High C/N Materials Mixed with Cattle Manure as Organic Amendments to Improve Soil Productivity and Nutrient Availability

A.A. Mariaselvam, W.S. Dandeniya[1*], S.P. Indraratne[1] and R.S. Dharmakeerthi[2]

Postgraduate Institute of Agriculture
University of Peradeniya
Sri Lanka

ABSTRACT: *Identification of organic materials, which can enrich the soil organic matter pool and improve the productivity of marginal lands, is a necessity in tropical countries. A study was conducted to comprehend the effect of organic materials of different quality on the soil carbon (C) pool size and N, P, K release from soil. Organic amendments (OA) with different complexities namely, cattle manure (CM), cattle manure-rice straw (CR), cattle manure-wood shavings (CW), and cattle manure-rice straw-wood shavings (CRW) mixtures as fresh (f) or incubated for two months (i), were used in a leaching column study, soil incubation experiment and greenhouse experiment using maize (Zea mays L.) as the test plant. The N, P and K release pattern from soil, soil organic matter content and biomass of maize in OA added soils compared to fertilizer-only (SF) and soil-only (S) treatments were determined. The nitrogen release and microbial activity were higher in fresh-OA added soils compared to other treatments. Phosphorous and K were higher in soils amended with incubated-OA than fresh-OA. The highest N, P and K release was obtained with CM-i, CRW-i and CM-f, respectively. Shoot biomass of maize was enhanced by 20-40% with the application of incubated-OA compared to SF. The total soil organic C and active organic C ranged from 10.85 to 13.50 g/kg and 0.31 to 0.64 g/kg, respectively, with soils treated with OA showing significantly high values compared to the control. The organic amendments used as fresh or incubated materials, did not impede plant growth and generally maintained or improved the soil nutrient status and C pool. Incubating OA prior to application improved the nutrient availability in soil.*

Keywords: *C/N ratio, soil C pool, soil fertility, rice straw, wood shavings*

INTRODUCTION

Use of organic amendments is an integral part of sustainable agriculture (Ajwa & Tabatabai, 1994). Organic amendments supply nutrients and replenish the soil organic matter (OM) pool. According to several studies, organic materials improve soil chemical, physical and biological properties and thereby contribute to the maintenance of overall soil fertility and productivity (Topoliantz *et al*., 2005, Bhogal *et al*., 2011).

Application of compost, green manure and animal manure to soil is known to supply nutrients (Ohno & Crannel, 1996; Odlare *et al*., 2008). But the effect of organic amendments on organic matter pool is poorly studied. Repeated application of organic amendments or

[1] Department of Soil Science, Faculty of Agriculture, University of Peradeniya, Sri Lanka
[2] Department of Soils and Plant Nutrition, Rubber Research Institute, Sri Lanka
[*] Corresponding author: warshisd@gmail.com

applications in high quantities have led to a marked improvement in soil OM pool (Miller *et al.*, 2002; Hao & Chang, 2002). Hai *et al.* (2010) reported concentration of various soil organic carbon fractions increased significantly due to application of farmyard manure for a period of 26 years. Increasing soil OM pool size by applying organic amendments such as compost and manure is challenging especially in tropical environments due to high decomposition rates.

Numerous studies have been conducted regarding the effect of diverse organic material, both animal and plant based, on soil nutrients and soil chemical properties (Bulluck *et al.*, 2002; Qian & Schoenau, 2002; Miller *et al.*, 2012). Application of poultry manure was reported to increase soil organic matter, N and P (Agbede *et al.*, 2008). Karami *et al.* (2012) reported that organic carbon, P, K, Mn and Fe increased while soil pH decreased when soil was amended with organic materials such as manure, rice husk, wheat straw, chopped reeds and licorice dregs. Short-term N availability decreased when the C/N ratio of manure exceeded 15 (Qian & Schoenau, 2002). Wheat straw rapidly decreased soil nitrate content within the first week of addition (Shindo & Nishio, 2005). Organic materials containing 0.22% or less P increased the amount of P adsorbed by soil (Singh & Jones, 1976). From 224 days long incubation study using different animal wastes, Morvan *et al.* (2006) found C/N ratio of the amendment significantly correlated with N mineralization rate and carbon mineralization varied from 5 to 62% of the organic C added. Thus, addition of organic inputs, especially high C/N materials to soil could cause nutrient imbalances in the short-run even though such material are required to improve soil OM content. Therefore, it is a challenge to combine different types of organic materials of diverse quality with mineral fertilizers to meet crop demands and retain or rebuild soil fertility.

Tropical climate in Sri Lanka is in favour of highly weathered and low organic matter containing soils (Mapa, 1999). One of the major limitations to crop production in Sri Lanka is low plant nutrient content (Kumaragamage, 2010).Through short-term effects on nutrient supply and long-term contribution to soil organic matter, organic materials have a prominent place in soil fertility management in the tropics (Palm *et al.*, 2001). Thus, introducing cost-effective organic materials, which could improve soil OM while complementing existing nutrient management practices, would be a best management practice. This should enable soil to strike a balance between supplying plant nutrients in the short-run and enriching nutrient reserve in the long-run. Information is scarce for tropical countries like Sri Lanka regarding the impact of organic materials of different quality on soil fertility. Therefore, this study was conducted with the aim of understanding the effect of organic materials of different quality on soil carbon pool size and the release of N, P and K using laboratory and greenhouse scale experiments.

METHODOLOGY

Study site and soil sampling

Soil samples were collected from a fallowed field (110 m^2) in the Agriculture Training Centre, Wagolla situated in the Low-country Wet Zone (LCWZ) of Sri Lanka. The soil order is Ultisols. The land was fallowed for the past six years and was covered with grasses (dominated by *Imperata cylindrica*) at the time of sampling. The field was divided in to 18 grids and four random samples were collected from each grid to prepare a representative composite sample. Stones and organic debris were removed. Soil was air-dried and sieved through a 2 mm sieve prior to use in experiments. All the experiments were conducted at the Department of Soil Science, Faculty of Agriculture, University of Peradeniya.

Soil characterization

Soil pH was measured in soil: water suspension (1:2.5) using a glass electrode (McClean, 1982) and soil electrical conductivity (EC), using a conductivity meter in a soil: water suspension (1:5). Organic matter content was analysed by modified Walkley and Black method using acid dichromate (Nelson & Sommers, 1996). Cation Exchange Capacity (CEC) was measured according to Summer and Miller (1996) using ammonium acetate buffer solution. Soil texture was determined by the pipette method (Gee & Bauder, 2002). All analyses were performed in triplicates.

Preparation of organic amendments

Cattle manure was collected from the cattle shed maintained by the Faculty of Veterinary Medicine and Animal Science, University of Peradeniya. Rice straw was collected from a conventionally cultivated rice field at Thihariya and wood shavings (a mixture from *Alstonia macrophylla, Swietenia macrophylla, Tectona grandis* trees) were collected from a timber mill at Peradeniya. Different combinations of these organic materials were used to develop treatments. Cattle manure (CM), cattle manure- rice straw at 2:1 ratio (CR), cattle manure-wood shavings at 2:1 ratio (CW), and cattle manure-rice straw-wood shavings at 4:1:1 ratio (CRW) mixtures as fresh (f) or incubated (i) were the eight treatments. Incubation was carried out at room temperature under aerobic condition for two months to facilitate partial decomposition of the material through the activity of mesophilic microorganisms.

Total organic carbon was measured by Walkley and Black method using acid dichromate and total nitrogen was determined using acid digestion followed by Kjeldhal distillation method (Bremner & Mulvaney, 1982). C/N ratio of materials was calculated.

Leaching column study

To study the effect of organic amendment on nutrient release pattern from soil, leaching columns were set-up in triplicates arranged in a complete randomized design. Each column was filled with 50g of soil after mixing with mineral fertilizer (recommended rate by the Department of Agriculture, Sri Lanka for irrigated maize crop) and organic material (fresh or incubated CM, CR, CW, or CRW at the rate of 1% w/w dry weight basis of soil). Two additional treatments of soil mixed with mineral fertilizer alone (SF) and unamended soil-only (S) were also included in the leaching column study. Leaching columns were maintained at room temperature in dark condition. Soils were leached with 100 ml distilled water at the first, second and eighth week after initiating soil incubation. Leachates were analysed for NO_3^--N, P and K. Nitrate nitrogen concentration was measured colourimetrically (Cataldo *et al*., 1975). Phosphorous concentration was measured using molybdenum blue colour method (Olsen & Sommers, 1982) and K using Flame Emission Spectrophotometer.

Soil incubation study

In a separate experiment, soil was mixed with each organic material in the fresh form at the rate of 1% on dry weight basis. A control was also set up using unamended soil (S). One kilogram of each treated soil was filled into plastic trays (3 cm depth) in four replicates and, covered with dark polythene and maintained in a dark room at room temperature. Moisture was maintained at 16% (gravimetric basis) throughout the incubation period using distilled water. Samples were collected after three months and analysed for total organic carbon (TOC) by modified Walkley and Black method (Nelson & Sommers, 1996) and active carbon by $KMnO_4$ oxidizable carbon method (Weil *et al*., 2003). A separate soil incubation study was maintained with fresh and incubated organic amendments (1% on dry weight basis of soil) to assess soil respiration during the first week of incubation using static incubation titrimetric method (Zibilske, 1994).

Greenhouse study

A greenhouse experiment was conducted using maize (Hybrid variety - *Sampath*) to study the effect of organic amendment on crop growth. Plastic pots were filled with 200g of soil mixed with mineral fertilizer at the rate developed for the experimental soil (Vinodhini, 2012) and organic material at the rates of 1% on dry weight basis. Two additional treatments as soil mixed with mineral fertilizer alone (SF) and unamended soil-only (S) were also included. The experiment was arranged in a complete randomized design with three replicates. Pots were seeded with four seeds and thinned out leaving two plants after one week. Plants were harvested after one month, oven dried at 60 ^{o}C and the shoot dry weight was measured.

Statistical analysis

Data were statistically analysed using the programme SAS 9.1.3 for Windows. Time series data were analysed using mixed procedure in SAS. Duncan Multiple Range Test (DMRT) was performed to compare means for treatment effects.

RESULTS

The C/N ratio of rice straw is reported to vary from 39 to 78 when analysed using Dumas combustion procedure (Devevre & Horwarth, 2000). When cattle manure was mixed with rice straw the initial mean C/N decreased from 25 to 9 after 98 days and when the same cattle manure was mixed with a mixture of saw dust and wood shavings the mean C/N decreased from 33 to 13 after 112 days (Changa *et al*., 2003). In their study total C was analysed by colourimetry and total N was determined using Dumas combustion method. In the present study, incubating rice straw and/or wood shavings with cattle manure reduced the C/N of the organic material prepared (Table 1).

Table 1. C/N ratios of organic amendments

	C/N ratio			
	CM*	**CR**	**CW**	**CRW**
Fresh	18	46	37	35
Incubated (2 months)	14	14	16	24

*CM-Cattle manure, CR-Cattle manure+Rice straw, CW-Cattle manure+Wood shaving, CRW-Cattle-manure+Rice straw+Wood shaving

Release of N, P and K from Soil as affected by Organic Amendments

Soil used in the present study was sandy clay loam in texture with an OM content of 2.1%. Soil was slightly acidic (pH of 5.1) having CEC of 10.5 cmol(+)/kg and EC of 164.2 µS/cm.

The cumulative release of N, P, and K from 50 g of soil varied among treatments with values ranging from 5.7 to 19.7 mg, 0.006 to 0.01 mg and 0.4 to 3.7 mg, respectively. A definite decline in the release of all three nutrients with time was observed in the unamended soil and P release reduced with time for all treatments except for CW (f) and SF (Table 2).

In all the treatments, cumulative N release was higher compared to the unamended treatment (S). Cumulative N release relative to SF treatment was generally higher in the treatments added with fresh material (Fig. 1). Significantly high N release was observed from soils amended with cattle manure (CM) both as fresh and incubated material in the first week. When cumulative N release for the whole period was considered, incubated CM showed a higher release than fresh CM. Higher amount of N was released from CM (i) and CR (i) than their fresh counterparts. CRW (i) showed the lowest N release followed by CW (i). Cumulative P release from soil was noticeably higher when incubated material was added than SF and S treatments (Fig. 1)

Table 2. N, P, K content in the leachate of soil mixed with mineral fertilizer and different fresh (f) or incubated (i) organic materials with time.

Treatment[#]		NO_3^--N (mg/l)			P (10^{-2}) (mg/l)			K (mg/l)		
		Time (weeks)								
		1st	2nd	8th	1st	2nd	8th	1st	2nd	8th
F	CM	126.7^{a}	44.8^{d}	17.1^{a}	4.9^{ab}	1.6^{a}	ND[¶]	18.3^{a}	19.4^{a}	9.4^{a}
	CR	61.4^{b}	66.7^{c}	1.5^{b}	4.9^{ab}	0.8^{a}	ND	9.2^{b}	8.1^{b}	1.1^{b}
	CW	78.3^{b}	42.5^{d}	1.3^{b}	5.7^{a}	0.4^{a}	0.7^{b}	7.7^{c}	5.6^{b}	0.4^{b}
	CRW	62.1^{b}	157.7^{a}	0.7^{b}	4.5^{b}	2.9^{a}	0.7^{b}	6.4^{d}	8.4^{b}	1.0^{b}
	SF	62.6^{b}	93.8^{b}	29.6^{a}	5.3^{ab}	1.6^{a}	2.5^{a}	4.6^{e}	7.4^{b}	2.5^{b}
	S	51.4^{b}	6.0^{e}	1.9^{b}	4.9^{ab}	2.8^{a}	0.4^{b}	2.7^{f}	1.3^{c}	0.4^{b}
I	CM	141.7^{A}	90.4^{AB}	0.8^{C}	7.7^{A}	1.6^{A}	ND	17.1^{A}	0.6^{D}	2.8^{A}
	CR	93.5^{B}	117.7^{A}	15.0^{BC}	5.7^{BC}	2.1^{A}	ND	12.4^{B}	15.6^{A}	3.7^{A}
	CW	47.5^{C}	35.6^{BC}	0.4^{C}	6.5^{ABC}	2.4^{A}	1.8^{AB}	9.7^{C}	12.2^{B}	1.8^{A}
	CRW	52.4^{C}	92.3^{AB}	33.1^{A}	7.3^{AB}	2.8^{A}	0.4^{B}	12.7^{B}	13.3^{B}	4.5^{A}
	SF	62.6^{C}	93.8^{AB}	29.6^{AB}	5.3^{C}	1.6^{A}	2.5^{A}	4.6^{D}	7.4^{C}	2.5^{A}
	S	51.4^{C}	6.0^{C}	1.9^{C}	4.9^{C}	2.8^{A}	0.4^{B}	2.7^{D}	1.3^{D}	0.4^{A}
f vs. I [ǂ]		Not Significant			Significant			Not Significant		

[#]CM-Cattle manure, CR-Cattle manure+Rice straw, CW-Cattle manure+Wood shaving, CRW-Cattle-manure+Rice straw+Wood shaving,SF-Soil+Fertilizer,S-Soil only. [¶]ND- Not Detected [ǂ] Significance of form of organic amendment (fresh vs. incubated) on nutrient release pattern from soil (P<0.05) according to mixed procedure analysis in SAS. Means with similar letters in a given column for each category (f and i) are not significantly different (P<0.05, n = 3).

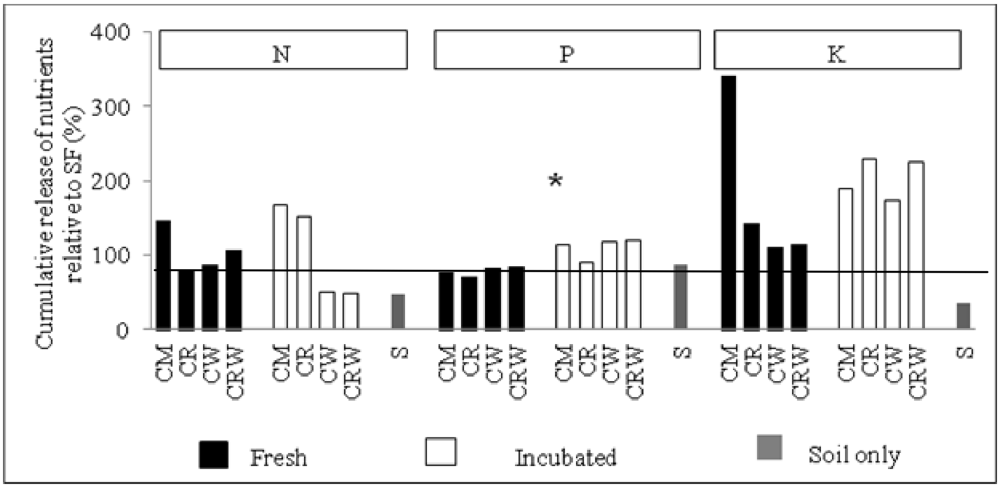

Fig. 1. Cumulative release of N, P, K over eight weeks from soil mixed with mineral fertilizer and different fresh (f) or incubated (i) organic materials relative to mineral fertilizer only treatment. CM-Cattle manure, CR-Cattle manure+Rice straw, CW-Cattle manure+Wood shaving, CRW-Cattle-manure+Rice straw+Wood shaving, SF-Soil+Fertilizer, S-Soil only. *Significant difference (P<0.05) between Fresh and Incubated materials.

All the treatments with amendments showed higher cumulative release of K compared to the S treatment. Organic amendments with fertilizers in combination caused higher K release than fertilizer alone (SF) treatment (Fig. 1). Fresh cattle manure (CM (f)) released the highest amount of K over time (Table 2). In general, incubated materials released higher amount of K than the fresh materials.

Soil carbon

After three months of incubation, total organic carbon and active carbon (labile fraction) contents in soil were significantly improved by the addition of organic amendment (Table 3).

Table 3. Total organic C and active C in soil incubated for 3 months with different organic materials

Organic material (fresh) Treatment*	TOC (g/kg)	Active C (g/kg)
CM	12.69[a]	0.55[ab]
CR	12.75[a]	0.64[a]
CW	13.07[a]	0.47[b]
CRW	13.50[a]	0.63[a]
S	10.85[b]	0.31[c]

*CM-Cattle manure, CR-Cattle manure+Rice straw, CW-Cattle manure+Wood shaving, CRW-Cattle-manure+Rice straw+Wood shaving, S-Soil only).Means followed by similar letters in a given column are not significantly different (P<0.05, n = 4).

Soil respiration

Application of organic materials resulted in higher respiration than soil only (S) treatment (Fig. 2). Microbial activity as indicated by respiration was significantly higher ($P<0.05$) when the added material was fresh compared to those of incubated.

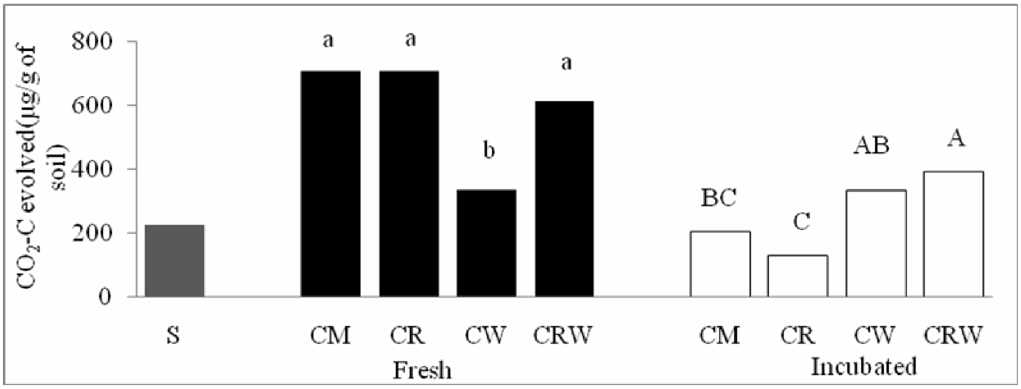

Fig. 2. CO_2-C evolved from soil incubated with organic amendments in the first week after incubation.CM-Cattle manure, CR-Cattle manure+Rice straw, CW-Cattle manure+Wood shaving, CRW-Cattle-manure+Rice straw+Wood shaving, S-Soil only. Similar letters above vertical bars for each category (fresh, incubated) show means are not significantly different ($P<0.05$, n = 3).

Aboveground plant biomass

Shoot dry weight of one month old maize plants that were grown with incubated organic amendments was higher relative to plants grown in SF treatment except CW (i) (Fig. 3).

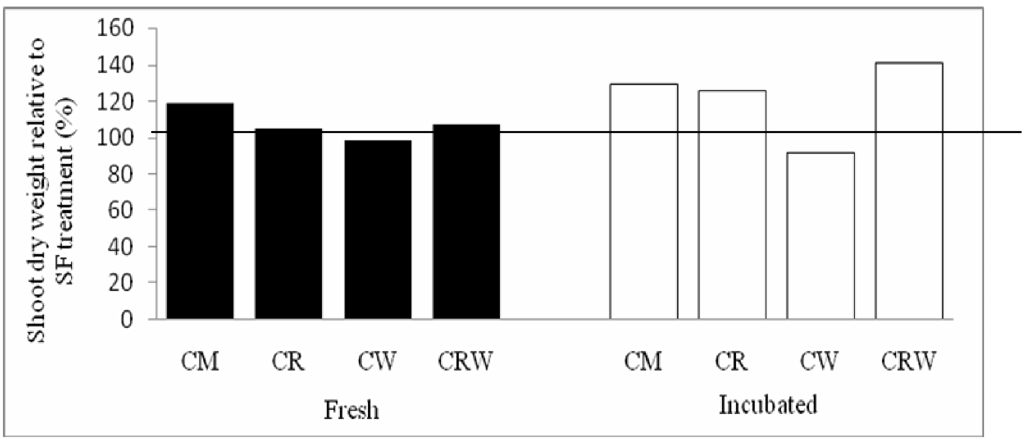

Fig. 3. Shoot dry weight of one month old maize plants grown with organic amendments and fertilizers relative to fertilizer alone (SF) treatment. CM-Cattle manure, CR-Cattle manure+Rice straw, CW-Cattle manure+Wood shaving, CRW-Cattle-manure+Rice straw+Wood shaving,SF-Soil+Fertilizer.

DISCUSSION

The dynamics of various nutrients in the soil and the soil microbial activity are variably affected by the composition of different organic amendments applied to the soil (Kwabiah *et al*., 2003). Kaur *et al.* (2005) found that the microbial biomass was metabolically active and total N, P and K improved in soils mixed with organic amendments with or without fertilizer. The changes in nutrient release patterns during the first few weeks after applying organic amendments are important since it has implications on crop growth. The nutrient releasing pattern from amended soils in the present study was differently affected by the type of amendment added. Furthermore, the pattern was different between nutrients. Form of organic materials, fresh or incubated, significantly affected nutrient release pattern and microbial activity in accordance with previous observations (Kwabiah *et al*., 2003; Kaur *et al.,* 2005).

Heaping of manure enhanced the availability of N (Rupende *et al*., 1998). Kirchmann (1991) reported that the CO_2-C evolution rates were higher from fresh manures than from aerobically treated manures. Soil solution acquires N via mineralization, and additions through urea and cattle manure; whereas, N immobilization removes N from the available pool. Net effect of these processes resulted in N levels higher than fertilizer only (SF) treatment. As observed by Paul and Beauchamp (1994) although net immobilization of inorganic N occurred with all manures, after three weeks, net mineralization occurred from soil amended with solid and composted beef cattle manure releasing previously immobilized N. Thus, higher N release from CM (i) compared to CM (f) may be due to re-mineralization of N due to microbial activity. Cattle manure, especially CM (i), is a potential N source for fulfilling crop N requirement.

Qian & Schoenau (2002) found a significant negative correlation between organic C/N ratio of cattle manure and N mineralization. Manures tended to decrease N availability in the short-term if the organic C/N ratio was over 15. Wood shaving is a high C/N ratio material compared to rice-straw. When manure was mixed with wood shavings, the NO_3^--N and total N of the soil were significantly lower than the manure only treatment (Sommerfeldt & Mckay, 1987). In the same study it was indicated that even when N fertilizer was added to manure containing wood shavings N is immobilized and N release is impeded. According to Miller *et al*. (2012) mineralizable soil N was reduced in aggregate sizes ≥0.47 mm when soil was amended with feedlot manure containing wood-chip compared to soils that received straw bedding. In addition to the N content, the quality and or complexity of C in the organic material also affected the nutrient release pattern as indicated by different N release pattern from materials with approximate C/N values.

Depending on the complexity, its P concentration and amount added, organic materials can either increase or decrease the P adsorption of a soil (Singh & Jones, 1976). Release of carbon accompanied P sorption indicates that soluble carbon may influence P sorption (Erich *et al*., 2002). Dissolved organic carbon (DOC) from decomposed organic materials enhanced extent of P release compared to DOC from fresh material (Hunt *et al*., 2007). Kwabiah *et al*. (2003) observed that some plant materials showed net P assimilation. In the present study, treating soils with incubated organic materials resulted in more P availability than amending with fresh materials. When wood shaving was added to the cattle manure- rice straw mixture the release of P was enhanced. According to Gagnon & Simard (1999) the use of wood bedding in dairy manure compost reduced P immobilization during incubation. Phosphorus sorption in soil aggregates (≥0.47 mm) in soils amended with wood-chips was lower compared to soils treated with straw bedding (Miller *et al*., 2012). CRW (i) has a possibility of enhancing P availability for crop growth.

In a study conducted by Tian *et al*. (1992) on nutrient release of a variety of plant residues, observed that all the residues released K rapidly whereas, other nutrients were immobilized to different extents. According to previous studies (Lupwayi & Haque, 1999; Eghball *et al.,* 2002) mineralization lead to K release in large quantities from cattle manure and it may serve as a significant source of K for crop growth. Incubation process might have facilitated the mineralization of K.

Several reports indicated that the addition of organic inputs to soil increase soil organic C in addition to supplying nutrients such as N, P, and K (Rajinder *et al*., 2005; Butler & Muir 2006; Karami *et al*., 2012). Active C pool influences the nutrient cycles and soil biological properties and can act as early indicators of soil quality following soil management practices (Weil *et al.,* 2003). Difference in active C was observed when there was a difference in soil management practices (Purakayastha *et al*., 2008; Culman *et al*., 2012). The effect of organic amendment on soil carbon content was assessed only after three months in the present study since it is equivalent to the length of a cropping season. However, it is important to assess the effects on soil carbon pool under long-term field experiments because organic matter dynamics in the presence of plants under field conditions would be different from those under laboratory incubations. Improved active C and total organic C in organic matter amended soils indicate the potentials of the tested materials to increase soil C reserves. Accordingly, CRW has the highest potential to increase soil carbon reserves among the tested materials.

Improved shoot biomass under organic amendments combined with mineral fertilizers could be attributed to the additional provision of nutrients and/ or slow release of nutrients by the organic materials improving the nutrient availability in soil over a longer period. Rice straw and wood shavings like high C/N materials mixed with cattle manure did not impede crop growth in the present study and these materials contributed to improve soil C contents. Cattle manure mixed with rice straw and/or wood shavings is better than using cattle manure or high C/N materials alone to improve soil fertility.

CONCLUSION

The composition and complexity of organic materials affect the nutrient release pattern from soil. The use of high C/N organic materials (wood shavings and rice straw) mixed with cattle manure, as freshly prepared or incubated materials did not impede plant growth and generally maintained or improved soil nutrient status and improved soil carbon levels. Incubation of wood shavings and/or rice straw with cattle manure prior to application to soil enhanced soil productivity in the short-run. Considering the positive effect on plant growth, soil nutrient status and improvements to the soil C pool, the high C/N organic materials mixed with cattle manure as used in the present study appeared to be more promising in improving soil fertility status than others.

ACKNOWLEDGEMENT

Financial assistance from HETC-QIG-W3-PGIA grant is acknowledged.

REFERENCES

Agbede, T.M., Ojeniyi, S.O. and Adeyemo, A.J. (2008). Effect of poultry manure on soil physical and chemical properties, growth and grain yield of sorghum in southwest, Nigeria. Am-Eur. J. Sust. Agr. *2*, 72-77.

Ajwa, H.A. and Tabatabai, M.A. (1994). Decomposition of different organic materials in soils. Biol. Fert. Soils. *18*, 175-182.

Bhogal, A., Nicholson, F.A., Young, I., Sturrock, C., Whitmore, A.P. and Chambers, B.J. (2011). Effects of recent and accumulated livestock manure carbon additions on soil fertility and quality. Eur. J. Soil Sci. *62*, 174-181.

Bremner, J.M. and Mulvaney, S.C. (1982). Nitrogen-Total. pp. 539-579. In: Page, A.L. (Ed). Methods of Soil Analysis, part 2.ASA, Madison, USA.

Bulluck, L.R., Brosius, M., Evanylo, G.K. and Ristaino, J.B. (2002).Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties on organic and conventional farms. Appl. Soil Ecol. *19*, 147-160.

Butler, T.J. and Muir, J.P. (2006). Dairy Manure Compost Improves Soil and Increases Tall Wheatgrass Yield. Agron. J. 98, 1090-1096.

Cataldo, D.A., Maroon, M., Schrader, L.E. and Youngs, V.L. (1975). Rapid colorimetric determination of nitrate in plant tissue by nitration of salicylic acid. Commun. Soil Sci. Plan. *6*, 71-80.

Changa, C.M., Wang, P., Watson, M.E., Michel Jr, F.C. and Hoitink, H.A.J. (2003). Assessment of the reliability of a commercial maturity test kit for composted manures. Compost Sci. Util. *11*, 127-145.

Culman, S.W., Snapp, S.S., Freeman, M.A., Schipanski, M.E., Beniston, J., Lal, R., Drinkwater, L.E., Franzluebbers, A.J., Glover, J.D., Grandy, A.S., Lee, J., Six, J., Maul, J.E., Mirsky, S.B., Spargo, J.T., Wander, M.M. (2012). Permanganate Oxidizable Carbon Reflects a Processed Soil Fraction that is Sensitive to Management. SSSAJ. 76, 494-504.

Devevre, O.C. and Horwath, W.R. (2000). Decomposition of rice straw and microbial carbon use efficiency under different soil temperatures and moistures. Soil Biol. Biochem. *32*, 1773-1785.

Eghball, B., Wienhold, B.J., Gilley, J.E. and Eigenberg, R.A. (2002). Mineralization of manure nutrients. J. Soil Water Conserv. *57*, 470-473.

Erich, M.S., Fitzgerald, C.B., Porter, G.A. (2002). The effect of organic amendments on phosphorus chemistry in a potato cropping system. Agric. Ecosyst. Environ. *88*, 79-88.

Gagnon, B. and Simard, R.R. (1999). Nitrogen and phosphorus release from on-farm and industrial composts. Can. J. Soil Sci. *79*, 481-489.

Gee, G.W. and Bauder, J.W. (2002). Particle size analysis. pp. 383-411. In: Clute, A. (Ed). Methods of soil analysis, part 1. ASA , Madison, USA.

Hai, L., Li, X.G., Li, F.M., Suo, D.R. and Guggenberger, G. (2010). Long term fertilization and manuring effects on physically separated soil organic matter pools under a wheat-wheat-maize cropping system in arid region of China. Soil Biol. Biochem. *42*, 253-259.

Hao, X. and Chang, C. (2002). Effects of 25 annual applications on soluble and exchangeable cations in soil. Soil Sci. *167*, 126-134.

Hunt, J.F., Ohno, T., He, Z., Honeycutt, C.W. and Dail, D.B. (2007). Inhibition of phosphorous sorption to goethite, gibbsite and kaolin by fresh and decomposed organic matter. Biol. Fert. Soils. *44*, 277-288.

Karami, A., Homaee, M., Afzalinia, S., Ruhipour, H. and Basirat, S. (2012). Organic resource management: Impacts on soil aggregate stability and other soil physico-chemical properties. Agric. Ecosyst. Environ.*148*, 22-28.

Kaur, K., Kapoor, K.K. and Gupta, A.P. (2005). Impact of organic manures with and without mineral fertilizers on soil chemical and biological properties under tropical conditions. J. Plant Nutr. Soil Sci. *168*, 117-122.

Kirchmann, H. (1991). Carbonic and nitrogen mineralization of fresh, aerobic and anaerobic animal manures during incubation with soil. Swed. J. Agr. Res. *21*, 165-173.

Kumaragamage, D. (2010). Site specific nutrient management in soils of Sri Lanka: A review of recent work using a systematic approach to formulate fertilizer recommendations for annual crops. J. Soil Sci. Soc. Sri Lanka. 22, 1-15.

Kwabiah, A.B., Stoskopf, N.C., Palm, C.A. and Voroney, R.P. (2003). Soil P availability as affected by the chemical composition of plant materials: Implications for P-limiting agriculture in tropical Africa. Agric. Ecosyst. Environ*.* *100*, 53-61.

Lupwayi, N.Z. and Haque, I. (1999). Leucaena hedgerow intercropping and cattle manure application in the Ethiopian highlands I. Decomposition and nutrient release. Biol. Fert. Soils. *28*, 182-195.

Mapa, R.B. (1999). Fertility Evaluation for Wet Zone Soils of Sri Lanka. J. Soil Sci. Soc. Sri Lanka. *11*, 1-8.

McClean, E.O. (1982). Soil pH and lime requirement. pp. 199-224. In: Page, A.L.(Ed). Methods of soil analysis, part 2. Am. Soc. ASA, SSSA, Madison, USA.

Miller, J.J., Bremer , E., Beasley, B.W., Drury, C.F., Zebarth, B.J. and Karney, F.J. (2012). Long-term effect of fresh and composted cattle manure on the size and nutrient composition of dry-sieved soil aggregates. Can. J. Soil Sci. *92*, 673-683.

Miller, J.J., Sweetland, N.J. and Chang, C. (2002). Soil physical properties of a Chernozemic clay loam after 24 years of beef cattle manure application. Can. J. Soil Sci. *82*, 287-296.

Morvan,T., Nicolardot, B. and Pean, L. (2006). Biochemical composition and kinetics of C and N mineralization of animal wastes: a typological approach. Biol. Fert. Soils. *42*, 513-522.

Nelson, D.W. and Sommers, L.E. (1996). Total carbon, organic carbon and organic matter. pp. 961-1010. In: Sparks, D.L. (Ed). Methods of soil analysis, part 3. ASA, SSSA, Madison, USA.

Odlare, M., Pell, M. and Svensson, K. (2008). Changes in soil chemical and microbiological properties during 4 years of application of various organic residues. Waste Manage. *28*, 1246-1253.

Ohno, T. and Crannell, B.S. (1996). Green and animal manure-derived dissolved organic matter effects on phosphorus sorption. J. Environ. Qual. *25*, 1137-1143.

Olsen, S.R. and Sommers, L.E. (1982). Phosphorus. pp. 403–430. In: Page, A.L. (Ed). Methods of soil analysis, part 2. ASA, SSSA, Madison, USA.

Palm, C.A., Gachengo, C.N., Delve, R.J., Cadisch, G. and Giller, K.E. (2001). Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. Agric. Ecosyst. Environ. *83*, 27-42.

Paul, J.W. and Beauchamp, E.G. (1994). Short-term nitrogen dynamics in soil amended with fresh and composted cattle manure. Can. J. Soil Sci. *74*, 147-155.

Purakayastha, T.J., Rudrappa, L., Singh, D., Swarup, A. and Bhadraray, S. (2008). Long-term impact of fertilizers on soil organic carbon pools and sequestration rates in maize–wheat–cowpea cropping system. Geoderma. *144*, 370-378.

Qian, P. and Schoenau, J.J. (2002). Availability of nitrogen in solid manure amendments with different C:N ratios. Can. J. Soil Sci. *82*, 219-225.

Rajinder, S.A., Gerzabek, M.H.,Haberhauer, G. and Eder, G. (2005). Long-term effects of cropped *vs*. fallow and fertilizer amendments on soil organic matter I. Organic carbon. J. Plant Nutr. Soil Sc. *168*, 108-116.

Rupende, E., Chivinge, O.A. and Mariga, I.K. (1998). Effect of storage time on weed seedling emergence and nutrient release in cattle manure. Exp. Agr. *34*, 277-285.

Shindo,H. and Nishio, T. (2005). Immobilization and remineralization of N following addition of wheat straw into soil: determination of gross N transformation rates by ^{15}N-ammonium isotope dilution technique. Soil Biol. Biochem. *37*, 425-432.

Singh, B. B. and Jones, J. P.(1976). Phosphorus sorption and desorption characteristics of soils as affected by organic residues. SSSA. Proc. *40*, 389-394.

Sommerfeldt, T.G. and Mackay, D.C. (1987). Utilization of cattle manure containing wood shavings:Effect on soil and crop. Can. J. Soil Sci. *67*, 309-316.

Summer, M.E. and Miller, W.P. (1996). Cation Exchange Capacity and Exchange coefficient. pp 1201-1229. In: Sparks, D.L. (Ed) Methods of soil analysis, part 3. ASA, SSSA, Madison, Wisconsin, USA.

Tian, G., Kang, B.T. and Brussaard, L. (1992). Biological effects of plant residues with contrasting chemical compositions under humid tropical conditions-Decomposition and nutrient release. Soil Biol. Biochem. *24*, 1051-1060.

Topoliantz, S., Ponge, J.F. and Ballof S. (2005). Manioc peel and Charcoal: a potential organic amendment for sustainable soil fertility in the tropics. Biol. Fert. Soils. *41*, 15-21.

Vinodhini, S. (2012). Formulation of site-specific fertilizer recommendation for maize cultivation in Wagolla farm , Kegalle. Undergraduate research thesis. Faculty of Agriculture, University of Peradeniya, Sri Lanka.

Weil, R.R., Islam, K.R., Stine, M.A., Gruver, J.B. and Samson-Liebig, S.E. (2003). Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. Am. J. Alternative Agr. *18*, 3-17.

Zibilske, L.M. (1994). C mineralization. pp. 835-863. In: Weaver, R.W. (Ed). Methods of soil analysis, part 2. SSSA, Madison, USA.