# Precision Manure Management on Site-specific Management Zones: Nitrogen Mineralization

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## ABSTRACT

Precise quantification of Nitrogen (N) mineralization in animal manure from different productivity level management zones (MZs) could result in efficient and safe utilization of manure as N fertilizer. The objective of this study was to compare N mineralization rates of dairy cattle manure within and across three productivity level MZs. To accomplish this, a 120 day laboratory incubation study was conducted at the Natural Resources Ecology Laboratory at

 

Colorado State University using a completely randomized design set as a 2 factor factorial. Treatments for the study, which included the field equivalent of, 22, 44, 67, and 134 Mg ha$^{-1}$ of applied animal manure, were replicated four times. Soils used in the study were collected from the top 15 cm of high, medium and low MZs from Fort Collins, Colorado, USA on a continuous corn (*Zea mays L.*) field. A significant difference ($P \leq 0.05$) in mineralized N across MZs was found across manure rates. The high, medium and low MZ N mineralization rates were compared and there was no significant difference in cumulative N mineralized between MZs over time. The lack of statistical difference in mineralized N between MZs is hypothesized to have been influenced by the lack of substantial difference in soil pH and particle sizes (only 6% clay difference between MZs). That being the case, a study involving spatially variable soils with significantly different soil particle size between MZs may result in a different conclusion. The results of the study support the hypothesis that variable rates of manure mineralize differently within MZs; however, the results do not support the hypothesis that variable rates of manure in soil may mineralize differently across MZs.

**Keywords**: Manure management, Nitrogen mineralization, Site-specific management zones.

 

**INTRODUCTION**

Precision or site-specific nutrient management across spatially variable soils in agricultural fields has been practiced for the past two decades in the United States of America. Precision nutrient management refers to variable rate application of nutrients, i.e., right amount of nutrients applied at the right place across a field. This concept of precision nutrient management has been widely employed for the management of nutrients, especially nitrogen (N). It was until recently when researchers in the State of Colorado merged the concept of precision nutrient manure with best manure management practices on field studies; hence, the concept of precision manure management was born. Precision manure management is relatively new (Moshia et al., 2008) and builds upon the concept of managing spatial variability in farm-fields with added potential for enhancing soil quality over time. Although not widely reported in literature, the concept of precision manure management is logical and more practical when coupled with site-specific management zones (MZs).

Site-specific management zones are sub-regions in a field that express a homogeneous combination of yield limiting factors (Doerge, 1999), and these yield limiting factors can be managed uniformly within each zone (Khosla et al., 2002). Earlier studies reported that the use of MZs in managing field inputs such as N is productive, profitable and environmentally beneficial (Clay et al., 1998; Swinton and Lowenberg-DeBoer, 1998; Khosla et al., 2002; Koch et al., 2004).

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**Nitrogen Mineralization and Site-Specific Management Zones**

The success of precision manure management depends upon a number of factors, among them being the mineralization rate of nutrients such as N, present in animal manure. Hence, understanding the rate of mineralization for N present in animal manure when applied variably across MZs would be of great value. Understanding the mineralization rate of N across MZs can decrease the potential for ground water contamination via leaching of nitrate-N ($NO_3$-N).

**Factors Influencing N Mineralization**

Quantification of N mineralized in animal manure could result in efficient and safe utilization of manure as a N source. Mineralization of organic N by microbial decomposition can be difficult to accurately predict when making nutrient recommendations due to the fact that many environmental and management factors affect the rate of N mineralization (Waskom, 1997). The type of manure added to the soil, residual N content of the soil, environmental conditions, and crop and soil management influence the rate of N mineralization (Snapp and Borden, 2005). The quality of animal manure applied is also known to play a key role in controlling the rate of N release (Swift et al., 1979). Additionally, Rice and Havlin (1994), Nahm (2005), and Bechtold and Naiman (2006) reported that the rate of N mineralization is influenced primarily by the substrate quality, moisture, soil pH, C: N ratio, animal species, temperature, accessibility of organic N to soil microorganisms, and soil particle size.

Gordillo and Cabrera (1997) and Schjönning et al. (1999) confirmed that soil characteristics greatly influence N mineralization rate. Hadas et al. (1983) studied the effect of temperature and

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soil type on mineral N release from animal manure under controlled environment. The study revealed no significant ($P \leq 0.05$) differences between clay and sandy soils at 25$^{o}$C, but the authors had no plausible explanation for the results. Previous studies reported that net mineralization of soil organic matter is more rapid in sandy soils than in clay soils (Catroux et al., 1987; Hassink et al., 1990; Ladd et al., 1990; Verberne et al. 1990). Verberne et al. (1990) found that the lower net mineralization in clay soils is assumed to be caused by greater physical protection of soil organic matter and microbial biomass.

Mzuku et al. (2005), in a study on spatial variability of soil properties across MZs, reported that soil texture varied significantly across MZs. The study further reported that the percentage of sand particles increased from the high to low MZs while the percentage of clay particles increased from low to high MZs. Soil texture influences water holding capacity, and soil water content was reported to increase from low to high MZs (Mulla and Bhatti, 1997). Soil texture directly affects soil electrical conductivity (EC) which is one of the key soil properties considered when delineating productivity level MZs (Franzen and Kitchen, 1999).

**Nitrogen Mineralization and Carbon Dioxide Evolution**

Nitrogen mineralization is the conversion of organic N into plant available inorganic N such as ammonium-N ($NH_4$-N) and $NO_3$-N. Ammonium-N and $NO_3$-N are a form of N that plants can absorb, but organic N cannot be used directly by plants (Barbarick, 2006). Nitrogen mineralization and immobilization are important processes in the N cycle (Cabrera et al., 2005). Nitrogen mineralization and immobilization occur simultaneously in soils, with the relative magnitudes determining whether the overall effect is net N mineralization or net N immobilization (Alexander, 1977).

Animal manure with high carbon (C) to N ratios are generally associated with relatively slow N release rates, due to N immobilization and limited soluble carbon to support microbial activity (Trinsoutrot et al., 2000). Under aerobic conditions, microorganisms feed on organic matter and in the process use N and other nutrients (Jezile, 2006). Carbon dioxide ($CO_2$) evolution from soil originates mainly from soil microbial activities and respiration. Rate of $CO_2$ evolution from soil has been reported as a common and reliable measure of microbial activity, substrate decomposition and metabolic status in soils (Witkamp, 1966). Inorganic N released from manure, or any organic material in soil, is a result of microbial decomposition and turnover of C and N by soil microbial biomass (Hadas et al., 1996).

**Nitrogen Mineralization and N Fertilizer**

Nitrogen contained in animal manure has potential as a valuable fertilizer, but due to environmental constraints, it may also be a factor that limits its use on agricultural lands (Barbarika et al., 1985). Delgado et al. (2005) reported that, although N is an essential nutrient that is a key component of intensive agricultural systems, its management to maximize yields and reduce losses to the environment is difficult. Binder et al. (1996) emphasized the importance of synchronizing manure N mineralization with crop use. Also, environmental loss of N can occur when the supply by animal manure and other sources exceeds crop demand. There is a challenge related to the use of animal manure as N fertilizer and a need to understand the dynamics of N mineralization. Previous laboratory studies have investigated N mineralization from applied animal manure (Castellanos and Pratt, 1981; Chae and Tabatabai, 1986; Bonde and Lindberg, 1988; Cabrera et al., 1993). However, there are no known published sources that reported the investigation of the N mineralization of variable rate applications of dairy cattle manure on MZs. The objective of this study was to evaluate and compare the N mineralization of variable rates of dairy cattle manure applied on soils collected from low and high management zones in a controlled environment.

## MATERIALS AND METHODS

The soil used in this study was classified as fine-loamy, mixed, mesic Aridic Haplustalf (Soil Survey Staff, 1980), sampled from a continuous maize (*Zea mays* L.) field near Fort Collins in northeastern Colorado. The field had no prior history of manure application. Soils were sampled from 0-15 cm depth. The 0-15 cm sampling depth was the depth at which farmers normally incorporate manure after application to a maize field.

The field was previously classified into site-specific management zones of high, medium and low productivity using the technique described by Fleming et al. (2000) and Hornung et al. (2006). The MZs delineation process involved a commercially available AgriTrak Professional Software to delineate the MZs boundaries.A gray scale bare soil aerial imagery of the field, farmer's perception of the topography data and farmer's past crop and soil management experiences were included in the delineation process (Hornung et al., 2006). Regions of darker color on the aerial image, areas of low-lying topography, and areas of historic high yields as reported by the farmer were designated as high MZs and vice-versa (Hornung et al., 2006).


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Soils of each of the three management zones were sampled with a JMC Backsaver probe (Clements Assoc., Newton, IA). Soils were air-dried at room temperature and subsequently passed through a 2-mm sieve (Tan, 1995). Homogenized fraction of the sieved soils was sent to a commercial laboratory (Harris Lab., Lincoln, NE) for the analysis of soil particle size with hydrometer method (Bouyoucos, 1962), Modified-walkey black organic matter (Nelson and Sommers, 1982), pH in water (U.S. Salinity Laboratory Staff, 1954), total C, total N, $NH_4$-N, and $NO_3$-N using Kjeldahl method (Bremner, 1965; Bremner and Keeney, 1965) (Table 1).

Dairy cattle manure was sampled from the manure pile to be used in a precision manure management study (Moshia et al., 2008) and thoroughly mixed after sampling. A portion was sub-sampled and sent to a commercial laboratory (Colorado Analytical Lab., Brighton, CO) for the analysis of pH, EC, total C, total N, $NH_4$-N, $NO_3$-N, water content and ash content in manure (Table 2). In the laboratory, manure samples were stored in a refrigerator to maintain moisture content and inhibit further microbial activities prior to analysis.

**Carbon Dioxide Evolution**

A 120 day laboratory incubation study was conducted at Colorado State University's Natural Resource Ecology Laboratory. Hundred-gram portions of soil were placed into plastic specimen cups (10 cm tall x 10 cm diameter). Dairy cattle manure was added to soils at rates of 0, 1.12, 2.24, 3.41, and 6.82 g, which was equivalent to field applications of 0, 22, 44, 67, and 134 Mg $ha^{-1}$ (0, 10, 20, 30 and 60 T/A respectively), assuming that 1 ha weighs $2 \times 10^6$ kg of soil in the 15 cm surface layer.


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Manure treatments were mixed with soils before moistening with deionized water. The soil water content was adjusted to soil volumetric water content at 75% field capacity ($\theta_{fc}$) with addition of deionized water at the beginning of the laboratory incubation study. Field capacity corresponded to gravimetric water contents of the soils in each management zone.

Each specimen cup containing soil-manure mixtures was placed in a 1 L (0.93 liter volume space) wide mouth mason jar containing 20 mL of water. The 20 mL of water in the jars was for minimizing the loss of moisture from the soil-manure mixture in the plastic specimen cups. Mason jar lids were fitted with rubber septa to allow headspace sampling. The mixtures were incubated at 25 ± 1°C in the darkroom for 120 days.

Headspace $CO_2$ was sampled from the mason jars using series A-2 Pressure-Lok® precision analytical syringe (VICI Precision Sampling Inc., Baton Rouge, LA, USA). An analysis of sampled $CO_2$ concentration was performed using LI-COR IRGA (infrared gas analyzer), Model LI-6252 $CO_2$ Analyzer (model LI-6252, LICOR, Lincoln, NE). After each sampling, the incubation jars were aerated for 10 minutes. Carbon dioxide evolved was determined at 0, 1, 2, 4, 7, 14, 21, 28, 35, 42, 49, 56, 63, 70, 77, 84, 91, 98, 105, 112, and 120 days after amendment.

The weight of the cups was monitored weekly to ensure constant water content of the soil-manure mixture during the incubation period. The water content of the soil-manure mixture was adjusted by weighing the samples and dropwise addition of the required amount of deionized water when the loss was greater than 0.05 g.


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**Nitrogen Mineralization**

For N mineralized, a separate set of replicated samples for each treatment per management zone was sacrificed after 0, 5, 10, 15, 30, 45, 60, 90 and 120 days of laboratory incubation. Soil samples of 50 g were extracted with 250 mL 2 M potassium chloride (KCl) after 30 minutes of shaking time. Extracts were filtered through Whatman® 40 filter papers and stored in a freezer to prevent further microbial processes until use for analyses. After all extractions were completed, samples were thawed, and concentrations of $NH_4$-N and $NO_3$-N in the extract were determined by continuous flow injection colorimetry using an AutoAnalyzer (Technicon Instrument Corporation, 1973). All inorganic N concentrations were expressed on an oven-dry basis.

Mineralization rates in the incubated soils were determined as discussed by Kaboneka et al. 1997 and Jezile (2006). Net N mineralization was calculated as the difference between soil inorganic N ($NH_4$-N + $NO_3$-N) in amended and unamended soils.

(a) Net $N_m = N_{m\ \text{amended soil}} - N_{m\ \text{unamended soil}}$ (1)

where $N_m$ = N mineralization (mg N $kg^{-1}$ soil)

(b) The percent N mineralization was calculated as follows:

% N mineralization = [(X-Y) / Z] x 100 (2)

where: X = mg of N mineralized from amended soil, Y= mg of N mineralized from unamended soil and Z = mg of N added in animal manure amendments.

**Experimental Design and Data Analysis**

The incubation experiment was designed as a two factor (management zones and animal manure) factorial. Four manure treatments of 22, 44, 67, and 134 Mg $ha^{-1}$ were replicated three times on each management zone of low, medium and high productivity. The statistical data analysis was performed using PROG GLM procedure in SAS (SAS Institute, 2005). Treatment means were compared using least significant difference ($P \leq 0.05$) (Steel et al., 1997), and curve fitting was performed with Microsoft Excel 2003 (Redmond, WA).

## RESULTS AND DISCUSSION

### Nitrogen Mineralization and Management Zones

A significant difference ($P \leq 0.05$) in mineralized N across MZs was found across manure rates. (Table 3). The regression curves of the net inorganic N ($NO_3$-N + $NH_4$-N) shows that N mineralization increase with manure rate and incubation time (Figure 1). The fundamental significance of Figure 1 is that, as incubation time increased, the total inorganic N mineralization increased significantly across low, medium and high MZs.

The high, medium and low MZ N mineralization rates were compared and there was no significant difference in cumulative N mineralized between MZs over time (Figure 2). The lack of statistical difference in mineralized inorganic N between MZs is hypothesized to have been influenced by the lack of substantial difference in soil particle sizes (only 6% clay difference between MZs) and pH (Table 1). Watts et al. (2007) studied the difference in N mineralization rate of dairy manure amended soils collected from an on-going precision agriculture project. The study revealed no significant difference on soils that had similar amounts of clay content and pH, but a wide difference in sand content. Our study findings agree with the results reported by Watts et al. (2007). Based on the results of this study it is sufficient to say that there was no difference in N mineralized between low, medium, and high management zones (Figure 2). Verberne et al. (1990) and Jastrow (1996) reported that in soils with high amounts of aggregates, the clay-sized particles are bound around organic material, thereby, protecting organic matter from decomposing. Watts (2007) added that it is only when soil aggregates are destroyed that the organic matter is exposed to microbial attack. However, these observations do not apply to our study since the addition of manure followed by immediate incubation would not influence aggregate stability or organic binding with clay.

While the aim of this study was not to compare percentage N mineralized with that of previous studies, the percentage N mineralized for dairy animal manure was lower for northeastern Colorado soils (Waskom, 1997; Marx, 2008; Table 4). The reason for lower mineralized inorganic N on across zones on all treatments (Table 3.4) was thought to be due to the high respiration rate as measured through $CO_2$ evolution (Figure 3). Franzluebbers (1999) reported that substantial N immobilization is likely to occur due to very high respiration rates during mineralization. Mineralized inorganic N was lower at initial mineralization stage followed by a gradual increase in mineralized N after day 15 (Figure 2). Koelsch (2005) reported that when applied to soils, manure increases the energy or food supply available to the soil microbial population. This energy supply stimulates soil microbial activity, which consumes more available N than the mineralization processes release. Thus, high microbial activity during initial manure mineralization from day 1 to 15 could have caused a reduced rate of release of available inorganic N. When the microbial populations reached a steady state (after 15 days as indicated by leveling off of $CO_2$ production, Figure 3) the available inorganic N slowly increases (Figure 2). The mineralized N can be a useful parameter for determining the potential impact of applied animal manure across and within MZs, and for estimating the N-supplying capacities of soils.

**Carbon Dioxide Evolution and N Mineralization**

The dairy animal manure used in the incubation study had a water content of 604.2 mg kg$^{-1}$ (Table 2), pH of 7.3, $NH_4$-N and $NO_3$-N content of 1171, and 22.3 mg kg$^{-1}$ respectively, and a total N content of 9.8 g kg$^{-1}$. The C/N ratio of the dairy animal manure was 21:1, suggesting that rapid mineralization of added organic N would be expected (Bitzer and Sims, 1988). Carbon dioxide evolution in manure amended soils increased more rapidly from time 0 to 14 and decreased steadily after peaking at 21 days (Figure 4), depending on manure rate.

The $CO_2$ evolution of all dairy manure treatments reached a peak at day 14 on low zone, and day 21 on high and medium zones. Only the 22 and 44 Mg ha$^{-1}$ treatments reached a peak $CO_2$ evolution at day 14 while manure treatments of 66 and 134 Mg ha$^{-1}$ reached a peak at day 21. After reaching the peak, $CO_2$ evolution started to decrease (Figures 3 and 4). The decrease in $CO_2$ evolution denotes dying of microbes and as the microbes die, the level of inorganic N increases. Figures 1 and 2 shows clearly that after day 14, the inorganic N accumulation curve increased nonlinearly.

The high rate of microbial activity is shown by the rate of $CO_2$ evolution during a 120 day laboratory incubation study (Figure 5). At the end of the study, cumulative $CO_2$ evolution on our study reported low levels of accumulated inorganic N per weight of added manure treatments. Calderon et al. (2004) proposed measuring the N ($N_2$ and $N_2O$) lost through denitrification, which was not possible in our study. Despite the fact that $NH_4$-N was the dominant form of inorganic N in the dairy manure used in the study (Table 2), $NO_3$-N was the dominant form of N in the soil when inorganic N was measured throughout the incubation period. The results of $NO_3$-N as a dominating form of inorganic N suggest that $NH_4$-N was nitrified and some $NO_3$-N was also released from dying microbes.

**CONCLUSIONS**

The objective of this study was to evaluate and compare the N mineralization of variable rates of dairy cattle manure applied on soils collected from low, medium, and high MZs, in a controlled environment. The lack of clearly pronounced differences in soil pH and particles size between MZs is hypothesized to be the main factor that resulted in no statistical difference of mineralized inorganic N over time between MZs. That being the case, a study involving spatially variable soils with significantly different soil particle size between MZs may result in a different conclusion based on our original hypothesis. Our major concern with higher manure rates such as 67 and 134 Mg $ha^{-1}$ on the low productivity MZ at a field level is the potential environmental pollution associated with such high rates of manure application. An agronomically and environmentally sound compromise must be made when determining manure application rates. Our rates may not supply the needed N to the plant while high rates can result in buildup of $NO_3$-N that will be subjected to leaching. The key is determining proper manure rates. This can be done by using accepted manure and soil testing procedures. The results of the study support the hypothesis that variable rates of manure mineralize differently within MZs; however, the results do not support the hypothesis that variable rates of manure in soil may mineralize differently across MZs.

 ACCEPTED MANUSCRIPT

**REFERENCES**


Alexander, M. 1977. *Introduction to soil microbiology*. 2nd edition: John Wiley & Sons, New York.

Barbarick, K.A. 2006. *Organic materials as Nitrogen Fertilizers*. Colorado State Univ. Coop. Ext. Bulletin No. 0.546, Fort Collins.

Barbarika, A.J., J.S. Lawrence, and D. Colacicco. 1985. Factors affecting the mineralization of nitrogen in sewage sludge applied to soils. *Soil Science Society of America Journal* 49: 1403–1406.

Bechtold, J.S., and R.J. Naiman. 2006. Soil texture and nitrogen mineralization potential across a riparian toposequence in a semi-arid savanna. *Soil Biology and Biochemistry* 38: 1325–1333.

Binder, D.L., D.H. Sander, K.D. Frank, and W.L. Shires. 1996. Nitrogen fertilizer equivalency of anaerobically digested municipal sludge. p.41–46. In *Proc. 12th North Cent. Ext.-Ind. Soil Fert. Conf.* St. Louis, MO. 20–21 Nov. Brookings, SD.

Bitzer, C.C., and J.T. Sims. 1988. Estimating the availability of nitrogen in poultry manure through laboratory and field studies. *Journal of Environmental Quality* 17: 47–54.

Bonde, T.A., and T. Lindberg. 1988. Nitrogen mineralization kinetics in soil during long-term aerobic laboratory incubations: A case study. *Journal of Environmental Quality* 17: 414–417.

Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analysis of soils. *Agronomy Journal* 54: 464–465.


 ACCEPTED MANUSCRIPT

Bremner, J.M., and D.R. Keeney. 1965. Steam distillation methods for determination of ammonium, nitrate, and nitrite. *Analytica Chimica Acta* 32: 485–495.

Bremner, J.M. 1965. Total nitrogen. In *Methods of Soil Analysis*, edited by C. A. Black. Part 2, pp. 1149–1178. American Society of Agronomy, Madison, WI.

Cabrera, M.L., D.E. Kissel, and M.F. Vigil. 2005. Nitrogen Mineralization from Organic Residues Research Opportunities. *Journal of Environmental Quality* 34: 75–79.

Cabrera M.L., S.C. Chiang., W.C. Merka., S.A. Thompson., and O.C. Poncorbo. 1993. Nitrogen transformations in surface-applied poultry litter: Effect of litter physical characteristics. *Soil Science Society of America Journal* 57: 1519–1525.

Calderon, F.J., G.W. McCarty, J.A.S. Van Kessel, and J.B. Reeves. 2004. Carbon and nitrogen dynamics during incubation of manured soil. *Soil Science Society of America Journal* 68: 1592– 1599.

Castellanos J.Z., and P.F. Pratt. 1981. Mineralization of manure nitrogen–correlation with laboratory indexes. *Soil Science Society of America Journal* 45: 354–357.

Catroux, G., R. Chaussod, and B. Nicolardot. 1987. Assessment of nitrogen supply from the soil. R. R. *Académie Agriculture Francais* 3: 71–79.

Chae, Y.M., and M.E. Tabatabai. 1986. Mineralization of nitrogen in soils amended with organic wastes. *Journal of Environmental Quality* 15: 193–198.

Clay, D.E., D.D. Malo, C.L. Reese and C.G. Carlson. 1998. Identifying good candidate for precision phosphorus management. SSMG. In Clay et al. (ed). *Site specific management guidelines.* Available at http://ppi-far.org/ssmg (verified 14 November, 2012). Potash and Phosphate Inst.: Norcross,GA.

 ACCEPTED MANUSCRIPT

Delgado, J.A., R. Khosla, W.C. Bausch, D.G. Westfall, and D.J. Inman. 2005. Nitrogen fertilizer management based on site-specific management zones reduces potential for nitrate leaching. *Journal of Soil and Water Conservation* 60: 402–410.

Doerge, T. 1999. Defining management zones for precision farming. *Crop Insights* 8(21): 1–5.

Eghball, B. 2002. Soil Properties as Influenced by Phosphorus- and Nitrogen-Based Manure and Compost Applications. *Agronomy Journal* 94: 128–135.

Fleming, K.L., D.G. Westfall, D.W. Wiens, and M.C. Brodahl. 2000. Evaluating farmer defined management zone maps for variable rate fertilizer application. *Precision Agriculture* 2: 201–215.

Franzen, D.W., and N.R. Kitchen. 1999. *Site-Specific Management Guidelines – Developing Management Zones to Target Nitrogen Applications*. http://www.ipni.net (verified 14 November, 2009). PPI: Norcross, GA.

Franzluebbers, A.J. 1999. Potential C and N mineralization and microbial biomass from intact and increasingly disturbed soils of varying texture. *Soil Biology and Biochemistry* 31: 1083–1090.

Gordillo, R.M., and M.L. Cabrera. 1997. Mineralizable nitrogen in broiler litter: II. Effect of selected soil characteristics. *Journal of Environmental Quality* 26: 1679–1686.

Hadas, A., B. Bar-Yosef, S. Davidov, and M.Sofer. 1983. Effect of pelleting, temperature, and soil type on mineral nitrogen release from poultry and dairy manures. *Soil Science Society of America Journal* 47: 1129–1133.


ACCEPTED MANUSCRIPT

Hadas, A., L. Kautsky, and R. Portnoy. 1996. Mineralization of Composted Manure and Microbial Dynamics in Soil As Affected By Long-Term Nitrogen Management. *Soil Biology and Biochemistry* 28: 733–738.

Hassink, J., D. Scholefield, and P. Blantern. 1990. Nitrogen mineralization in grassland soils. In: Gaborcik N, Krajcovic V, Zimkova M (eds) *Proceedings of the 13$^{th}$ General Meeting of the European Grassland Federation* 2: 25–32.

Hornung, A., R. Khosla, R. Reich, D. Inman, and D.G. Westfall. 2006. Comparison of site-specific management zones: Soil-color-based and yield-based. *Agronomy Journal* 98: 407–415.

Jastrow, J.D. 1996. Soil aggregate formation and the accrual of particulate and mineral-associated organic matter. *Soil Biology and Biochemistry* 28: 665–676.

Jezile, G.G. 2006. *Effects of lime and chicken manure on soil pH, microbial activity and N mineralization in two acid South African Ultisols*. PhD Dissertation. Colorado State Univ., Fort Collins.

Kaboneka, S., W.E. Sabbe, and A. Mauromoustakos. 1997. Carbon decomposition kinetics and N mineralization from maize, soybean and wheat residues. *Communication in Soil Science and Plant Analysis* 28: 1359–1373.

Khosla, R., K. Fleming, J.A. Delagado, T.M. Shaver, and D.G. Westfall. 2002. Use of site-specific management zones to improve nitrogen management for precision agriculture. *Journal of Soil and Water Conservation* 57(6): 513–518.

Koch, B., R. Khosla, M. Frasier, D.G. Westfall, and D. Inman. 2004. Economic feasibility of variable rate nitrogen application utilizing site-specific management zones. *Agronomy Journal* 96: 1572–1580.

Koelsch, R. 2005. *Livestock and poultry environmental stewardship curriculum*. Lesson 30 No. 2: Nutrient management. Iowa State Univ. Ames, IA.

Ladd, J.N., M. Amato, L. Jocteur-Monrozier, and M. Van Gestel. 1990. Soil microhabitats and carbon and nitrogen metabolism. In: *Proceedings of the 14th International Congress on Soil Science* August 12–18, 1990, Kyoto, Japan. 3: 82–87.

Marx, E. 2008. *Developing a Nitrogen budget for organic soil fertility. Colorado agriculture conference and trade show.* Island Grove Park, Greeley, CO. www.colostate.edu/Dept/CoopExt/Adams/cabas/pdf/NitrogenBudgetforOrganicFarming-Marx.pdf. (verified 14 November, 2012).

Moshia M.E., R. Khosla, D.G. Westfall, J.G. Davis, and R. Reich. 2008. Precision Manure management across site-specific management zones for enhancing maize grain yield. [CD-ROM]. *Proceedings of the 9th International Conference on Precision agriculture*. 20-23 July, Denver, CO.

Mulla, D.J., and A.U. Bhatti. 1997. An evaluation of indicator properties affecting spatial patterns in N and P requirements for winter wheat yield. p. 145–153. In J.V. Stafford (ed.) *Precision agriculture '97. 1st European Conference on Precision Agriculture.* Warwick Univ., UK. Bios Scientific Publ., Oxford, Herndon, VA.


ACCEPTED MANUSCRIPT

Mzuku, M., R. Khosla, R. Reich, D. Inman, F. Smith, and L. MacDonald. 2005. Spatial variability of measured soil properties across site specific management zones. *Soil Science Society of America Journal* 69: 1572–1579.

Nahm, K.H. 2005. Factors influencing nitrogen mineralization during poultry litter composting and calculations for available nitrogen. *World Poultry Science Journal* 61: 238–255.

Nelson, D.W., and L.E. Sommers. 1982. Total carbon, organic carbon and organic matter. p. 539–579. *In:* A. L. Page et al. (ed.) Methods of soil analysis: Part 2. Chemical and microbiological properties. ASA Monograph Number 9.

Rice, C.W., and J.L. Havlin. 1994. Integrating mineralizable nitrogen indices into fertilizer nitrogen recommendations. p. 1–13. In J.L. Havlin et al (ed.) *Soil testing: Prospects for improving nutrient recommendation.* SSSA Spec. Publ. No. 40. SSSA. Madison, WI.

SAS. 2005. *SAS Users Guide: Statistics*. Version 9.1 Edition. SAS Institute, Cary, North Carolina, NC.

Schjönning, P., I.K. Thomsen, J.P. Mobert, H. de Jonge, K. Kreisensen, and B.T. Christensen. 1999. Turnover of organic matter in differently textured soils: I. Physical characteristics of structurally disturbed and intact soils. *Geoderma* 89: 177–198.

Snapp, S.S., and H. Borden. 2005. Enhanced nitrogen mineralization in mowed or glyphosate treated cover crops compared to direct incorporation. *Plant and Soil* 270: 101–112.

Soil Survey Staff. 1980. *Soil survey of Larimer County, CO. U.S*. USDA-NRCS. Soil Survey. U.S. Gov. Print. Office, Washington, DC.

Steel, R.G.D., J.H. Torrie and D.A. Dickey. 1997. *Principles and procedures of statistics: A biometrical approach*. 3rd ed. McGraw-Hill Companies, Inc., New York, NY.

 ACCEPTED MANUSCRIPT

Swift, M.J., O.W. Heal, and J.M. Anderson. 1979. *Decomposing in terrestrial ecosystems*. Studies in Ecology, 5. Blackwell Sci. Publ., Oxford.

Swinton, S.M., and J. Lowenberg-DeBoer. 1998. Evaluating the profitability of site-specific farming. *Journal of Production Agriculture* 11: 439–446.

Tan, K.H. 1995. Soil sampling, preparation and analysis. Marcel Dekker, Inc., New York. NY.

Technicon Instrument Corporation, 1971. Nitrate and Nitrite in Water. Industrial method No. 32–69W. Technicon Instrument Corporation, Tarrytown, New York, NY.

Trinsoutrot, I., S. Recous, B. Bentz, M. Linères, D. Chèneby and B. Nicolardot. 2000. Biochemical quality of crop residues and carbon and nitrogen mineralization kinetics under non-limiting nitrogen conditions. *Soil Science Society of America Journal* 64: 918–926.

U.S. Salinity Laboratory Staff. 1954. pH reading of saturated soil paste. p. 102. *In:* L. A. Richards (ed.) Diagnosis and improvement of saline and alkali soils. USDA Agricultural Handbook 60. U.S. Government Printing Office, Washington, D.C.

Verberne, E.L.J., J. Hassink, P. De Willigen, J.J.R. Groot, J.A. Van Veen. 1990. Modelling organic matter dynamics in different soils. *Netherlands Journal of Agricultural Science* 38: 221–238.

Waskom, R.M. 1997. *Improving nutrient management through refined estimates of mineralization, soil nutrient distribution, and plant N status*. Doctoral dissertation. Colorado State Univ., Fort Collins.



ACCEPTED MANUSCRIPT

Watts, D.B. 2007. *Mineralization of N in soils amended with dairy manure as affected by environmental conditions*. Doctoral dissertation. Auburn Univ., Auburn.

Watts, D.B., H.A. Torbert, and S.A. Prior. 2007. Mineralization of N in Soils Amended with Dairy Manure as Affected by Wetting/Drying Cycles. *Communication in Soil Science and Plant Analysis* 38: 2103–2116.

Witkamp, M. 1966. Rates of Carbon Dioxide Evolution from the forest floor. *Ecology* 47: 492–494.

 

Table 1. Selected pre-study topsoil properties sampled on management zones at 0-15 cm sampling depths

| Management Zones | Sand | Clay | Soil textural Class | OM† | EC‡ | pH | Total C | Total N | $NH_4$-N | $NO_3$-N |
|---|---|---|---|---|---|---|---|---|---|---|
| | g $kg^{-1}$ | | | g $kg^{-1}$ | dS $m^{-1}$ | | g $kg^{-1}$ | | mg $kg^{-1}$ | |
| High | 472 | 364 | Clay Loam | 18 | 0.8 | 7.8 | 15.6 | 1.12 | 7.6 | 27.5 |
| Medium | 532 | 304 | Sandy Clay Loam | 16 | 0.9 | 7.8 | 18.2 | 0.54 | 5.3 | 15.1 |
| Low | 452 | 304 | Sandy Clay Loam | 15 | 1.0 | 7.8 | 19.6 | 0.78 | 4.7 | 15.2 |

†OM=Soil organic matter,

‡EC = Electrical Conductivity

Table 2. Selected characteristics of dairy cattle manure (DCM) used in for laboratory incubation study. Nutrients, organic matter,

and ash contents are on a dry weight basis.

| Year and Source | Total N | Total P | Organic Matter | Ash | Water Content | $NO_3$-N | $NH_4$-N | EC† | pH† | C/N ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | g $kg^{-1}$ | | | | | mg $kg^{-1}$ | | d S $m^{-1}$ | | |
| DCM | 9.80 | 2.47 | 392.0 | 608.0 | 604.2 | 22.3 | 1171 | 4.75 | 7.30 | 21.0 |

†Electrical conductivity (EC) and pH were determined on 5:1 water to dry manure ratio.

 

Table 3. Least square mean comparisons of N mineralized on 22, 44, 67, and 134 Mg $ha^{-1}$ of dairy manure treatments on low, medium and high management zones ($P \leq 0.05$).

| Low zone | | | | |
|---|---|---|---|---|
| Treatments | 22 Mg $ha^{-1}$ | 44 Mg $ha^{-1}$ | 67 Mg $ha^{-1}$ | 134 Mg $ha^{-1}$ |
| 22 Mg $ha^{-1}$ | NS | 0.0043 | <.0001 | <.0001 |
| 44 Mg $ha^{-1}$ | – | NS | 0.0144 | <.0001 |
| 67 Mg $ha^{-1}$ | – | – | NS | 0.0018 |
| 134 Mg $ha^{-1}$ | – | – | – | NS |
| Medium zone | | | | |
| Treatments | 22 Mg $ha^{-1}$ | 44 Mg $ha^{-1}$ | 67 Mg $ha^{-1}$ | 134 Mg $ha^{-1}$ |
| 22 Mg $ha^{-1}$ | NS | 0.0399 | <.0001 | <.0001 |
| 44 Mg $ha^{-1}$ | – | NS | 0.002 | <.0001 |
| 67 Mg $ha^{-1}$ | – | – | NS | 0.0114 |
| 134 Mg $ha^{-1}$ | – | – | – | NS |
| High zone | | | | |
| Treatments | 22 Mg $ha^{-1}$ | 44 Mg $ha^{-1}$ | 67 Mg $ha^{-1}$ | 134 Mg $ha^{-1}$ |
| 22 Mg $ha^{-1}$ | NS | <.0001 | <.0001 | <.0001 |
| 44 Mg $ha^{-1}$ | – | NS | 0.0006 | <.0001 |
| 67 Mg $ha^{-1}$ | – | – | NS | 0.0003 |
| 134 Mg $ha^{-1}$ | – | – | – | NS |

 

Table 4. Total and percentage mineralized nitrogen (N) in laboratory incubation study on low, medium, and high management zones manured with 22, 44, 67 and 134 Mg $ha^{-1}$ of dairy manure.

| | Low zone | | Medium zone | | High zone | |
|---|---|---|---|---|---|---|
| Treatment | Total min. N | N mineralized | Total min. N | %N mineralized | Total min. N | %N mineralized |
| Mg $ha^{-1}$ | mg $kg^{-1}$ | % | mg $kg^{-1}$ | % | mg $kg^{-1}$ | % |
| 22 | 80.4a | 24.2 | 80.96a | 24.3 | 85.3a | 21.7 |
| 44 | 130.5b | 26.2 | 121.23b | 24.2 | 134.6b | 24.9 |
| 67 | 174.3c | 25.5 | 178.43c | 24.8 | 173.0c | 23.5 |
| 134 | 228.8d | 26.7 | 226.23d | 22.9 | 211.2d | 22.5 |

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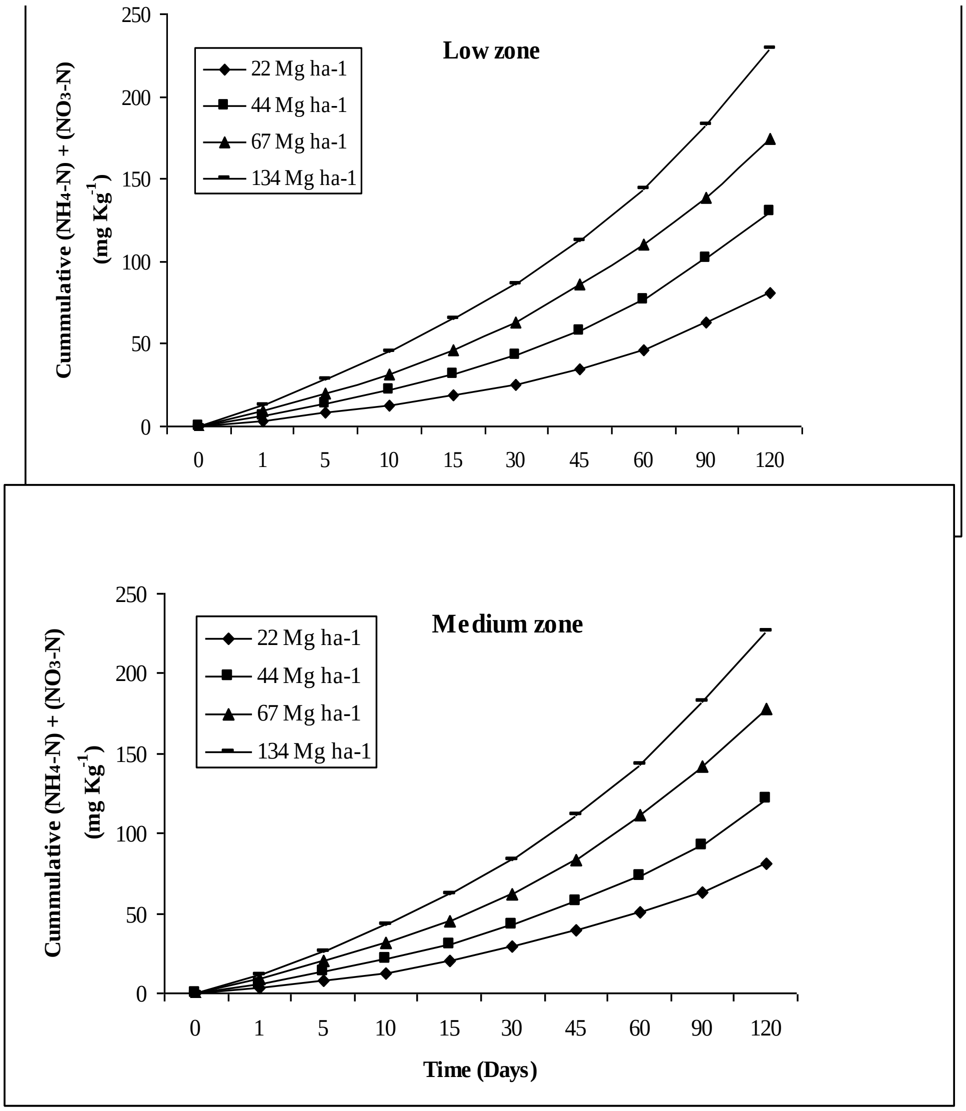
Low zone
22 Mg ha-1
44 Mg ha-1
67 Mg ha-1
134 Mg ha-1
Cummulative (NH4-N) + (NO3-N) (mg Kg-1)
0
50
100
150
200
250
0 1 5 10 15 30 45 60 90 120
Medium zone
22 Mg ha-1
44 Mg ha-1
67 Mg ha-1
134 Mg ha-1
Cummulative (NH4-N) + (NO3-N) (mg Kg-1)
0
50
100
150
200
250
0 1 5 10 15 30 45 60 90 120
Time (Days)

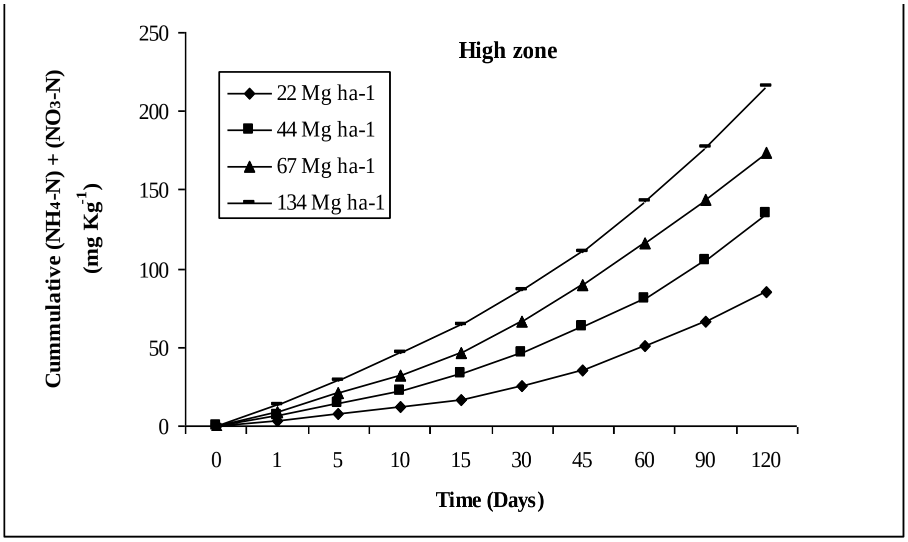


Fig. 1. Regression cumulative inorganic nitrogen ($NH_4$-N + $NO_3$-N) mineralized during a 120 days laboratory incubation study on low, medium, and high management zones manured with 22, 44, 67 and 134 Mg ha$^{-1}$ of dairy animal manure.


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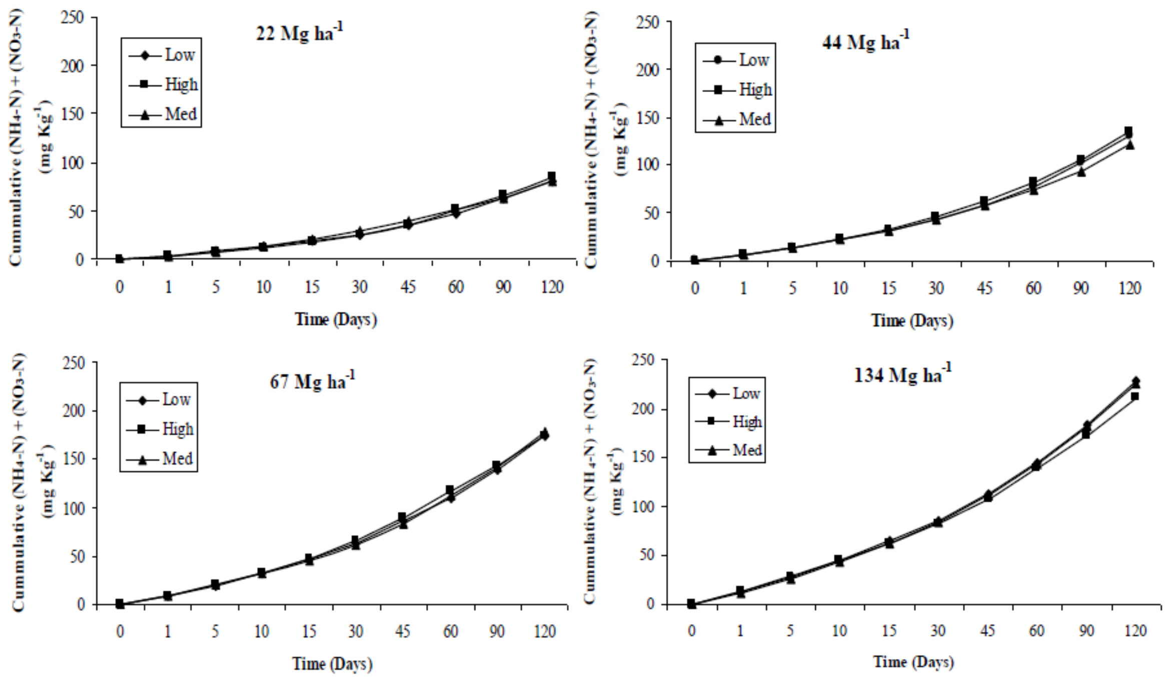


Fig. 2. Regression curve of cumulative inorganic N ($NH_4$-N + $NO_3$-N) mineralized during a 120 days laboratory incubation study on low and high management zones manured with 22, 44, 67 and 134 Mg $ha^{-1}$ of dairy manure.

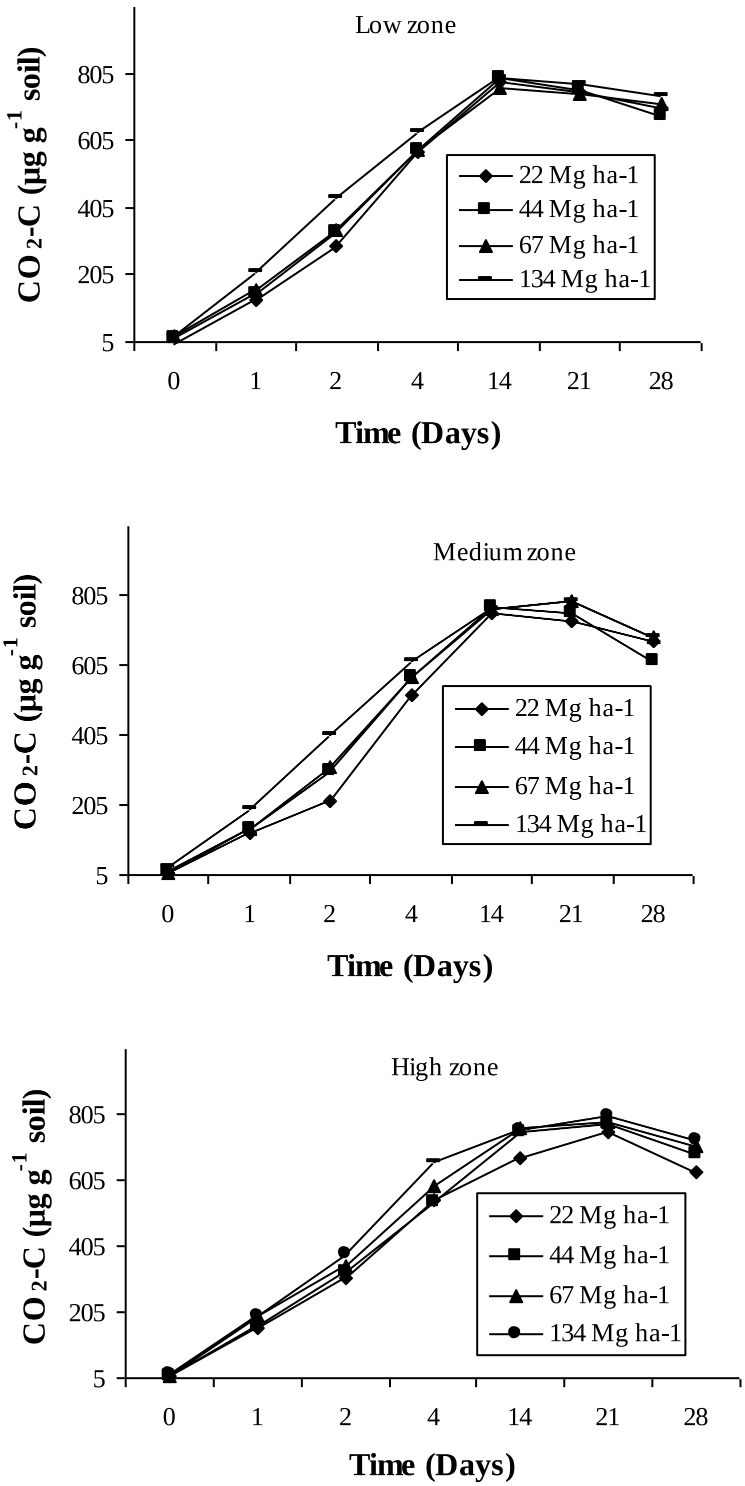


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Fig. 3. A 28 day snapshot of carbon dioxide ($CO_2$) evolved from 22, 44, 67, and 134 Mg ha$^{-1}$ of dairy manure on low, medium and high management zones respectively during a 120 days laboratory incubation study.

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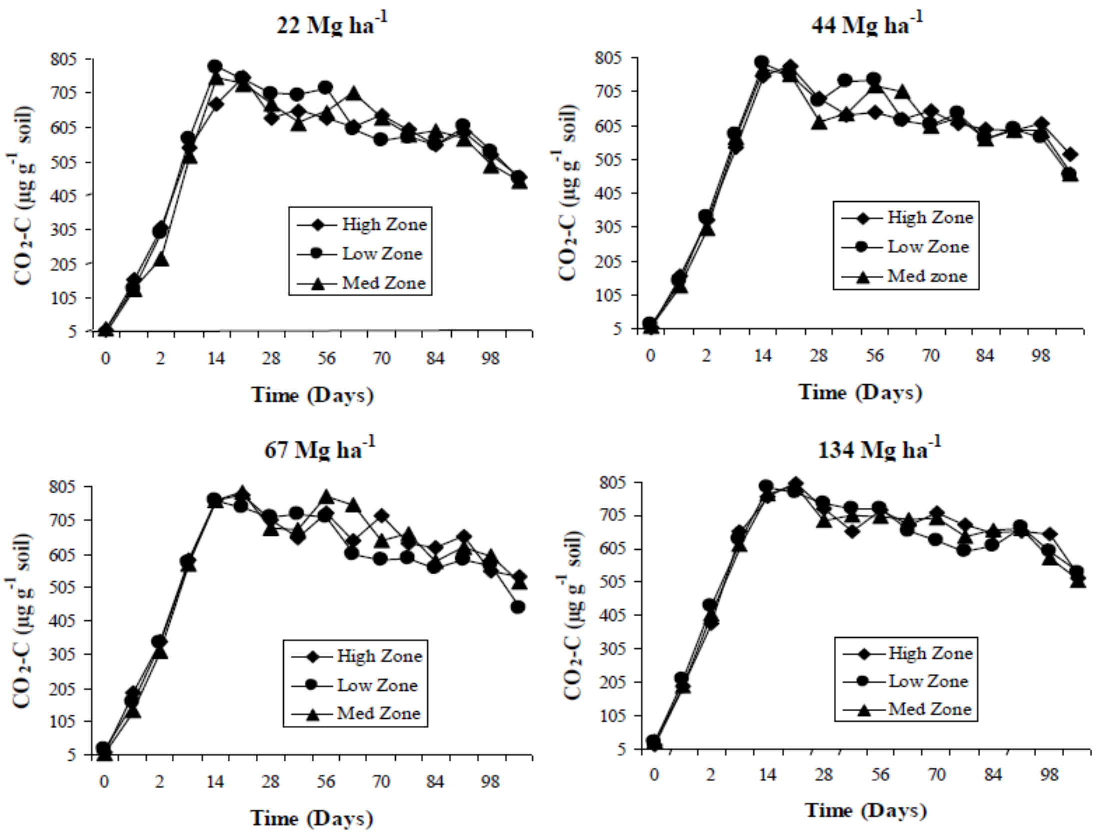


Fig. 4. Carbon dioxide evolved during a 120 days laboratory incubation study on low, medium and high management zones manured with 22, 44, 67 and 134 Mg $ha^{-1}$ of dairy manure.

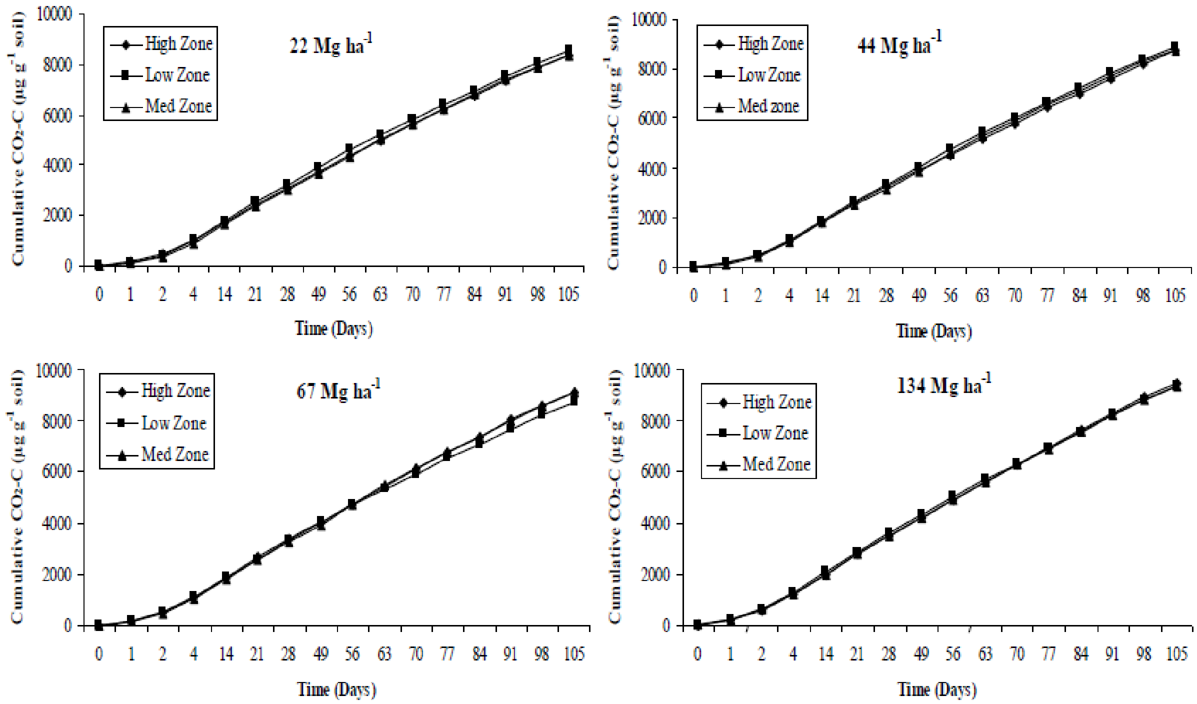


Fig 5. Regression curve of cumulative carbon dioxide ($CO_2$) evolved during a 120 days laboratory incubation study on low, medium and high management zones manured with 22, 44, 67 and 134 Mg ha$^{-1}$ of dairy manure.