Agro-Science Journal of Tropical Agriculture, Food, Environment and Extension
Volume 14 Number 3 September, 2015 pp. 35-40
ISSN 1119-7455

MINERALIZATION RATE CONSTANTS, HALF-LIVES AND EFFECTS OF TWO ORGANIC AMENDMENTS ON MAIZE YIELD AND CARBON-NITROGEN STATUS OF LOAMY ULTISOL IN SOUTHEASTERN NIGERIA

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ABSTRACT

Mineralization rate constants and half-lives of cattle dung (CD) and swine wastes (SW) and their effects on soil organic Carbon (SOC), Nitrogen (STN) and maize yield were evaluated for two years. The study was conducted on a deep, coarse-textured, porous and brownish red soil in Nsukka, southeastern Nigeria. Each of CD and SW was applied at four rates (0, 10, 20 and 40 t ha^{-1}) in a split-plot design as main plot and sub-plot treatments, respectively. The organic materials were only added the first year and residual effect evaluated the second year. The results showed that SW had less C and more N than CD. Also the C/N ratio of CD (5:1) was higher than SW (3:1). Sole SW had higher mineralization rate constants and lower half lives than sole CD but their combined application enhanced both parameters. Mineralization rate constants also increased with increasing rate of application while the half-lives decreased. The CD increased SOC in both years while SW increased SOC and STN in the first year and only SOC in the second year. In addition, C and N contents of the organic materials contributed 45% and 40% changes in SOC and STN, respectively at the end of first year cultivation. In the second year, only SOC was affected by the C content of the organic material thus contributing 28% of changes in SOC. Both C and N contributed 85% changes in grain yield of first season maize with N contributing 69% improvement. In the second year, N alone contributed 56% of the change in grain yield. So SW had less half-lives than CD depicting faster decomposition and release of plant nutrients. There were significant interactions of CD and SW on SOC, STN and maize grain yield.

Key words: cattle dung, swine waste, mineralization rate constants, soil organic carbon, maize yield

INTRODUCTION

Low soil fertility is one the problems militating against maximum crop production. The majority of Nigerian soils are inherently of low fertility status due to dominance of low-activity clays, and are being further degraded at an alarming rate through intensification of crop production and inappropriate farming practices. Continuous cultivation of crops on these soils has resulted in increased rate of weathering and rapid loss of fertility over few years of cultivation. Nutrients exported from the soil through harvested biomass and lost from the soil through various processes such as soil erosion (Swift *et al*., 1994), leaching (Cahn *et al*., 1993), and denitrification (Lensi *et al*., 1992) need to be replaced with nutrients from external sources. This will restore the fertility of these soils for sustainable crop production. Therefore, soil fertility management (SFM) is very crucial.

Organic residues addition to soils is particularly important for maintenance of fertility of tropical soils. The choice of residue will depend on its availability and quality. So there is need to assess the quality of organic materials used to restore soil fertility. Organic carbon (C) and nitrogen (N) contents, C/N ratios and mineralization rates are used to assess the quality of organic residue. According to Palm *et al*. (2001), the minimum data set required to assess resource quality consists of N, lignin and soluble polyphenol contents. Decomposition rates and organic C are other factors used to assess the quality of organic materials. Cadisch and Giller (1997) stated that the decomposition rate of organic materials is a very relevant factor of organic resource quality.

The relevance of organic carbon in the soil cannot be overemphasized. Bationo *et al.* (2003) noted that organic carbon stabilizes about 98% of

DOI: http://dx.doi.org/10.4314/as.v14i3.7

soil N. Thus, total N in the soil and the amount released for plant uptake depend on its content of organic carbon. Soil organic carbon (SOC) affects several critical soil functions and is strongly affected by management practices (Obalum *et al*., 2011). Enhancing SOC content can improve a soil's capacity for productivity, nutrient cycling, filtering and buffering of pollutants and portioning of water. The SOC can also improve a soil's resistance to compaction and erosion. Assessment of the quality of organic amendments and their influence on SOC and nutrient release dynamics in low-fertility soils is, therefore, very essential. Consequently, this research investigated the mineralization rate constants and half-lives of cattle dung (CD) and swine waste (SW) at various combinations and their effects on carbon-nitrogen status of a coarse-textured Ultisol and maize yield in southeastern Nigeria. The maize (*Zea mays* L.) variety used was cv Oba Super II and was planted two seeds per hill. Planting was repeated the next season to evaluate the residual effect of the organic amendments.

MATERIALS AND METHODS

Site Description

The study was conducted at the Teaching and Research Farm of the Department of Soil Science, University of Nigeria, Nsukka in Enugu State (Latitude 06^0 52′N and Longitude 07^0 24′E). It has derived savanna vegetation and characterized by sub-humid tropical climate receiving a mean annual rainfall of about 1600 mm, with mean minimum and maximum temperature of 21 and 31 ^{0}C, respectively. The geologic formations of the soil are sandy deposits of false-bedded sandstones (Nwadialor, 1989), hence the soils are coarse textured, porous, deep, well-drained and red to reddish brown in colour. The predominant clay minerals are kaolinites (Akamigbo and Igwe, 1990). They are classified as Ferric Acrisols according to IUSS Working Group of FAO (2006) or as Typic Paleustults (Nwadialor, 1989).

Field Experiment and Treatments

The experiment comprised 16 treatments of various combinations of CD and SW as soil amendments replicated in three blocks. Cattle dung at four levels; 0, 10, 20 and 40 t ha^{-1} were the main plot treatments while swine wastes at the same levels were the sub-plot treatments in a split-plot. These application rates of the organic amendments corresponded amounted to 0, 18, 36 and 72 kg CD per main plot and 0, 3, 6 and 12 kg SW per subplot. At the onset of the experiment before applying the organic materials, soil samples were collected at eight points from the total area and bulked into one to obtain a composite sample. The field was manually cleared, ploughed and ridged. Then, the main-plots and subplots were demarcated. Main plot treatments (CD) were randomized first followed by randomization of subplot treatments (SW) within each main plot. Organic manures were incorporated into the soil two weeks before planting.

Assessment of Maize Yield and Soil Sampling

Maize grain and stover were harvested, air-dried and weighed. Soil samples were collected from subplots immediately after amendment and after harvest.

Laboratory Analysis

The soil samples were air-dried and passed through 2-mm sieve before physicochemical analysis. The composite soil sample was analyzed for particle size distribution as well as for soil organic carbon (SOC) and soil total nitrogen (STN) while the soil samples collected from the treatment plots after maize harvest were analyzed for SOC and STN. The SOC was determined by the Walkley and Black wet oxidation method (Nelson and Sommers, 1982). Determination of STN was by the Kjeldahl digestion procedure (Bremner and Mulvaney, 1982). Also, the organic amendments (CD and SW) were analyzed for their C and N contents.

Mineralization Rate Constants and Half-life

Mineralization rate constant was calculated after determining the residual organic carbon in the soil due to the organic amendments. Mineralization rate was then calculated using the equation proposed by Gilmour *et al.* (1977) as follows:

$$K = \{(2.303/ (t2 - t1)\} \log (C1/ C2) \text{ --------- } (1)$$

where K is organic carbon mineralization rate constant per day, C1 is amount of organic carbon in the soil (g) at beginning of the experiment (t1), and C2 is residual amount of organic carbon at the end of the study (t2), with t1 and t2 expressed in days.

Half-life (T_{50}) of the organic wastes was determined using the equation:

$$T_{50} = \frac{(In\ (0.50))}{K} = \frac{0.693}{K} \text{ --------------------- } (2)$$

where T_{50} is half-life, i.e., the time it took for 50% of the amendments to mineralize (days), and K is organic carbon mineralization rate constant.

Data Analysis

The effects of the treatments were tested for significant differences using analysis of variance (ANOVA) procedure appropriate for a split-plot experiment in randomized complete block design (Steel and Torrie, 1981) and, thereafter, Fischer's least significant difference (F-LSD) used to differentiate significant means. The main plot and sub-plot treatment effects as well as the interaction were clearly shown. Furthermore, the contribution of C and N of the organic amendments to SOC, STN and maize yield for the two planting seasons were determined using regression analysis.

RESULTS AND DISCUSSION

Soil Properties

Data on texture and SOC and STN of the soil of the study area are shown on Table 1. The textural class is sandy loam. It had medium SOC, low STN and average C:N ratio (12:1) (Landon, 1991). Ultisols of southeastern Nigeria are known for their low nutrient status (Asadu and Ugwu, 1997).

Characterization of Cattle Dung and Swine Waste

Table 2 shows the properties of the organic soil amendments of this study. Organic C content of CD was higher than that of SW whereas total N content of SW was higher than that of CD. The C:N ratio for CD was 5:1 while SW was 3:1 showing that decomposition rate of SW would be higher than CD. Waste material derived from beef and dairy animals contains a large fraction of fibrous material because of the type of ration (such as roughages) fed to these animals (Reddy *et al*., 1980).

Effect of C and N Content on Mineralization Rate Constant and Half-Life

Mineralization rate constants and half-life of the organic materials are shown in Table 3. Comparing single applications of the organic materials, SW had higher mineralization rate constants and consequently lower half-life than CD. Notably, SW at 10 t ha^{-1} had half of its content decomposed in 198 days while at 40 t ha^{-1} it took 109 days for half of its content to be mineralized; at 10 t ha^{-1}, CD took longer time to decompose (347 days!). The CD had larger content of carbon and thus higher C:N ratio than SW. Therefore, the higher decomposition rate of SW compared to CD was probably because large amounts of added carbon tend to lower the biodegradation process (Alexander and Scow, 1989). Higher rates of the amendment with higher C inputs resulted in lower mineralization rate. A mixture of SW and CD affected the mineralization rate. In amendments with equal amounts of CD and SW (CD1SW1, CD2SW2, CD3SW3), the mineralization rate constants were stable (0.005); but the more the SW, the lower the constant. For example, CD1SW1 had value of 0.005 and CD1SW2 had 0.003.

Treatment Effects on Soil Organic C and Total N

The contents of C and N added to the soil at the start of the experiment according to the different rates of the organic amendments are shown in Fig. 1. Addition of organic materials increased soil C and N in all the plots over the control. The initial SOC and STN contents in the soil were 24 and 2.08 t ha^{-1}, respectively. It is known that organic carbon addition increases SOC and soil nutrients.

Tables 4 and 5 show the main effect and interaction of the amendments on SOC and STN. The effect of the treatments on SOC and STN after the first cropping varied among the treatments.

Table 1: Physico-chemical properties of the soil

Parameter	Value
Clay (g/kg)	180
Silt (g/kg)	70
Sand (g/kg)	750
Textural Class	Sandy loam
Organic C (g/kg)	12
Total N (g/kg)	1.04
C:N ratio	1.2

Table 2: Organic C and N contents of cattle dung and swine waste

Parameters	Cattle dung	Swine waste
Organic C (g/kg)	78.6	68.4
Total N (g/kg)	14.6	19.2
C: N ratio	5:1	3:1

Table 3: Mineralization rate constant and half life

Treatment	Minera. rate constant	Half-life (days)
CD_0SW_0	0.005	154
CD_0SW_1	0.004	198
CD_0SW_2	0.005	144
CD_0SW_3	0.006	108
CD_1SW_0	0.002	347
CD_1SW_1	0.005	139
CD_1SW_2	0.003	217
CD_1SW_3	0.004	173
CD_2SW_0	0.004	193
CD_2SW_1	0.004	158
CD_2SW_2	0.005	139
CD_2SW_3	0.004	193
CD_3SW_0	0.003	239
CD_3SW_1	0.007	98
CD_3SW_2	0.008	92
CD_3SW_3	0.004	161

Higher rates of sole SW had significantly higher SOC and STN than the control after the first cultivation and higher SOC after the second season. For example, in the first year SW2 had SOC value of 17.8 g kg^{-1} and SW3 had 18.6 g kg^{-1} over control with a value of 16.8 g kg^{-1}. Sole CD was significantly higher than the control for SOC in both years but there was no significant difference for STN. This was because CD had very low N so what it added to the soil could not affect STN. Bationo *et al.* (2003) stated that organic carbon stabilizes about 98% of soil nitrogen. Thus, STN in the soil and the amount released for plant uptake depends on N content of organic amendment. The difference in decomposition rate of the amendments and maize uptake of N would therefore explain the differences in SOC and STN. Reddy *et al*. (1980) stated that the decomposition of animal wastes depends on the rate of degradation of C species. There was also significant interaction of the organic amendments on SOC and STN only during the first year with higher rates having higher values.

Table 4: Soil organic C (SOC, g/kg) and total N (STN, g/kg) after first and second planting

Treatments	After 1st planting		After 2nd planting	
	SOC	STN	SOC	STN
Control	16.8	1.51	14.3	1.2
SW_1	16.6	1.47	13.0	1.1
SW_2	17.8	1.54	13.5	1.2
SW_3	18.6	1.63	15.2	1.2
$LSD_{(0.05)}$	0.1	0.01	0.04	NS
CD_0	15.5	1.46	13.0	1.1
CD_1	17.8	1.55	14.0	1.2
CD_2	18.2	1.58	14.3	1.1
CD_3	18.3	1.54	14.6	1.3
$LSD_{(0.05)}$	0.14^{xx}	NS	0.08^{xx}	NS

CD - cattle dung; SW - swine waste

Contributions of C and N in the Organic Amendments to Changes in SOC and STN

Table 6 shows the regressions with C and N in the organic amendments as independent variables and SOC and STN as dependent variables. The C contributed highly significantly (45%) to changes in SOC after first cropping and significantly (28%) after the second cropping, while N contributed highly significantly (40%) to changes in STN after first cropping but made no significant contribution in the second cropping.

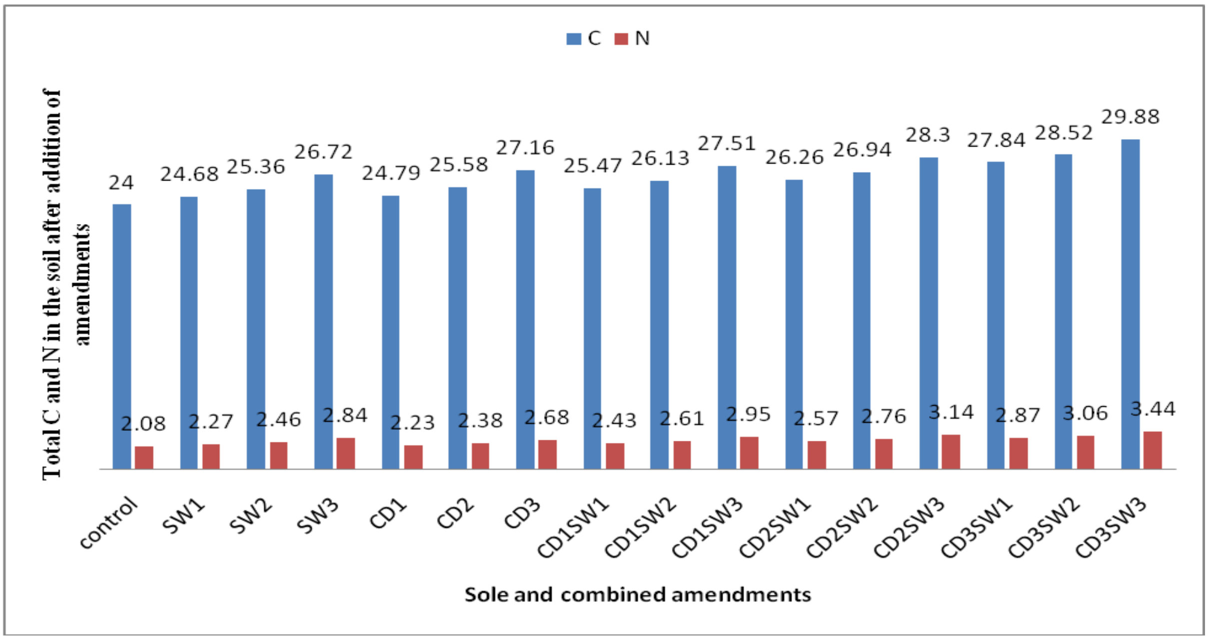

Fig 1: The organic C and nutrient N in the soil after addition of the organic amendment

Table 5: Interaction effect of the amendments on soil organic carbon (OC) and soil total nitrogen (STN)

Treatments	Soil properties				Treatments	Soil properties			
	First year		Second year			First year		Second year	
	SOC (g/kg)	STN (g/kg)	SOC (g/kg)	STN (g/kg)		SOC (g/kg)	STN (g/kg)	SOC (g/kg)	STN (g/kg)
CD_0 SW_0	13.1	1.44	13.6	1.1	CD_2 SW_0	18.8	1.65	13.6	1.1
CD_0 SW_1	13.7	1.32	12.8	1.1	CD_2 SW_1	16.4	1.43	13.6	1.1
CD_0 SW_2	16.4	1.43	12.8	1.1	CD_2 SW_2	18.7	1.58	13.6	1.1
CD_0 SW_3	18.8	1.64	12.8	1.1	CD_2 SW_3	18.8	1.64	16.4	1.1
CD_1 SW_0	16.7	1.43	13.6	1.1	CD_3 SW_0	18.7	1.52	16.4	1.4
CD_1 SW_1	18.4	1.61	12.8	1.1	CD_3 SW_1	17.7	1.52	12.8	1.1
CD_1 SW_2	18.0	1.58	14.6	1.4	CD_3 SW_2	18.0	1.58	12.8	1.1
CD_1 SW_3	18.1	1.58	15.0	1.1	CD_3 SW_3	18.8	1.64	16.4	1.4
$LSD_{(0.05)}$	0.02	0.07	NS	NS	$LSD_{(0.05)}$	0.02	0.07	NS	NS

Table 6: Regression equations relating C and N in the organic amendments to soil organic carbon (SOC) and soil total nitrogen (STN) measured at maize harvest

Independent Variables	Regressions	
	2001	2002
Organic C	$SOC = 1.55 + 0.000076OC; R^2 = 0.45^{**}$	$SOC = 1.28 + 0.000046OC; R^2 = 0.28^{*}$
Total N	$STN = 0.14 + 0.000017N; R^2 = 0.40^{**}$	NS

*significant at 5% probability level; **highly significant at 1% probability level

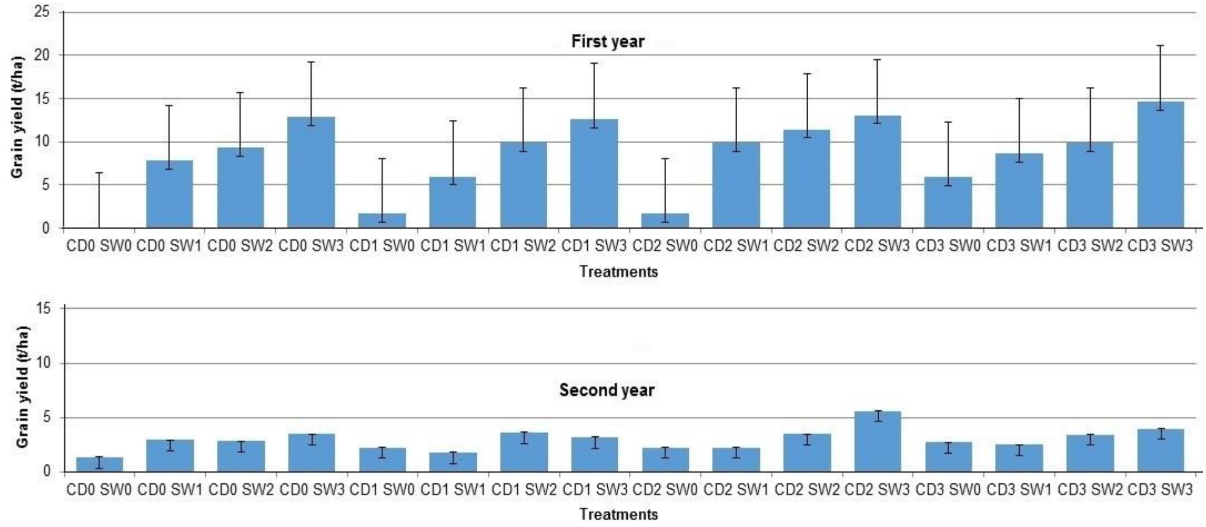

Fig. 2: Effect of treatments on maize grain yield

Table 7: Regression equations relating maize grain yield to soil organic C and total N (n = 16)

Independent Variables	Regressions 2001	Regressions 2002
Step 1 STN (t ha^{-1})	Grain yield = 2.56 + 0.0099STN R^2 = 0.69**	Grain yield = 1.75 + 0.0020 STN R^2 = 0.56**
Step 2 STN and SOC (t ha^{-1})	Grain yield = 2.81- 0.0059SOC+0.035STN R^2 = 0.85**	

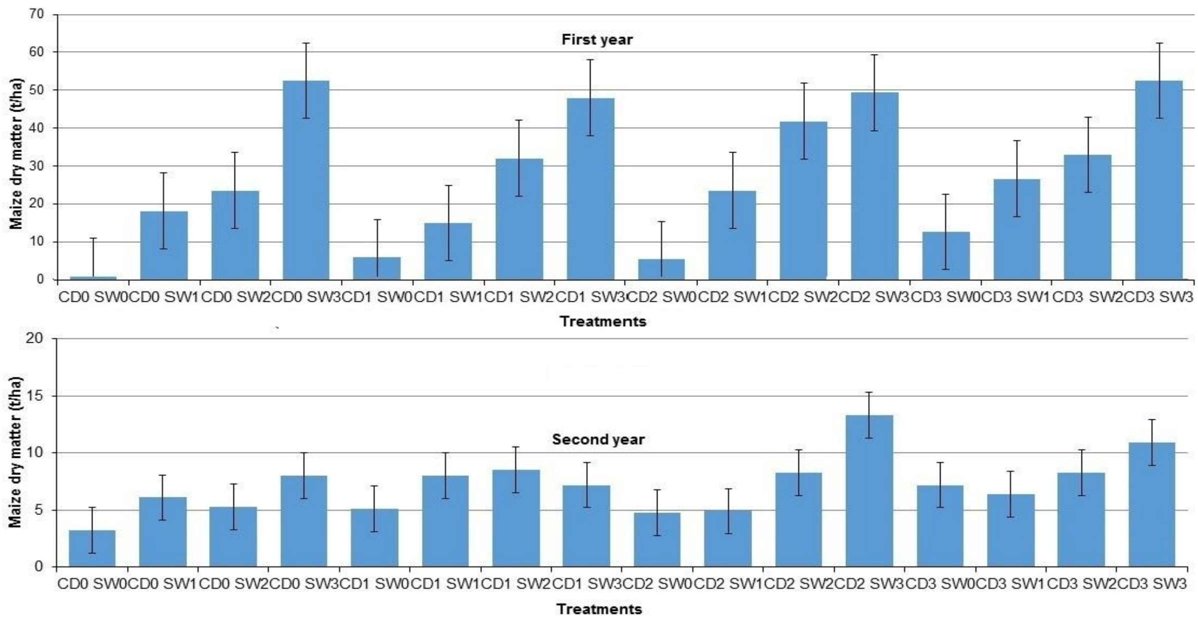

Fig. 3: Effect of treatments on maize dry matter

Productivity of the Soil as Assessed by Maize yield

Considering the single applications of the amendments, CD0SW3 had significantly highest grain yield, and CD3SW0 was lower than CD0SW1 (Fig. 2). There was significant interaction with CD3SW3 having the highest grain yield. Between the two amendments, SW was superior to CD in enhancing maize yield. This is attributed to both the differences in decomposition rates and N contents of the amendments. Swine waste increased maize grain yield highly significantly over the control and over CD, with same rates s of CD and SW differing from each other. Maize yield was directly influenced by N level in the organic materials, thus contributing 68% increase in maize yield while both N and C contributed 85% changes in grain yield after the first year cultivation (Table 7). In the second year, only N contributed 56% changes in grain yield with SOC being insignificant. Effect of the treatments on dry matter yield is also shown (Fig. 3).

CONCLUSIONS

Carbon (C) and Nitrogen (N) contents of organic materials can be used to assess their quality as organic amendments and their influence on soil productivity. This research has shown that the quantity of C and N contained in cattle dung and swine waste determined their mineralization rates as well as soil organic carbon (SOC), total nitrogen (STN), and maize grain yield. The higher the content of N in the amendments, the higher the rate of decomposition but high C content led to low rate of decomposition when the materials were added to the soil. Carbon in the organic amendments contributed 45% changes in SOC and 40% changes on STN during first cultivation. Maize grain yield during the first planting was also determined by SOC and STN. The STN contributed 69% of the variations in grain yield while both SOC and STN contributed 85% of such effects. In the second year, only STN significantly influenced grain yield of maize (R^2 = 0.56). Recommendations from this research are that swine waste should be applied for immediate nutrient need of crops whereas cattle dung should be applied earlier before crops are planted for their future nutrient need.

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