

ANIMAL MANURES MINERALIZATION AND PLANT NITROGEN UPTAKE IN AN ULTISOL IN ABAKALIKI SOUTHEAST NIGERIA.

Okonkwo, C. I.¹, J.N.Nwite¹, C. onyibe¹, I.A.Nweke² and C.N.Mbah¹

¹DEPARTMENT OF SOIL SCIENCE AND ENVIRONMENTAL MANAGEMENT
EBONYI STATE UNIVERSITY, ABAKALIKI.

²DEPARTMENT OF SOIL SCIENCE, ANAMBRA STATE UNIVERSITY,ULI.

Corresponding Authors Email;cnmbah10@yahoo.com

Accepted 16th July 2011.

Effective use of animal manures in agricultural production systems requires information on the net impact of animal manures on soil N mineralization or immobilization. The processes of Nitrogen(N)-mineralization, N-nitrification and N-immobilization including CO₂ evolution were studied using different types of animal manures as soil amendment. The objectives of this study were to measure the cumulative N-mineralization, nitrification, immobilization and evaluate how these transformations affect N uptake. High N-mineralization and N-nitrification were observed in 2009. The pattern of N-mineralization and immobilization were Poultry dropping(PD)>Sewage sludge(SS)>Goat dropping(GD)>Cow dung(CD)> control(C). N-nitrification declined in 2009 relative to both N-mineralization and N-immobilization. However, in 2008 and 2009, there was a surge in N-nitrification. Results show relationship between N-mineralization, N-nitrification and the N content of ear leaves. The high N content of ear leaves of maize suggests that the animal manures used in this study could supply enough N to crops. The quantity of CO₂ evolved was significantly greater in the CD + soil relative to the other treatments. A stage of intense CO₂ evolution was observed between 1-3 weeks of study, but declined as from the 6th week.

Key words: nitrification, immobilization, amendment, organic matter.

INTRODUCTION

Inputs from animal manure N have remained approximately stable, but management strategies to increase their fertilizer value have not been fully exploited. The amount of fertilizer N potentially replaceable by manure N in the year of application has been shown to correspond to the amount of ammonical N in slurry (Petersen, 1996). However, some manure N will remain in the soil (Jensen *et al.*, 2000; Sorensen and Amato, 2002), and therefore long-term annual inputs of organic manures cause an accumulation of soil organic matter (SOM)-N (Sommerfield, 1988; Chang *et al.*, 1991; Thomson and Christensen, 2004). Similarly, long-term annual incorporation organic manure results in an accumulation of SOM-N, partly from N in the organic manures and partly due to organic manure-induced N immobilization. This residual N is gradually mineralized. Thus annual inputs of organic manure could potentially cause soil mineralization to increase (Chang, *et al.*, 1991; Whalen *et al.*, 2001; Luxhoi *et al.*, 2004). In-field N mineralization rate is dependent on many factors, including the climatic conditions. However, it has been observed that application of organic manures may lead to the immobilization of soil mineral N (Dugan 1973; Beloso *et al.*, 1993) and can cause N deficiencies in plants and depress crop yield (Clark *et al.*, 1995). The addition of organic wastes can increase organic matter (Cortellini *et al.* 1996, Maynard, 1995), cation exchange capacity and soil microbial (Rothwell and Hortensic,

1969) and enzymatic activities (Serra-Wittling *et al.*, 1996) in the soil.

To maximise the utilization of manure N, it is therefore important to take into account the fate of the residual N from these sources in the years after application. The effective use of animal manures in agricultural production systems requires information on the net impact of animal manures on soil N mineralization or immobilization. We need to manage animal manure amendments to provide sufficient N to meet crop demands while preventing the leaching of excess NO₃-N.

The objectives of this study therefore was to measure the cumulative N-mineralization, N-nitrification and N-immobilization processes as affected by the application of the different animal manures, evaluate how these transformation processes affect plant uptake of N and determine the effects of the different animal manures on soil respiration.

Materials and Methods.

Location;

The study was conducted for three years (2008-2010) at the experimental Farm of the Ebonyi State University, Abakaliki (06° 04'N and 18° 65' E) Southeast of Nigeria. Typical of the humid tropics, it has a pseudo-bimodal rainfall pattern from April to November. Total rainfall ranges between 1500-2000 mm, with a mean of 1800 mm. The area is characterised by high temperatures, with mean daily temperature range of 27-31°C.

Field Layout;

The experiment was established in a randomized complete block design replicated four times with five treatments comprising of : 5t ha⁻¹ of cow dung (CD); 5t ha⁻¹ of swine slurry (SS); 5t ha⁻¹ of poultry droppings (PD); 5t ha⁻¹ of goat droppings (GD); Control with no application of animal manure.

All the animal manures were obtained fresh from the experimental farm of the Department of Animal production, of the University and air dried at room temperature. The animal manures were broken into smaller particles to ensure even distribution on the plots. The experimental site was manually cleared and all debris removed. The animal manures were applied uniformly on the surface of each plot measuring 4m x 4m and incorporated into the soil in 2008 and 2009. There was no application of the animal manures in 2010 to test the residual effects of these manures. Maize SWAN-1-Y was planted at 50cm x 50cm inter- and intra-row spacing. At tasseling, ear leaves of 5 tagged maize plants were sampled for the analysis of N-content using procedure described by Reuter and Robinson (1993).

Field Incubation;

Field incubation was carried out by the procedure described by Okonkwo, *et al.*, (2008). Four PVC tubes (5cm in diameter and 30cm in length) were pounded to a depth of 20cm, in each plot in duplicates of three tubes (A,B, and C). Tubes A were removed immediately and returned to the laboratory for the determination of initial N-mineralization, N immobilization, and N-nitrification. The remaining tubes were incubated in the field for 5 weeks. One sets of tubes were covered with aluminium foil to keep out moisture and avoid leaching losses. At 5 weeks, the remaining tubes were removed and taken to the laboratory for the determination of cumulative N-mineralization, N- immobilization, and N-nitrification. The difference between cumulative N-mineralization and N-nitrification was assumed to be the N-immobilization.

Laboratory Analysis;

Initial set of soil cores that were removed immediately after insertion of the PVC tubes, were taken to the University laboratory. The cores were removed, bulked, sieved (8 mm mesh) and mixed to form a composite sample. 20g of portions of the composite soil (dry weight basis) were extracted in 80ml, 1M KCl, for 45 min. in an end-over-end shaker. The extracts were filtered and NH₄⁺-N determined using procedure described by Alves *et al.* (1982) while the NO₃⁻-N was determined using Gines *et al.* (1989) methods.

Cumulative N-Mineralization;

At 5 weeks after insertion, the remaining PVC tubes were removed from the plots and transferred to the laboratory for the determination of cumulative N-mineralization. The soil was sieved (6 mm mesh) and bulked. 100g (on dry weight basis) was added to 200ml of 1M KCl and extracted for 1h in an end-over-end shaker. The

extracts were filtered and NH₄⁺-N and NO₃⁻-N in the soil extracts were determined.

Cumulative N- Nitrification.

10 grams (fresh weight) of sieved soil was put into 250ml conical flasks with 100ml of 0.5M (NH₄)₂ SO₄ in 1mM, K₂HO₄ at pH 7.2. Then 1ml of 1M NaCO₃ was added to prevent NO₂⁻ oxidation (Belsler and Mays, 1980). Then the flasks were kept in a rotatory shaker at 20°C in the dark. Microbial activity was inhibited by the addition 3M KCl. The samples were centrifuged and the supernatant analysed for NO₃⁻-N.

Soil Incubation Study.

In 2008 soil samples were collected from a depth of 0-10 cm, air-dried, and passed through a 2mm sieve. The treatments(animal wastes) were thoroughly incorporated into 100 g of soil in 250-ml Erlenmeyer flasks. The soil-treatment mixtures were adjusted to 10kPa soil moisture potential, as determined by a pressure plate method (Cassel and Klute, 1986), with distilled CO₂-free water or KNO₃ solution made with distilled CO₂-free water (Zibilske, 1994). In 2009, soil samples were taken at the same depth and fresh animal manures added accordingly, while in the 2010 soil samples were taken with no addition of animal manures. The incubation flasks were randomly placed in an incubation chamber and connected to a manifold system supplying continuous aeration with CO₂-free air. The design was similar to that described by Zibilske (1994). Temperature was maintained at constant 20°C. The effluent air stream was bubbled through 60 ml of 1M NaOH solution in 100 ml Erlenmeyer flasks for CO₂ removal. The flasks were removed at predetermined time periods of 0, 1, 2, 4, 6, 8, and 12 wk. Total CO₂-C, collected in the NaOH flasks, was determined by the addition of excess of 1.5 M BaCl, followed by titration with standardized HCl using a phenolphthalein indicator (Zibilske, 1994).

Statistical Analysis.

Analysis of variance was performed on the data obtained on N-mineralization, N-nitrification and N-immobilization using the PROC MIXED procedure in SAS (1985). The CO₂ evolution data were analysed using PROC GLM procedure in SAS(P=0.05).

RESULTS AND DISCUSSION

The results of the initial N-mineralization, nitrification and immobilization are shown in Table 1. Comparatively, there was greater N-mineralization than N-nitrification or N-immobilization. N-nitrification decreased relative to the N-mineralization by 36%, 12%, 18%, 16% and 20% in the control, cow dung (CD), swine slurry (SS), poultry droppings (PD), and goat droppings (GD) respectively. However, initial mineralization indicated higher values where animal manures were applied irrespective of the fact that the PVC tubes were withdrawn immediately after insertion, indicating that mineralization of the animal manures had started. The lowest N-mineralization, nitrification

and immobilization were observed in the control plots. In line with the above observation, Dugan (1973) and Beloso *et al.*, (1993) reported increased N mineralization following addition of animal wastes.

Table 2 shows cumulative N-mineralization, nitrification and immobilization as influenced by the different animal manures at 5 weeks after incubation (WAI). All the processes determined (mineralization, nitrification and immobilization) were positively influenced by the animal manures when compared to the initial values (Table1). Mineralization and immobilization were generally highest in 2008. The highest N-mineralization of 68.83 kg N ha⁻¹, nitrification of 32.19 kg N ha⁻¹ and immobilization of 36.14 kg N ha⁻¹ were obtained in the PD amended plots. In the three years of study, values of these three processes were significantly different (p < 0.05) in the PD amended plots relative to the C, CD and GD treatments. The lowest values of these processes were observed in the control plots. The values in the control decreased with time indicating that SOM-N levels were diminishing. Comparing the values obtained in plots amended with PD and the control, mineralization increased by 90% and immobilization also increased by 96% relative to the control in 2008. However, N-nitrification for the same treatment increased by 80% in 2008 relative to the control. The pattern of N-mineralization and N-immobilization were in the following orders: PD > SS > GD > CD > control in the three cropping seasons. Soil

N- nitrification declined over the growing season in 2008 relative to both N- mineralization and N-immobilization. The increase in cumulative N-mineralization was an indication that the animal manures released substantial amount of mineral N to the soil system with time. However, there were differences in N-mineralization over time. More N-mineralization occurred in 2009, but declined in the residual year(2010). Similar observations were made by Okonkwo, *et al.* (2008) working on N-mineralization from pruning of legumes in alley cropping system. Among the different animal manures applied, PD showed significant difference (p < 0.05) relative to the others at 5WAI. The lowest cumulative N-mineralization occurred in the CD amended plots, ranging from 33.81 kg N ha⁻¹ (2008), 64.07 kg N ha⁻¹ (2009) and 41.61 kg N ha⁻¹ (2010). However, N-mineralization decreased yearly in the control plots. The residual effect of the animal manures on N- mineralization was found to be higher than in 2008. The occurrence of more residual mineralized-N could be attributed to two reasons: first, the addition of animal manures in the second year increased the residual mineralization processes, and secondly, the decomposition rate of the animal manures could result in slow N release. The percentage increase in the residual cumulative N-mineralization relative to the initial values were 58% in CD, 66% for SS, 68% in both PD and GD amended plots. Therefore, the continued amendment of the soil for the period 2008 and 2009 was responsible for the high soil residual N-mineralization.

Table 1. Initial soil N-mineralization, nitrification and immobilization.

	N-mineralization	N-nitrification	N-immobilization
	----- kg ha ⁻¹ -----		
C	6.00	4.84	1.16
CD	11.10	8.77	2.39
SS	14.84	10.21	4.43
PD	17.82	13.06	4.70
GD	13.56	9.18	4.38
LSD (0.05)	1.29	1.04	0.98

C = Control, CD = Cow dung, SS = Swine slurry, PD = poultry droppings, GD = Goat droppings.

Table 2. Cumulative N-mineralization, nitrification and immobilization as affected by animal manures at 5WAI.

	N-mineralization			N-nitrification			N-immobilization		
	----- kg ha ⁻¹ -----								
	2008	2009	2010	2008	2009	2010	2008	2009	2010
C	3.42	2.19	1.44	2.17	1.42	0.79	1.25	0.77	0.65
CD	33.81	64.07	41.61	10.25	44.71	32.82	23.56	19.36	8.76
SS	56.47	82.56	62.14	21.35	66.22	50.56	35.10	16.14	11.58
PD	68.83	114.23	82.52	32.19	84.45	68.11	36.14	29.78	14.41
GD	45.11	72.02	58.78	19.94	61.88	48.64	25.17	12.13	10.14
L	3.48	4.13	3.69	4.06	5.42	4.32	2.04	1.22	1.09

C = Control, CD = cow dung, SS = Swine slurry, PD = Poultry droppings, GD = Goat droppings, L = LSD (0.05).

Soil N-nitrification declined over the growing season in 2008 relative to both N-mineralization and N-immobilization. The low values obtained for N-nitrification could be due to plant uptake and continued immobilization. Again the declines in the quantities of soil $\text{NO}_3\text{-N}$ in the same year despite application of animal manures suggest continued increase in immobilization. There was greater nitrification in the second year. Nitrification increased with increase in mineralization. This was so because ammonification and nitrification were parts of N-mineralization processes and are useful criteria to study decomposition of organic material. Ammonification is the indicator for the release of N bound in organic material. Nitrification (i.e. the oxidation of ammonium to nitrite and nitrate) is carried out by sensitive bacteria. This increase in N-nitrification values was indicative of the pattern in which N-mineralization would proceed. The highest N-nitrification value of $84.45 \text{ kg N ha}^{-1}$ (2009) was obtained in the PD amended plots. In the same year, SS had 66.22 kg ha^{-1} , GD 61.88 kg ha^{-1} , and 44.71 kg ha^{-1} for CD. Nitrification was also found to be high enough in the third year when residual effect was studied. The values obtained in that year were higher than the result in the first year (2008). This could be that the soil immobilization-mineralization equilibrium had shifted and mineralization resulted in increased soil $\text{NO}_3\text{-N}$. The presence of high N-nitrification in the third year could be that enough animal manure was left in the soil to encourage N-mineralization process.

The results of the N-immobilization at the different study periods varied among treatments and the time of study. The N-immobilization values were very low in the third year (2010) relative to results from 2008 and 2009. Among amended plots with animal manures, CD and GD were very low in N-immobilization. The low values obtained from these two treatments (CD and GD) in 2009 and 2010 when compared to the values obtained for both N-mineralization and N-nitrification showed that mineralization and nitrification were favoured in this study more than immobilization. In the three years of study the N-immobilization from the PD amended plots was significantly different ($p < 0.05$) relative to the control, CD, SS and GD amended plots.

Table 3 shows the N content of maize ear leaves at tasseling. There was a relationship between the N content of ear leaves and the cumulative N-mineralization and N-nitrification. In the three years of study, the N content from $67.82 \text{ kg N ha}^{-1}$ in the CD to $158.71 \text{ kg N ha}^{-1}$ in the PD (2008), $92.66 \text{ kg N ha}^{-1}$ to $185.22 \text{ kg N ha}^{-1}$ in both the CD and PD respectively (2009) and $83.20 \text{ kg N ha}^{-1}$ to $167.10 \text{ kg N ha}^{-1}$ for the same treatments respectively (2010). The level of N content in the ear leaves of maize is an indication of the available N for plant nutrition resulting from both

mineralization and nitrification. The highest N content observed in the ear leaves occurred in the second year of study. This is a clear manifestation that with increase in cumulative N-mineralization and N-nitrification, a corresponding increase in the N content of ear leaves occurred. The observed relationship between mineralization, nitrification and N content lied on the level of animal manures in the soil. The relative N content of maize ear leaves in the control plots were by far very low when compared with results obtained from the plots amended with animal manures. Therefore, the high N content observed in the ear leaves of maize showed that the animal manures had the capacity of supplying high N to crops in line with the observations of Thomson and Christensen, (2004).

Table 4 shows the cumulative $\text{CO}_2\text{-C}$ evolution for soil only (control) and soil amended with different animal manures. The application of the different animal manures to the soil stimulated soil microbial activity. Cumulative CO_2 evolution or soil respiration resulted in a significant increase ($p < 0.05$) in $\text{CO}_2\text{-C}$ evolution for animal manure amended soil than the control soil. Higher CO_2 accumulation in the animal manure amended soils reflects higher soil respiration rates than the control. This could be attributed to the high mineralization obtained in the manure amended soil. The quantity of CO_2 evolved and probably the rate of soil respiration was significantly greater in the CD + soil relative to the other animal manures amended treatments ($p < 0.05$) between 1-12 weeks of study.

In the incubation process, three stages were noted; a stage of intense activity at the beginning resulting in higher evolution of CO_2 , caused by the soil + amendment mixtures, corresponding to the use of the easily metabolised C present in the amendments and in the soil. A stage of total reduced activity between the 9-12 weeks, characterised by a drop on CO_2 evolution. A stage in total reduction in CO_2 evolution in the third year of study. The residual effects of the amendments in terms of biological activity leading to CO_2 evolution were very low relative to the first and second year results. This showed that there was a decreased amount of easily degradable organic matter.

The incubation data shows that at 1-3 weeks, the quantity of C mineralised was on the increase, and greater for CD + soil. From the first week onwards, the following sequence emerged: CD + soil > GD + soil > SS + soil > PD + soil > Control soil. The sequence could be explained thus; the increase in the amount of CO_2 produced corresponded with the transformation of easily degradable material, which was more in the CD than for the amendments. The quantity of CO_2 released during mineralization was related to the type and stage of mineralization of the animal manures, indicating that from a certain time onwards the animal manures had a level of stability, which modified soil microbial activity resulting in reduced CO_2 evolution. The results of this study is in line with the observations of Dugan, 1973; Beloso *et al.*, 1993 and Clark *et al.*, 1995).

Table 3. N content of maize ear leaf at tasseling (N kg ha⁻¹)

Treatments	2008	2009	2010
C	26.01	21.27	16.30
CD	67.82	92.66	83.20
SS	120.34	156.82	131.28
PD	158.71	185.22	167.10
GD	108.55	140.81	122.61
LSD (0.05)	12.63	15.12	13.89

C = Control, CD = Cow dung, SS = Swine slurry, PD = Poultry droppings, GD =Goat droppings.

Table 4. Cumulative CO₂ evolved from animal manures within 12 weeks.

Weeks	2008											
	1	2	3	4	5	6	7	8	9	10	11	12
C	30	29	27	26	24	22	17	15	13	10	7	6
CD	147	156	164	150	144	137	130	124	113	99	75	66
SS	119	120	136	118	102	94	76	69	53	44	36	28
PD	105	113	129	99	87	73	64	55	41	38	29	23
GD	127	130	142	121	114	106	94	85	73	69	58	46
L	8.7	8.5	8.2	7.9	7.6	7.5	6.4	5.7	5.2	4.7	3.8	3.4
	2009											
C	36	32	30	27	26	24	22	18	14	12	9	7
CD	186	227	256	224	207	192	185	177	169	151	132	118
SS	138	188	215	194	173	161	155	132	118	96	87	66
PD	126	157	198	177	165	157	141	128	106	89	62	58
GD	142	196	232	208	193	176	164	144	123	104	93	81
L	9.6	11.9	12.8	2.2	10.7	10.5	10.3	9.3	8.5	8.1	5.8	5.3
	2010											
C	27	24	23	20	19	16	14	12	11	8	5	3
CD	98	102	129	105	86	78	64	59	47	33	20	14
SS	82	90	108	79	66	51	44	37	28	15	11	8
PD	77	86	97	73	60	44	32	25	21	13	8	5
GD	88	96	118	88	79	63	55	42	30	21	12	10
L	4.3	4.7	6.3	4.1	3.8	3.5	3.2	3.0	2.7	2.3	2.1	0.9

C = Control, CD = Cow dung, SS = Swine slurry, PD = Poultry droppings, GD =Goat droppings..L= LSD (0.05)

CONCLUSION

The results of this study showed that continuous amendment of soil with animal manures increased cumulative N-mineralization and nitrification, without increasing cumulative N-immobilization. Plant N uptake was positively related to the mineral N generated from mineralization and nitrification processes. Also N from both residual mineralization and nitrification was sufficient to improve N uptake when compared to the control. The mineralization of organic C in the soil + amendment depended on the type of animal manures. The rate of mineralization was more significant in the CD + soil mixture relative to the other animal manures. However, all the animal manures + soil mixture showed

significant differences in CO₂ evolution to the control. Mineralization and nitrification of animal manures results in releasing of available N for plant nutrition .

REFERENCES.

- Alves, B. J. R., R. M. Boddey, S. Urguiaga, 1982. A rapid and sensitive flow injection technique for the analysis of ammonium in soil extracts. *Communication in Soil Science and Plant Analysis*. 23:14-20.
- Beloso, M.C., M.C. Villar, A. Cabaneiro, N.M. Carballas, S.J. Gonzalez-Prieto, and T. Carballas, 1993. Carbon and nitrogen mineralization in an acid soil fertilized with compost urban refuse. *Bioresource Technol.* 45: 123-129.

- Belser, L. W. and E. L. Mays. 1980. Specific inhibition of nitrate oxidation by chlorate and its use in assessing nitrification in soils and sediments. *Applied and Environmental Microbiology*. 39: 505- 510.
- Cassel, D.K. and A. Klute, 1986. Water potential: Tensiometry. p.563-596. In A. Klute (ed.), *Methods of Soil Analysis. Part 1. Physical and Mineralogical methods*. 2nd.ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.
- Chang, C., T.G. Sommerfield and T. Entz. 1991. Soil chemistry after eleven annual applications of cattle feedlot manure. *Journal of Environmental Quality*. 20: 474-480.
- Clark, G.A., C.D. Stanley, and D.N. Maynard, 1995. Municipal solid waste compost in irrigated vegetable production. *Proc. Soil Crop*
- Cortellini, L.G., Toderi, G. Baldoni and A. Nassisi., 1996. Effects on the content of organic matter, nitrogen, phosphorus and heavy metals in soil and plants after application of compost and sewage sludge. p. 457-468. In: M.de Bertoldi et al., (ed.). *The science of compost*. Blackie Academic & Professional, Chapman & Hall, London.
- Duggan, J.C. 1973. Utilization of municipal refuse compost: 1.Field scale compost demonstration. *Compost Sci*. 14: 24-25.
- Gines, M. F., F.H. Bergamin, E. A. G. Zagatto and B. F. Rels, 1989. Simultaneous determination of nitrate and nitrite by flow injection analysis. *Anactin. Acta*. 114: 191-197.
- Jensen, L. S., I. S. Pedersen, T. B. Hansen, and N. E. Nielsen, 2000. Turnover and fate of 15 N-labelled cattle slurry ammonium-N applied in the autumn to winter wheat. *European Journal of Agronomy*. 12: 23-35.
- Luxhoi, J., K., Debosz, L. Elsgaard, and L. S. Jensen, 2004. Mineralization of nitrogen in Danish soils, as affected by short-medium-and long-term annual slurries. *Biology and Fertility of Soils*. 39: 569-572.
- Maynard, A.A. 1995. Cumulative effect of annual addition of MSW compost on the yield of field grown tomatoes. *Compost Sci. Util*. 3:47-54.
- Okonkwo, C.I., J.S.C. Mbagwu and S.O. Egwu, 2008. Nitrogen mineralization from pruning of three multipurpose legume and maize uptake in alley cropping system. *Agro-Science*, 7 (7): 143-148.
- Petersen, J. 1996. Fertilization of spring barley by combination of pig slurry and mineral nitrogen fertilizer. *Journal of Agricultural Science*, 127; 151-159.
- Reuter, D. and J.B. Robinson, 1993. *Plant Analysis. An interpretation Manual*. Lukata Press. Melbourne, Australia. p.155.
- Rothwell, D.F. and C.C. Hortenstine, 1969. Composted municipal refuse. Its effects on carbon dioxide, nitrate, fungi, and bacteria in Arredondo fine sand. *Agron.J*. 61: 837-840.
- SAS Institute Staff-1985. *SAS User's Guide*, 1985 (Ed). Statistical Analysis System Institute. Inc. carry NC.
- Serra-Wittling, C., S. Houot, and E. Barriuso. 1996. Modification of soil water retention and biological properties by municipal solid waste compost. *Compost Sci. Util*. 4: 44-52.
- Sommerfield, T.G., Chang, C. and T. Entz. 1988. Long-term annual manure applications increase soil organic matter and nitrogen, and decrease carbon to nitrogen ration. *Soil Science Society of America Journal*, 52: 1668-1672.
- Sorenson, P. and M. Amato, 2002. Remineralisation and residual effects of N after application of pig slurry to soil. *European Journal of Agronomy*, 16: 81-95.
- Thomson, I.K. and Christensen, B.T. 2004. Yields of wheat and soil carbon and nitrogen contents following long-term incorporation of barley straw and ryegrass catch crops. *Soil use and Management*, 20:432-438.
- Whalen, J.K., Chang, C. and Olson, B.M. 2001. Nitrogen and phosphorus mineralization potentials of soils receiving repeated annual cattle manure application. *Biology and Fertility of Soils*, 34: 334-341.
- Zibiliske, L.M. 1994. Carbon mineralization. P. 835-863. In: R.W.Weaver (ed.) *Methods of Soil Analysis. Part 2. Microbiological and biochemical properties*. SSSA Book Ser. 5. SSSA. Madison, WI.