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Full Length Research Paper

Tillage and manure effect on soil physical and chemical properties and on carbon and nitrogen mineralization potentials

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The objective of this work was to study the effects of tillage and liquid manure applications on some physical and chemical properties and also on the carbon and nitrogen mineralization potential from a meadow soil. Our results indicated that tillage and manure applications had no effect on the concentration of Cu, Mn, total N and organic C in the 0 - 15 cm layer of soil after 15 years of treatment. However soil P, Ca, Mg and Zn contents increased significantly with manure applications. Soil organic matter and total N significantly decreased in the 15 – 30 cm depth. No significant change could be detected in soil structural stability in both layers. Moreover, tillage affected significantly soil soluble C and the C/N ratio. Application of 100 t ha^{-1} manure significantly increased soil soluble C. The results of this study suggest that tillage increased significantly the soil N mineralization rate. The potentially mineralizable nitrogen (N_0) was higher in tilled than in no-tilled soil and was at its maximum in the 0 – 15 cm layer of the soil. Furthermore, a significant positive interaction was observed between tillage and manure application on N mineralized after 1.4 wk (N_e). No significant change was detected in both C mineralization rate (C_m) and potentially mineralizable C (C_0). The total amounts of mineralizable carbon (C_m) and nitrogen (N_m) significantly decreased in 15 – 30 cm depth and were very closely correlated with the total amounts of C or N and mineralization rate constants (K).

Key words: Carbon and nitrogen mineralization potentials, k constants, physical and chemical properties.

INTRODUCTION

Soil biological properties play an important role in the transformation and the cycling of plant nutrients, especially carbon and nitrogen. In general, soil organic matter is the main source of N by means of microbial mineralization. Tracy et al. (1990) found for winter wheat that no-tilled soils accumulated greater NO_3-N, NH_4-N, PO_4-P at the 0 - 2.5 cm soil depth, than did recently plowed soil. Below the 5 cm depth, tillage did not influence net N, P and S mineralization.There were higher CO_2-C evolution rates early of the incubation in soil from no-till, compared with those measured after plowing treatments, but at the end of the incubation period all treatments were releasing similar amounts of CO_2-C (Tracy et al., 1990). El-Haris et al. (1983) determined nitrogen mineralization potential (N_0) in a soil from a long-term crop rotation tillage experiment and found that the average N_0 was unaffected by tillage or crop rotation in the 0 – 15 cm depth when sampling was performed in the fall. In the spring sampling, average N_0 for either chisel plowing or no-till was significantly higher than for moldboard plowing. Moldboard tillage also resulted in significantly lower organic C and a narrower C/N ratio in the top 15 cm relative to the no-tilled treatment (El-Haris et al., 1983). Bennett et al. (1975)

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also found that N_0 in the surface 15 cm layer was higher for the no-tilled than for conventially tilled corn (*Zea mays*) plots. Carter and Rennie (1982) reported that potential net mineralizable C and N were significantly greater in surface soil under zero tillage in comparison to conventional tillage.

Animal manure supplies additional mineralizable C and N that directly stimulated microbial activity and growth (McGill et al., 1986). Manure improved soil fertility by increasing the labile organic N constituent such as the amino compounds. This was reflected by a higher N-supplying power in manured soils (Campbell et al., 1986). The rate of net mineralization of N depends on manure composition and on soil physical, chemical and biological properties. If animal manure is applied regularly in large quantities over a long period of time, it increases the soil organic matter content, soil porosity, mineralizable N, Na-HCO_3-extractable-P, microbial activity and reduce the bulk density (Spratt and McCurdy, 1966; Sweeten and Mathers, 1985; Sommerfeldt and Chang, 1985).

N_0 values can be calculated based on the hypothesis that the rate of N mineralization is proportional to the quantity of N comprising the mineralizable substrate (Stanford and Smith, 1972). However, N_0 is affected by many factors such as moisture, aeration, temperature, nature and quantity of organic matter, nature and quantity of the previous crop residues as well as by, other soil physical, chemical and biotic properties (Simard and N'dayegamiye, 1993; Ellert and Bettany, 1992).

Tillage and manure application influence soil moisture, soil temperature, pH, soil organic matter (OM) distribution and soil physical, chemical and biological properties and thus their rates (K_n, K_c) and potentials of C and N mineralization (Flowers and Arnold, 1983; Doran, 1980a, 1980b; N'dayegamiye and Coté, 1989).

The objective of this study was to determine the influence of tillage and liquid manure application on some soil physical and chemical properties and on C and N mineralization potential in a meadow soil.

MATERIALS AND METHODS

Soil sampling

This study was conducted on a silt-loam at the MAPAQ experimental farm in St. Lambert, Quebec, Canada. Treatments were in a split-plot design consisting of no-till and tillage as main treatments and three liquid manure rates (0, 50, 100 t ha^{-1}) as secondary treatments. Since 1978, some plots have never been plowed down (no-tilled treatments) whereas in the tilled treatment, soil was plowed in the fall every 5 years. Liquid manure was applied in the spring of each year. Soil sampling for this study was performed in June 1994 and in July 1995. Soil samples were taken from 0 – 15 cm and 15 – 30 cm depths. The moist soil samples were sieved (> 6 mm) to remove roots and stubble in the field and were kept at 4°C until performing both physical and microbial activity analyses. For chemical analysis, sub-samples were air-dried and screened at 2 mm and 250 µm.

Physical analysis

Distribution of aggregate size was carried on samples sieved at 6 mm. Structural stability measurements were determined by wet sieving (> 2 mm; > 1 mm ; > 0.5 and 0.25 mm) on moist soil as described by Angers and Mehuys (1993).

Chemical analysis

Soil pH was measured in a soil : water ratio of 1:2. The organic C content was determined by wet oxidation procedure (Walkley and Black, 1934). Total N was estimated by Kjeldahl digestion (Nelson and Sommers, 1982). Macro-and micronutrients were extracted using the Mehlich-III solution (Mehlich, 1984). Soil water-soluble C was assessed as previously described by Dormaar et al. (1984).

Nitrogen and carbon mineralization measurements (Incubation Studies)

Field-moist samples (400 g), were incubated for 270 days in 4-L cylinders to insure optimum aeration and microbial activity (Stanford and Smith, 1972). Carbon dioxide evolution was trapped in 1 N NaOH (5 mL) solution and the excess of NaOH was titrated with HCL 1 M (5 mL) (Anderson, 1982). For N mineralization analysis, the soil samples were leached as described by Stanford and Smith (1972), with 100 mL of 0.01 M $CaCl_2$ followed by 25 mL of N-free nutrient solution (0.002 M $CaSO_4.2H_2O$; 0.002 M $MgSO_4$; 0.005 M $Ca(H_2PO_4)_2.H_2O$ and 0.0025 M K_2SO_4). Nitrogen-N was determined colorimetrically on a Technicon Autoanalyzer.

Data analysis

Analysis of variance for determining the effects of both tillage and manure upon soil biological, physical and chemical characteristics, was determined by SAS general linear model procedure (SAS Institute, 1990). The multiple comparison test was carried out with protected Fisher's least significant difference (LSD). Linear correlations were calculated between physical and chemical characteristics and between C and N mineralization parameters. The soil carbon and nitrogen mineralization potentials (C_0 and N_0) were determined by the cumulative model of Ellert and Bettany (1988), $I_{ct} = M_0 (1-e^{-kt})$ where I_{ct} is the cumulative amount of C and N mineralized (mg kg^{-1}) after time t (in wk) and M_0 is the potentially mineralizable C or N and k is the first order rate constant ($week^{-1}$).

RESULTS

Soil physical properties

Tillage and manure application did not have any significant effect on soil aggregates distribution. The observed soil structural stability determined by mean weight diameter (MWD) was generally low for this type of soil and was not influenced by tillage or manure application.

Table 1. Analysis of variance the effect of tillage and liquid manure on somechemical properties of a meadow soil.

Treatment	pH (H_2O)	P	K	Ca	Mg	Cu	Mn	Zn
Tillage (T)	0.62	4.45**	9.7**	2.64	2.98	4.75	3.65	39.2**
Manure (M)	6.65**	27.3**	0.75	5.66*	5.61*	1.64	1.25	31.6**
Depth (D)	0.08	6.46*	1.59	24.4**	1.08	9.43	0.11	87.9**
T X M	0.41	4.18*	0.98	2.5	1.62	1.96	1.64	23.1**
T X D	0.06	6.13*	0.09	0.0	0.06	4.33	0.13	21.7**
D X M	0.32	5.81**	1.89	1.72	1	1.81	0.95	26.3**
T X M X D	0.58	5.42*	0.14	0.39	1.01	0.68	0.95	16.4*

**, * Significant at $p \leq 0.01$ and $p \leq 0.05$.

Table 2. Analysis of variance effect of tillage and manure on carbon and nitrogen mineralization parameters and on some chemical characteristics of a meadow soil.

Treatment	C	N	C_s	C/N	OM/C_s	N_m	C_m	C_e	N_e
Tillage (T)	3.39	1.02	14.68**	13.4 **	0.00	13.9 **	0.93	2.8	0.11
Manure (M)	2.84	0.19	34.99**	1.36	3.54	1.47	1.64	3.18	1.8
Depth (D)	44.23**	86**	0.65	47.7**	6.43*	28.2**	8.35**	7.38*	18.92**
T X M	0.92	0.38	17.16**	3.5	3.82*	0.99	1.27	1.71	5.56*
T X D	0.01	0.37	5.69*	0.00	0.62	2.68	0.44	2.09	0.09
M X D	3.77*	2.22	0.61	1.56	0.06	1.59	0.66	0.24	0.98
T X M X D	0.26	1.13	6.68**	3.29	0.18	0.75	0.58	1.13	0.97

*, ** Significant at $p < 0.01$ and $p < 0.05$, respectively.
N_m, total amount of N mineralized and N_e, N mineralized over 10 days.
Cm, total amount of C mineralized and C_e, C mineralized over 10 days.
OM, organic matter; C_s, soluble carbon.

Soil chemical properties

Some chemical properties of the soil samples from the different tillage and liquid manure treatments are presented in Table 1. Liquid manure application increased significantly soil P, Ca, Mg and Zn levels. In the absence of manure application tillage significantly reduced surface soil (0 - 15) P content. However surface manured plowed soils had a P levels much higher than those observed in no-tilled soils. At the 15 – 30 cm depth, tillage did not affect soil P content. In both tilled and no-tilled soils the addition of 50 t ha^{-1} liquid manure slightly increased soil pH.

Soil C and N levels and C and N mineralization

Results on the influence of both tillage and liquid manure upon soil C and N levels and mineralizable C and N and the statistical analyses of these parameters are presented in Table 2. Contents of organic carbon are maximum in the upper layer (0 – 15 cm) of the no-tilled treatment that did not received manure application and the upper layer of the tillage treatment with 100 t ha^{-1} manure application. The soil N contents significantly decreased in 15 – 30 cm depth. No statistical effect of tillage and manure appli-cation was observed for soil C and N contents. Without manure application, tillage slightly increased soil soluble carbon (C_s). However, soils receiving 100 tha^{-1} liquid manure had the highest content of C_s which was signi-ficantly reduced by tillage. The C mineralized over 10 days (C_e) significantly decreased in 15 – 30 cm depth. Tillage increased significantly the net mineralized nitrogen (N_m) and the N mineralized over 1.4 wk (N_e) significantly decreased in 15 - 30cm depth. Cumulative net minera-lized N and C showed a curvi-linear relationship with time. A significant interaction between tillage and manure was observed on initial mineralized N. Figures 1 and 2 illus-trate the effect of tillage and liquid manure application on the cumulative C and N mineralized in 270 days incubation.

Soil C and N mineralization potentials

Results from on the effect of both tillage and liquid manure on the potentially mineralizable C and N (C_0 and N_0) are shown in Table 2. Tillage and manure treatments did not have any significant effect on C_0 and N_0 or on their mineralization rate constants K_c and K_n.

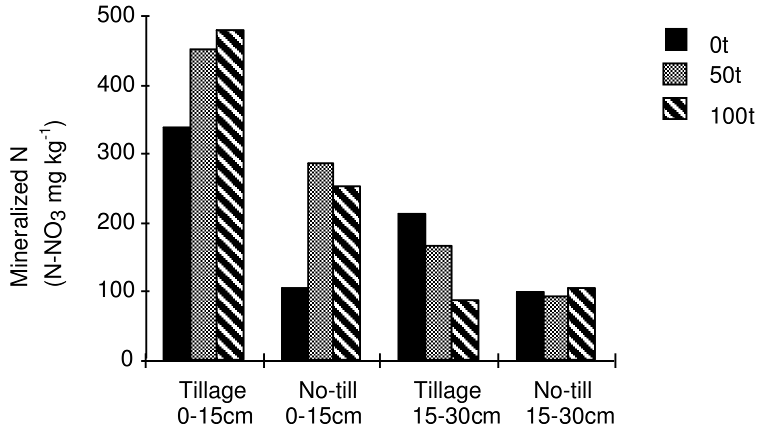

Figure 1. Effect of tillage and liquid manure on cumulative N mineralized over 270 d incubation.

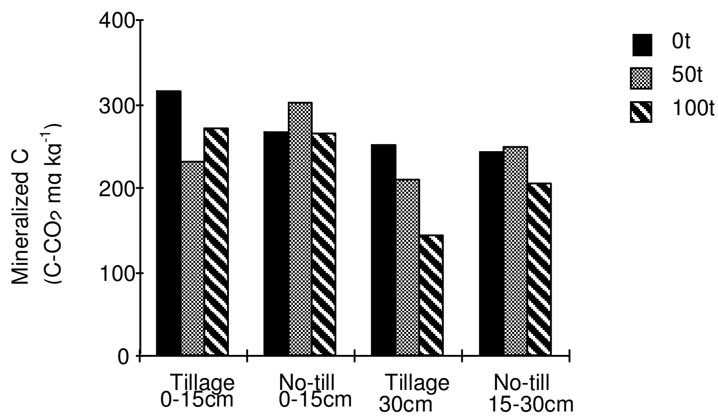

Figure 2. Effect of tillage and liquid manure on cumulative C mineralized over 270 d incubation.

Relations between some chemical properties and C and N mineralization parameters

The pH was negatively related to the rate constant of N related to net mineralized N (N_m; $P \leq 0.05$) and initially mineralized N (N_e; $P \leq 0.01$). Also the soil N content was highly correlated to N_m ($P \leq 0.01$) and N_e ($P \leq 0.01$). The soil structural stability (MWD) was not related to nitrogen mineralization parameters. The soil N content was highly correlated to the total amount of C mineralized (C_m; $P \leq 0.01$). The soluble C is significantly related to potentially mineralizable C (C_0; $P \leq 0.01$). The soil structural stability (MWD) was not related to carbon mineralization parameters.

Relationships between calculated and measured C and N mineralization parameters

The linear correlation between measured and calculated mineralization parameters are given in Table 3. The total amount of N mineralized (N_m) was correlated with rate constant Kn ($P \leq 0.05$) and with the N_e fraction ($P \leq 0.01$). The total amount of C mineralized (C_m) was co-rrelated with C_0 ($P \leq 0.05$) and with the initial mineralizable C (C_e) ($P \leq 0.05$). The C_m was inversely related to the rate constant K_c of the Ellert equation ($P \leq 0.01$). The potential C mineralization (C_0) was also inversely related to K_c ($P \leq 0.05$). The initial mineralizable C (C_e) was closely correlated to K_c of the Ellert equation ($P \leq 0.01$).

DISCUSSION

In this work no difference was observed between soil physical properties measured for a meadow soil following different tilth and manure treatments. Sommerfeldt and Chang (1985) observed that increasing rates of manure on irrigated land tended to decrease the amount of soil aggregates < 1 mm and increase those > 1 mm of soil.

They reported that tillage treatments affected the aggregate size distribution at a depth of 0 – 15 cm. Despite the absence of any statistically significant value for the mean weight diameter (MWD), it was 24 and 15% higher in the no-till soil than in the tilled soil at 0 – 15 cm and 15 – 30 cm depth respectively. Our results corroborate the results of Karlen et al. (1994) who obtained average stability values (MWD) of 46 and 96% for long-term no-till and plow treatments respectively.

Phosphorus is relatively immobile in the soil and so tends to remain near the site of application unless mixed or incorporated to soil. Under zero-tillage (ZT) and conventional tillage (CT) available P was concentrated in the surface 15 cm of soil (Grant and Bailey, 1994). In the meadow soil used in this study, conventional tillage significantly ($P < 0.05$) reduced the level of available P in the surface (0 – 15 cm) layer of the soil that did not receive manure. However as previously reported (Campbell et al., 1986) the available P level increased significantly following manure application.

Manure treatments did not show any effect on soil K. However, it was higher in tilled compared the no-tilled soil. Grant and Bailey (1994) found that the concentration of K was generally higher in the surface soil under zero-tillage, presumably because of the lack of mixing normally attributed to plowing.

Tillage did not have any effect on soil Ca and Mg levels. However as previously observed by N'dayegamiye (1990) the addition of manure significantly increased soil Ca and Mg contents.

Tillage practices did not influence the soil pH as observed by Doran (1987). Our results indicated however that there was significant effect of manure application on soil pH. The application of 50 t ha^{-1} of manure increased the soil pH values as observed by Antoun et al. (1985).

Soil organic C was not affected by the addition of manure and was generally present at higher concentration in the surface soil (0 – 15 cm). In the absence of manure treatment the surface soil under no-tillage contained significantly more carbon than under tillage. This is in agreement with the results of Blevins et al. (1983) who found in the 0 – 5 cm surface layer that organic C and N were approximately twice as high with no-tillage as with conventional tillage. Grant and Lafond (1994) also observed that total carbon content was higher in the surface soil of the zero tillage treatment compared with the conventional tillage system. These results indicate that tillage influences the organic C pools. In no-tilled soil, C accumulation can be attributed to a decrease in the rate of organic matter oxidation resulting from higher soil moisture and lower temperature (Tracy et al., 1990). On the other hand, C loss rate from soil is greatly accelerated by conventional tillage as indicated by Doran (1980a). Richter et al. (1990) observed that annual tillage changed dominant plant species from grasses to annual herbs and consequently altered the distribution of carbon in root biomass. In annually tilled plots, herb-dominated root biomass averaged about 232 g C/m^2 compared with about 753 g C/m^2 in no-tilled plots. As previously observed by N'dayegamiye and Coté (1989), manure application did not affect soil total N content.

Cumulative N mineralization after 270 days (N_m) was higher in plowed treatments than in no-tilled treatments. Our data confirm those of Carter and Rennie (1984) and El-Haris et al. (1983) who found that cumulative N mineralization was higher under conventional than zero tillage system.

We observed that the initial N mineralization (N_e) was higher in the 15 - 30 cm plowed soil (51%) than in no-tilled soil. The observed rates of N_e are in the same range as those obtained from comparable meadow soils from Québec (Simard and N'dayegamiye, 1993).

The cumulative model of Ellert and Bettany (1988) was used to describe the effect of tillage on a meadow soil. Nitrogen mineralization potential (N_0) and N mineralization rate coefficients (K_n) were calculated. The rate constant (K_n) values calculated with this model ranged from 0.0045 to 0.0458 day^{-1}. Nitrogen mineralization potential (N_0) was affected by many factors as soil moisture, aeration, temperature, nature and quantity of organic matter, nature and quantity of the previous crop residues. Other soil physical and biotic properties can influence K_n (Cassman and Munns, 1980; Macdonald et al., 1995; Simard and N'dayegamiye, 1993). Higher K_n values and lower N_0 values in the no-till treatments compared with those cal-culated for the plowed soils suggest that the mineralizable substrate concentration was lower but decomposed more rapidly under no-till condition.

Under no-till, the ratios of organic matter/soluble C (OM/Cs) are in general higher than in plowed soils. This indicated that N_0 and K_n were quite different in the two tillage systems. An inverse relationship between N_0, N_m and K_n values was evident, suggesting that a major part of the microbial biomass is easily mineralizable (Torben and Rosswal, 1987).

We did not observe any effect of manure application on the initial N mineralization (N mineralization over 10 days, N_e) or on the total amount of N mineralized (after 270 days incubation, N_m).

Our results with liquid manure are not comparable to those of Campbell et al. (1986) who observed that mineralizable N increased significantly by the addition of barnyard manure. As observed by Lindemann and Cardenas (1984), the addition of 50 and 100 t ha^{-1} liquid manure increased the total amount of N mineralized respectively by 34 and 41% in the 0 – 15 cm soil. We observed that total amount N mineralization decreased with increasing manure application in 15 – 30 cm depth in plowed treatments.

In this study, K_n values decreased with increasing rates of manure application. Our results are different from the observations of Boyle and Paul (1989), who found that N and C mineralization rates (K_n,K_c) increased with sludge application rate. The average k_n value was slitghly greater for subsoil than surface soil in plowed treatments, as previously calculated by Campbell et al. (1981).

As compared with the value for untreated soil, N_0 values were higher with 50 t ha^{-1} (32.45%) and 100 t ha^{-1} (42.78%) manure application in the surface plowed soil. Also N_0 values increased with 50 and 100 t ha^{-1} manure application in no-till soil at all depths. Our results agree with those of Nídayegamiye and Coté (1989) who also observed that high liquid manure application rates increased N_0.

Tillage also influenced strongly the amount of soluble C. The soluble C (C_s) has been suggested as an index of organic matter decomposition and humification (Hu et al., 1972). In this study, C_s was higher in plowed treatments than in no-till treatments.

Cumulative net mineralized C showed a curvilinear relationship with time. These results suggested that CO_2-C production in all samples decreased during incubation.

It is interesting to note that in the absence of manure application, the C_s values obtained from plowed soils are negatively correlated with the C_m values (r = -1; for C_s, 10.22 and 14.7 mg kg^{-1} and C_m, 314.54 and 249.62 mg kg^{-1}). Under no-till condition C_s values are positively correlated with the C_m values (r =1 for C_s, 8.73 and 7.64 mg kg^{-1} and C_m. 265.55 and 241.91 mg kg^{-1}). This indicated that the index developed by Hu et al. (1972) would apply mainly for forest soils and for soil maintained under no-till conditions. In manured soils calculated r values are not statistically significant but in tilled soils C_s values seem to be positively correlated to the C_m values and the contrary is observed under no-till conditions. More work is required to establish the exact relationship between C_s and C_m values in soils submitted to different tillage and manure applications.

The cumulative model of Ellert and Bettany (1988) was used to describe the effect of tillage on the level of the potential mineralizable C (C_0) and to calculate the first order rate constant for mineralizable C (k_c). Tillage showed no significant effect on C mineralization potential (C_0). The K_c values were higher in no-till soil than plowed soil in 0 - 15 cm depth but were higher in plowed soil than in no-till soil in 15 – 30 cm depth. Higher K_c values were obtained by Franzluebbers et al. (1995) in wheat and soybean crops under conventional tillage (0.33 day^{-1}) and no-tillage (0.34 day^{-1}).

Results suggested that there was no effect of tillage on total mineralized C (C_m), however depth significantly affected C_m values. In fact, under both tillage and zero-tillage systems, greater C_m were observed in surface (0 – 15 cm) soils compared with deeper soil (15 – 30 cm). Carter and Rennie (1982) also observed that potential net mineralizable C and N were significantly greater in surface soil under zero-tillage in comparison to conventionnal tillage. But the reverse situation was observed at the lower depth.

Easily mineralizable C (mineralizable C after 10 days of incubation, C_e) was 51.61% higher in no-till soil than in plowed treatments in 0 - 15 cm. However, C_e was 70.61% higher in plowed treatments than in no-till soil in 15 - 30 cm depth. These results reflected the different availability of easily decomposable substrates between no-till and plowed soils. These results were similar to those of Franzluebbers et al. (1994 and 1995) who observed that carbon mineralization was higher in conventional tillage for the 0 – 20 cm depth those in no-till soil.

Conclusion

The results of this study showed significant effect of tillage on soil P, K, Zn, soil C/N, soluble C and cumulative N mineralized. Also cumulative N mineralization was significantly affected by tillage and very closely related to levels of soil chemical properties. There were large differences in N mineralization potentials (N_0) in plowed treatments and no-till treatments. Differences in rate constant (K_n) increased in no-till soil as compared to plowed soil. Results obtained in our study indicated that C mineralized (C_m) and C mineralization potential (C_0) were not affected by tillage. The data showed that soil structural stability was not affected by tillage and manure application.

Generally, there were significant effect of liquid manure on soil pH, P, Ca, Mg, Zn and soluble C. The data showed that cumulative N mineralization (N_m) and N mineralization potentials (N_0) were greater at 0 - 15 cm depth in soils receiving manure. However, cumulative N mineralized decreased with increasing manure rates within 15 - 30 cm depth. The K_n and K_c values decreased with manure application. Potentially mineralizable C and N (C_0, N_0) were higher in the surface (0 – 15 cm) than in the deeper (15 – 30 cm) layers.

These results indicated that tillage and liquid manure application have significantly influenced N and C mineralization parameters and some soil chemical properties. The results indicated the presence of close relationships between N and C mineralization parameters and some soil chemical properties and suggested that tillage and manure application influence to some extent the soil characteristices. Furthermore, both tillage and manure influence soil organic matter dynamics and quality

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