F., and Burgess, C. P. (2002). Mineralisation of organic matter in intact versus sieved/refilled soil cores. *Soil Research*, *40*(1), 149-160.

Strong D.T, Sale PWG, Helyar KR (1998) The influence of the soil matrix on nitrogen mineralisation and nitrification. I. Spatial variation and a hierarchy of soil properties. *Australian Journal of Soil Research 36, 429–447.*

Visconti-Moreno, E. F., and Valenzuela-Balcázar, I. G. (2023). Pores distribution influences the soil microorganism's response to changes in temperature and moisture. *Eurasian Journal of Soil Science*, *12*(1), 28-36.

Watts, D. B., and Torbert, H. A. (2014). Nitrogen mineralization in soils amended with manure as affected by environmental conditions. In *Applied Manure and Nutrient Chemistry for Sustainable Agriculture and Environment* (pp. 83-98). Dordrecht: Springer Netherlands.

Zhang, X., Dong, W., Dai, X., Schaeffer, S., Yang, F., Radosevich, M. and Sun, X. (2015). Responses of absolute and specific soil enzyme activities to long term additions of organic and mineral fertilizer. *Science of the Total Environment*, *536*, 59-67.