Tropical and Subtropical Agroecosystems, 5 (2005): 25 - 31

Tropical and Subtropical Agroecosystems

SIMULATION STUDY TO ASSESS THE POTENTIAL OF SELECTED AGRO-ORGANIC WASTES FOR ABILITY TO REDUCE N VOLATILIZATION FROM COW MANURE

[EVALUACIÓN DEL POTENCIAL DE RESIDUOS AGRO-ORGÁNICOS PARA LA REDUCCIÓN DE LA VOLATILIZACIÓN DE N PROVENIENTE DE HECES BOVINAS]

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SUMMARY

Six agro-organic wastes were evaluated for their ability to reduce N losses from cattle manure during storage. The materials were selected based on their low pH, high C: N ratios or high cation exchange capacity. They included; filter mud (FM), sawdust (SD), a common by-product of the timber industry, maize stover (MS), wood ash (WA), Ondiri peat (OP), and coffee pulp (CP), a waste product from coffee factories. Manure samples equivalent to 40 g (dry weight basis) were combined with 20% of each of the amendments and placed in 500 ml elernmeyer flasks. Volatilization of ammonia was determined using a laboratory gas train simulator and volatilized NH_3 was collected in 100 ml of 2% boric acid and determined by titration with 0.01 M H_2SO_4. Mixing organic amendments with manure significantly reduced NH_3 losses relative to non-amended manure heaps with the exception where wood ash was added. The total N content of the untreated manure prior to incubation was 17.11 g N kg^{-1} and after 51 days declined to 9.36 g N kg^{-1} which translated to a 43% loss from the initial levels. The cumulative NH_3 losses ranged between 7.6% to 78.7% of the initial N, depending on the type of amendment. The N losses were positively correlated (r^2=0.855) to the initial pH of the amended manures. Addition of sawdust, resulted in least mass and carbon loss and the original mixture was unchanged showing that minimal decomposition had occurred.

Key words: Livestock manure, agro-organic wastes, ammonia volatilization.

RESUMEN

Se evaluó el potencial de seis residuos agro-orgánicos para reducir la pérdida de N a en heces de bovino durante su almacenamiento. Los materiales fueron seleccionados considerando su bajo pH, alta relación C:N o alta capacidad de intercambio catiónico. Los materiales fueron, sólidos insolubles del jugo de caña (filter mud (FM)), aserrín (SD), rastrojo de maíz (MS), ceniza de madera (WA), Turba de "Ondiri" (OP), y pulpa de café (CP). Muestras de heces equivalentes a 40g MS fueron combinados con 20% de cada material y colocados en matraces elernmeyer. El NH_3 volatilizado fue colectado por arrastre de aire hacia 100 ml de solución de ácido bórico y titulado con H_2SO_4. El mezclado de las heces con los materiales redujo significativamente las pérdidas de NH_3 en relación con las muestras sin adición de material excepto cuando se agregó WA. El contenido de N total de las muestras de heces al inicio de la incubación fue de 17.11 g N kg^{-1} y después de 51 días declinó a 9.36 g N kg^{-1} en las heces no mezcladas (reducción de 43%). Las pérdidas acumuladas de N variaron entre 7.6% a 78.7% del contenido inicial de N dependiendo del tipo de material empleado. Las pérdidas de N fueron correlacionadas positivamente (r^2=0.855) al valor inicial de pH de las mezclas. La adición de aserrín resultó en menores pérdidas de masa y carbono y la mezcla original no sufrió modificación.

Palabras clave: Heces, residuos agro-orgánicos, volatilización de amoniaco.

INTRODUCTION

The high potential arable land in the highlands of central Kenya are densely populated (800 persons km^2) invariably, soils are now intensely and continuously cultivated to provide sufficient food (Woomer, *et al.,* 1998; Murage, 2000) with minimal soil inputs. Soil fertility status has evidently declined leading to reduction in crop yield in a number of areas thus threatening food security (Smaling *et al.,* 1993; Karanja, *et al.,* 1997; Kihanda, *et al.,* 1996).

Livestock manure produced on farms, is a valuable nitrogen source for crop production and a soil conditioner in majority of the smallholder farms in Kenya. However, available nitrogen in these manures is often insufficient for optimum crop yields because considerable N loses through ammonia (NH_3) volatilization occur due to poor handling and management practices. These losses indirectly increases cost of crop production and additionally, NH_3 emissions can be detrimental to natural ecosystem. Nonetheless, NH_3 losses can be reduced by amending manure with organic materials that directly adsorb NH_4^+, reduce manure pH, or promote microbial production of organic acids that decreases the manure pH, or increase microbial N immobilization (Subair, *et al.,* 1999; Kirchmann and Witter, 1989; Al-Kanani, *et al.,* 1992).

Although a range of chemical amendments have been evaluated on reducing NH_3 volatilization from manure, there is little cited literature on use of agro-organic wastes to minimize NH_3 emissions during manure storage and subsequently during application. The study aimed at evaluating a range of agro-organic wastes for their ability to reduce N losses from manures used in Kenya.

MATERIAL AND METHODS

The experiment was conducted under controlled conditions at the Department of Soil Science Research laboratory (University of Nairobi) in March to May 2001. Six agro- organic wastes commonly found or used in smallholder farms were evaluated for their ability to reduce N losses from cattle manure during storage.

Characterisation of agro-organic wastes and manure mixtures

Cattle manure was collected from cattle sheds at the University of Nairobi field station. The organic amendments included; filter mud (FM) from Muhoroni sugar industry, sawdust (SD) by-product of timber mills, maize stover (MS) which is the most common crop residues on farms. Other materials were, wood ash (WA) easily obtained from traditional cooking "jikos", Ondiri peat (OP) which is a partially decomposed peat from the Kikuyu Ondiri swamps in Kiambu District, and coffee pulp (CP), which is a waste product from coffee factories. Samples were air-dried, homogenized, and ground to pass a 2-mm sieve and placed in sample bottles. The samples were analyzed for total macro-elements (N, P, K, Ca), organic carbon, inorganic N (NH_4^+ and NO_3^-), pH, cation exchange capacity (CEC) and moisture content. Moisture was determined by drying the sub-samples at 65 ^oC for 72 hours. Manure pH was determined in 1:5 manure: water mixture using a pH meter. Exchangeable NH_4^+ and NO_3^- were determined using methods described by Okalebo *et al.,* (2002) and Anderson and Ingram (1993). Total N was determined by steam distillation after Kjeldal digestion (Bremner and Mulvaney, 1982) using moist samples to avoid N losses during drying and values corrected for water content. Organic C was determined by Kurmies procedure (Walinga, *et al.* 1992). Other macro-elements (P, K, and Ca, Mg) were determined following the wet ashing technique (Okalebo, *et al.* 2002). The neutral 1M NH_4OAc saturation procedure was used to determine the CEC.

Ammonia volatilization from organic amended manures

Ammonia loss under laboratory conditions was determined using a gas train simulator as described by Kithome et al., (1999). Manure samples equivalent to 40 g (dry weight basis) were combined with 20% of each of the amendments and placed in 500 ml elernmeyer flasks. The samples were thoroughly mixed and moistened before placing them in the flasks. An air inlet tube was provided and passed through distilled water, 0.5 M H_2S0_4, and then through distilled water to supply NH_3 free humidified air that ensured adequate oxygen supply to the aerobic micro-organisms and prevented the drying of the manure. Air coming from the outlet tube was passed through 100 ml 2% boric acid to trap volatilized NH_3 and was determined by titration with 0.001 M H_2S0_4. The acid traps were changed daily for the first 15 days of incubation and then every second day until day 51. The experiment was set out in a completely randomized design replicated three times.

The amount of N volatilized was expressed as a percentage of the initial total N at the start of the experiment. After 51 days of incubation, samples were weighed and homogenized and sub-samples were then taken and analyzed for moisture, pH, NH_4^+ and NO_3^-, total N and organic C. Carbon and mass loss were determined as given in equation equations 1 and 2.

$$C_L = I_C - F_C \qquad \textit{Equation 1}$$

$$M_L = I_M - F_M \qquad \textit{Equation 2}$$

Where; C_L = Carbon loss (g kg^{-1}), I_C = Initial carbon (g kg^{-1}), F_C =Final carbon (g kg^{-1}), M_L = Mass loss (g), I_M = Initial mass (g) and F_M = Final mass (g)

All statistical analysis were done using Genstat 5 Release 3.2 (1995) and the least significant differences were calculated to separate the effects of amendments (Gomez and Gomez, 1984).

RESULTS

Chemical characteristics of manure and agro-organic wastes

The results of the chemical characteristics of fresh manure and organic amendments are presented in table 1. The pH from the manure extract was slightly alkaline while that of the organic amendments ranged from slightly acidic to alkaline Wood ash was alkaline, sawdust and coffee pulp slightly acidic (5.2 and 5.6 respectively) while maize stover was neutral. Total N in the organic amendments was lowest in wood ash and highest value of 2% in coffee pulp. Wood ash had the highest base content (Na, K, Ca and Mg) as well as P content. However, in the organic materials coffee pulp and filter mud had the highest base contents. Sawdust had the highest organic carbon with C: N and lignin: N ratios of 366 and 231 respectively.

Table 1. Chemical characteristics of the agro-organic wastes and cattle manure

Organic material	pH	Na	K	Ca	Mg	P	N	C	C/N	Lignin/N
	1:5	←		g kg^{-1}		→	%	%	ratio	ratio
Filter mud	7.2	1.3	20.7	43.5	33.3	8.4	1.2	19.3	17	7
Saw dust	5.2	1.7	2.1	6.5	Trace	2.2	0.1	51.3	366	231
Maize stover	7.0	2.6	69.1	8.5	16.7	8.4	0.9	41.4	49	8
Wood ash	13.6	55.7	228.9	67.5	18.3	76.3	0.1	3.7	37	23
Ondiri peat	5.1	8.7	3.8	4.0	4.2	12.4	1.4	23.5	17	21
Coffee pulp	5.6	7.4	118.5	28.5	16.7	16.4	2.0	40.1	20	7
Cattle manure	8.2	-	8.7	10.4	-	6.4	1.7	26.5	16	8

Effect of agro-organic wastes on N, C and mass losses from cattle manure under laboratory condition

Organic amendments reduced NH_3 losses relative to the control except were wood ash was added. Coffee pulp, maize stover, sawdust and Ondiri peat significantly reduced NH_3 losses (Table 2). Total N content of the manure prior to incubation was 17.11 g N kg^{-1} and after 51 days it declined to 9.36 g N kg^{-1} giving a net N loss equivalent of 43 %.

Organic carbon lost from manure mixtures ranged from 17 to 52.5%. The loss from the control was significantly higher ($p \leq 0.05$) than in other treatments. There were no significant differences in organic C lost from manure amended with filtermud, maize stover, wood ash, Ondiri peat and coffee pulp but where sawdust was added the lowest organic carbon loss of 17.1% was recorded. Biomass loss from manure mixtures ranged from 37.14 to 53.08% (Table 2). Manure amended with maize stover and coffee pulp lost significantly higher ($p \leq 0.05$) mass 53.1 and 51.1 % respectively than other treatments except where wood ash was added and was 47.1%. Addition of sawdust, resulted in lowest loss in biomass and the original mixture was unchanged showing that minimal decomposition had occurred.

Cumulative NH_3 losses ranged from 7.6% to 78.7% of the initial N, depending on the type of amendment (Table 2). The pattern of NH_3 volatilization in this study varied with the treatments, but generally, the rate of loss was rapid at first and declined after 9 days of incubation leveling out after 14 days. For non-amended cattle manure, most of NH_3 was volatilized within the first 10 days of incubation (Figure 1).

Nitrogen loss was positively correlated (r^2=0.8554) to the pH of amended manure (Figure 2). Treatments that had higher initial pH (wood ash, filtermud and non-amended manure) lost more nitrogen than those with lower pH values (coffee pulp, sawdust and Ondiri peat), with wood ash gave the highest N loss.

Table 2. The effect of agro-organic wastes on N, C and mass losses after 51 days of incubation

Treatment	NH_3 volatilized ($g\ kg^{-1}$)	N- loss (%)	C- loss (%)	Mass- loss (%)
Non-amended manure	7.37	43.08	52.5	45.3
Manure + Filtermud	4.94	31.21	39.2	42.6
Manure + Sawdust	3.52	24.15	17.1	21.1
Manure + Maize stover	2.32	14.72	43.2	53.1
Manure + Wood ash	11.27	78.72	35.6	47.1
Manure + Ondiri peat	2.55	16.50	32.0	37.1
Manure + Coffee pulp	1.39	7.55	38.6	51.1
$LSD_{0.05}$	0.231	7.39	10.12	8.33
CV	10.7	4.1	15.7	11.2

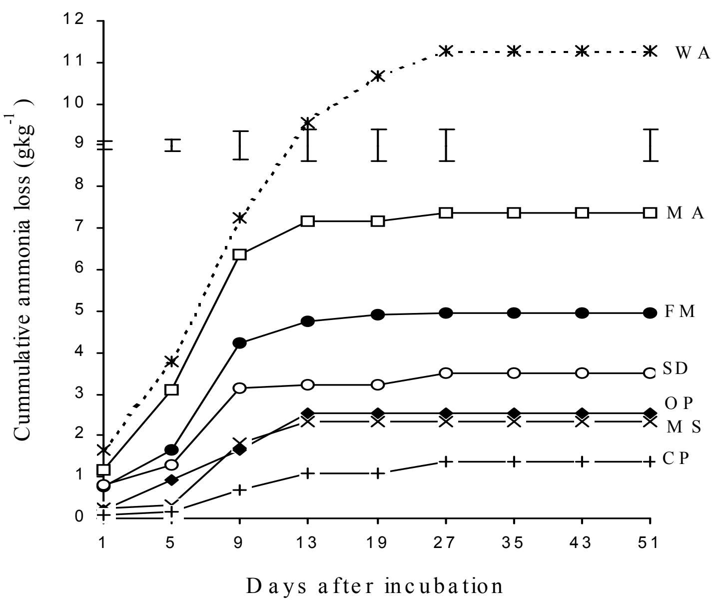

Figure 1. The effect of various organic amendments on cumulative NH_3 lost during 51 days of incubation.
(WA= Wood ash, MA= Cattle manure, FM= Filtermud, SD= Sawdust, OP= Ondiri peat, MS= Maize stover, CP= Coffee pulp.)

DISCUSSION

Effect of agro-organic wastes on N, C and mass losses from cattle manure under laboratory condition

The energy and nutrient balance of organic materials is indicated by the C: N ratio and the ideal C: N ratio lies between 15 and 25:1. Al-Kanani *et al.*, (1992) reported the presence of insufficient carbon for the micro-organisms to make use of all the N when the C: N ratio was below 15:1 which resulted in NH_3 volatilization. Conversely, when the C: N ratio was greater than 25:1, there was insufficient N for the micro-organisms to develop. Though materials with high carbon and low N would be expected to cause net N immobilization when mixed with animal manures (Subair *et al., 1999*), manure amended with sawdust with high C: N ratio lost more N than that amended with coffee pulp, maize stover and Ondiri peat that had lower C: N ratios. Sawdust had higher lignin: N ratio (231) than other organic amendments. Subair *et al.* (1999), reported that slow decomposing materials, with high lignin content exhibited a low rate of N immobilization, with immobilized N remaining in organic form for a long time. In contrast, low lignin materials exhibited high rates of decomposition, causing rapid N immobilization and subsequent re-mineralization without producing a pool of stable organic N (Subair *et al.*, 1999). Subair *et al.,* (1999) concluded that materials with moderate lignin contents were more effective in reducing volatile N loss from amended manure. In this study, coffee pulp and maize stover with lower lignin: N ratios were more effective in reducing N lost through ammonia volatilization.

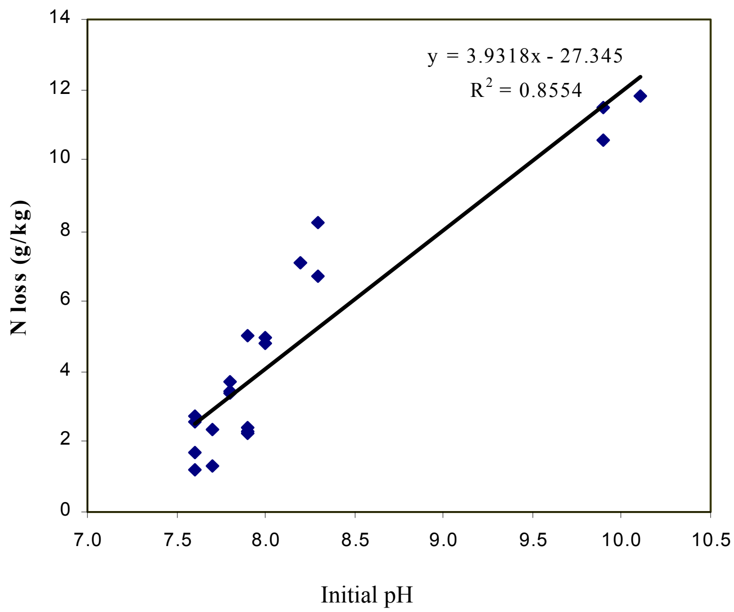

Figure 2. The effect of the initial pH on nitrogen loss from manure amendment mixtures

Addition of amendments reduced NH_3 losses relative to the control (non-amended cattle manure) with the exception of the cattle manure amended with wood ash. Coffee pulp, maize stover, saw dust and Ondiri peat significantly reduced NH_3 losses. It is likely that coffee pulp with a pH of 5.6 reduced NH_3 emissions by decreasing the manure pH during decomposition. Peat and sawdust reduced NH_3 lost through retention of NH_4^+ and other NH_3 producing compounds, rendering these compounds partially unavailable to chemical and/or biological breakdown. Kirchmann and Witter (1989) suggested that NH_3 loss during manure decomposition may be reduced through the adsorption of NH_3 and NH_4^+ by suitable amendments. Kirchmann (1989) and Mathur, *et al.* (1990) reported that organic materials such as peat and wood shavings could adsorb NH_3. Thus, addition of coffee pulp encouraged NH_3 retention while wood ash encouraged NH_3 volatilization.

Total N content of manure prior to incubation was 17.11 g N kg^{-1} and after 51 days declined to 9.36 g N kg^{-1}. This loss of N was equivalent to 43% of total N applied. This value was slightly higher than values reported earlier (Gordon *et al.* 1988; Beauchamp *et al.* 1982; Al-Kanani *et al.* 1992) which ranged from 13 to 31 %. Higher NH_3 volatilization from manure in this laboratory study may be attributed to the longer incubation time of 51 days as compared to 3 days for (Gordon *et al.* 1988) and 6 or 7 days for (Beauchamp, *et al.* 1982).

The pattern of NH_3 volatilization varied with the amendment, but generally, the rate of loss was rapid in the first 10 days of incubation and decreased with time. For the non-amended cattle manure, most of the NH_3 was volatilized within the first 10 days of incubation and this was similar to observations reported by Subair *et al.* (1999) and Al-Kanani *et al.* (1992) while composting liquid hog manure. In the first five days of incubation, NH_3 volatilization values were not very different in all treatments except wood ash, but were lower than the control, which was possibly due to the relative abundance of labile components and the resulting microbial activity in the amendments. After the initial period, there was greater NH_3 volatilization from the manure amended with wood ash than any other treatment.

Manure amended with coffee pulp, maize stover and non-amended cattle manure lost the greatest percentage of carbon because of their low lignin: N ratio. Mass loss during composting of the cattle manure ranged from 37.14 to 53.08% and was consistent to the range of 35 to 50% reported by Eghbal *et al.* (1997) with the exception of sawdust treatments that had a lower mass loss of 21.14%. Addition of sawdust, resulted in significantly lower mass loss than all the other treatments.

CONCLUSION

The results of this study show that there is considerable scope of improving the quality of cow manures with readily available and sometime free agro-organic wastes some of which are pollutants for stabilizing biodegradation process during their storage period. A reduction in NH_3 losses was achieved when manure was amended with coffee pulp, maize stover and sawdust. The common practice in the agricultural areas is to burn these wastes e.g. maize stover and sawdust while coffee pulp is usually left to rot in the factory grounds while small amounts are used as coffee mulch. Mixing these materials with stored manure would be economical and a more environmentally acceptable practice of managing the wastes as well as enhancing synchronization of nutrient release with crop uptake.

ACKNOWLEDGEMENTS

We acknowledge with deep gratitude, the financial support from the European Union and the Rockefeller Foundation Forum on Agricultural Research Husbandry (FORUM). We are indebted to the 3 farmers, Mr. Wagacha, Mr. Gathagu and Ms Wanjiku for their co-operation and participating in the trials and the staff of the Department of Soil Science for their assistance in analysis of the samples.

REFERENCES

Al-Kanani, T., Akochi, E., Mackenzie, A.F., Ali, I. And Barrington, S. 1992. Organic and inorganic amendments to reduce ammonia losses from liquid hog manure. Journal of Environmental Quality, 21: 709-715.

Anderson, J.M., and Ingram, J.S.I., 1993. Tropical Soil Biology and Fertility: A Handbook of Methods. CAB International, Wallingford, Oxon, England, 221pp.

Beauchamp, E.G., Kidd, G.E. and Thutell, G., 1982. Ammonia volatilisation from liquid dairy cattle manure in the field. Canadian Journal of Soil Science, 62:11-19.

Bremner, J.M. and Mulvaney, R.L. 1982. Nitrogen Total, p. 595-624. In: A.L. Page et al. (ed). Methods of soil analysis. Part 2. Agron. Monogr. 9. 2nd ed. American Society of Agronomy and Soil Science Society of America, Madison, WI.

Eghbal, B., Power, J.F., Giller, J.E. and Doran, J.W. 1997. Nutrient, carbon and mass loss during composting of beef cattle manure. Journal of Environmental Quality, 26: 189-193

Gordon, R., Leclerc, M., Schuepp, P. and Brunke, R. 1988. Field estimates of ammonia volatilization from swine manure by a simple micrometeorological technique. Canadian Journal of Soil Science, 63:369-380.

Karanja, N.K., Woomer, P.L., Kapkiyai, J., Bunyasi, S., and Murage, E.W. 1997. Agriculture Resource Management in Smallholder Systems in Central Kenyan Highlands. Department of Soil Science, University of Nairobi. Technical Report and Financial Statement, Rockefeller Foundation. Forum for Agricultural Research Husbandry (Grant RF94- 031 No. 35.).

Kihanda, F.M. and Wood, M. 1996. Effect of manure quality and soil type on the N mineralization in farmyard manures in the sub-humid highlands of Central Kenya. Paper Presented at the International Symposium on Carbon and Nutrient Dynamics in Natural and Agricultural Tropical Ecosystems. Harare, Zimbabwe, 29th April to 4th May, 1996.

Kirchman, H. 1989. A 3-year balance study with aerobic, anaerobic and fresh ^{15}N labelled poultry manure. In: Nitrogen in Organic wastes Applied to soils. In Hansen, A., and Henriksen (ed), K.111-125. Academic Press.

Kirchman, H. and Witter, E. 1989. Ammonia volatilization during aerobic and anaerobic decomposition. Plant and Soil, 115:35-41.

Kithome, M., Paul, J.W. and Bomke, A.A. 1999. Reducing nitrogen losses during simulated composting of poultry manure using organic and inorganic amendments or chemical amendments. Journal of Environmental Quality, 28:194-201.

Mathur, S.P., Panti, N.K. and Levesque, M.P. 1990. Static pile, passive aeration composting of manure slurries using peat as a bulking agent. Biological Wastes 30:323-333.

Murage, E.W., Karanja, N., Smithson, P.C. and Woomer, P.L. 2000. Diagnostic indicators of soil quality in productive and non-productive smallholders' field of Kenya's Central Highlands. Agricultural Ecosystems and Environment, 79: 1-8.

Okalebo, J.R., Gathua, K.W. and Woomer, P.L. 2002. Laboratory Methods of Soil Analysis 2nd Editiion: A Working Manual. Soil Science Society of East Africa Technical Publication No. 1. Marvel EPZ (Kenya) LTD, Nairobi, Kenya.

Smaling, E.M.A. 1993. Soil Nutrient Depletion in Sub-Saharan Africa. In: The role of plant nutrients for sustainable crop production in Sub-Saharan Africa. (van Reuler, H. and Prins, W.H. (eds). pp. 53-67. Dutch Association of Fertiliser Producers, Leidschendam, the Netherlands.

Smaling, E.M.A., Stoorvogel, J.J. and Winmeijer, P.N., 1993. Calculating soil nutrient balances at different scales II District scale. Fertilizer Research, 35: 237-250.

Subair, S., Fyles, J.W. and O'Halloran, I.P. 1999. Ammonia volatilization from liquid hog manure amended with paper products in the laboratory. Journal of Environmental Quality, 28: 202 - 207.

Walinga, I., Kithome, M., Novozamsky, I., Houba, V.J.G. and vander Lee, J.J. 1992. Spectrophotometric determination of organic carbon in soil. Communications in soil Science and Plant analysis 23 (15&16): 1935-1944.

Woomer, P.L., Bekunda, M.A., Karanja, N. Morehouse, T. and Okalebo, J.R. 1998. Agricultural resource management by smallhold farmers in East Africa. Nature and Resources 34(4): 22-33.

Submitted January 09, 2004 - Accepted March 15, 2005