ORIGINAL RESEARCH

Impact of Integrated Use of Rice Straw Mulch and Inorganic Fertilizers on Soil N, P, K and Organic Matter in Direct Seeded Lowland Rice (*Oryza sativa* L.) Fields

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Abstract

Integrated use of organic and inorganic fertilizers can improve the crop productivity and sustain soil health and fertility. This study evaluated the impact of a rice straw mulch (4t /ha rate) on soil nutrient status in dry- direct seeded rice (DDSR) and wet- direct seeded rice (WDSR) fields with recommended rates of N, P and K mineral fertilizers in the Anuradhapura District, a major rice growing area of Sri Lanka. Total N, available P, extractable K and soil organic matter content (SOM) was measured at planting, 35 days after sowing, panicle initiation and at harvesting. Application of a rice straw mulch to WDSR, significantly increased the extractable K content in the top 0-10 cm of soil (*i.e*. 112.6 ppm in dry season (DS), 119 ppm in wet season (WS)), when compared to chemical weeded WDSR (*i.e*. 76.1 ppm in dry season and 99.8 ppm in wet season) at the panicle initiation stage.

The K release was greater over the first 35 days after rice straw application in both seasons. The SOM changes were minor during 2 years of treatment application. Although the percentage of total N was significantly high in WS, it did not vary among treatments of study. The available P content was not significant in DS in treatments and in WS the available P content was significantly reduced in the rice straw treated WDSR plots. The study indicated the possibility of enhancing the soil extractable K stocks in WDSR by integrated use of rice straw mulch and mineral fertilizers in both seasons in this region.

Key words: Available P, Dry-direct Seeded Rice, Extractable K, Soil Organic Matter, Wet-direct Seeded Rice

Introduction

A critical aspect of soil management in rice production systems in Sri Lanka is the maintenance of soil productivity, which is affected by soil nutrient status or soil fertility. A survey carried in the dry zone revealed that many farmers especially in the dry zone major irrigation schemes have either abandoned or leased their rice fields [1]. This situation may have an impact on field management practices and long-term soil fertility as the tenants are not interested in investing in long-term soil development activities.

Application of crop residues along with inorganic fertilizers into soil increases the productivity of the system and also sustains the soil health for longer periods [2]. The crop residues are a resource, constituting a readily available source of nutrients and organic material for rice farmers. For example, about 40% of N, 30–35% of P, 80–85% of K, and 40–50% of S absorbed by rice remain in the vegetative parts at maturity [3]. But the occurrence of microbial immobilization of applied N fertilizer is a major problem encountered in profitable utilization of cereal crop residues [4]. An obvious solution to the N immobilization would be to place fertilizer below the C-enriched surface soil layer formed due to surface placement of crop residues [5]. Studies on soil nutrient dynamics in integrated system management of inorganic fertilizers and rice straw may provide a future implication on reduction of mineral fertilizers in rice farming. In

2009, the Government of Sri Lanka has expended Rs. 22,215 million to import 50,795 MT of fertilizers[6]. Therefore, technology development for combined use of organic and inorganic fertilizers may help to save the cost involved in fertilizer importation to a certain extent while maintaining productivity of rice fields.

Hence, this study was carried out to validate the hypothesis that the application of rice straw mulch helps to increase soil nutrient status in direct seeded lowland rice soil in the low country dry zone of Sri Lanka, without causing the immobilization of N in an integrated system of rice straw mulch and mineral fertilizers.

Materials and Methods

Experimental site

The site was located in Puliyankulama in the Anuradhapura District at 8°, 21'0" N, 80° 23' 0" E. The study was conducted over a two year period from May 2009 to March 2011, to encompass two minor dry seasons (DS) and two major wet seasons (WS) that correspond to the South-West (April to September) and North-East monsoons (October to February) respectively. The soil of site was Low Humic Gley with a sandy clay loam texture [7]. The rainfall during the study period was 72.5 mm, 650.4 mm, 209.8 mm and 1386.7 mm in 2009 DS, 2009/10 WS, 2010 DS and 2010/11 WS, respectively. The mean seasonal temperature was around 29^0 C and 26^0 C for DS and WS respectively, with an average maximum temperature of 33.5^0 C in DS and 30^0 C in WS and an average minimum temperature of 25.2^0 C in DS and 22.6^0 C in WS.

Description of the experiment

The study was conducted to test six treatments. The treatment combinations were, dry-direct seeded rice (DDSR) + non-weeded (UW), DDSR + rice straw mulch (RSM), DDSR + chemical weeding (C), wet-direct seeded rice (WDSR) + UW, WDSR + RSM and WDSR + C. The treatments were arranged in a randomized complete block design (RCBD) with three replications in all seasons of study.

At the onset of the rains in early May 2009, 18 plots of 6 m x 3 m were prepared and divided into three blocks, each having 6 plots. Tillage operations for DDSR and WDSR were practiced separately by starting the land preparation for WDSR, two weeks earlier than for the DDSR plots. First, nine plots where the puddle-land preparation is required were tilled two weeks prior to crop establishment and water was impounded. Harrowing was done after two weeks in same plots followed by fine leveling. In the 9 plots where direct seeding was practiced, the soil was moistened, followed by ploughing and rough leveling, on the same day.

An improved rice variety Bg 352 (duration 3.5 month) was used for both DDSR, and WDSR systems. WDSR plots were sown with pre-germinated seeds into puddle-soil at a seed rate of 137.5 kg / ha. DDSR plots were sown with dry seeds onto moist plots at the same rate. In the six plots, where rice straw was a treatment, a layer of air dried rice straw collected from the previous rice crop of Bg 352 was applied uniformly, just after sowing, at the rate of 4t/ha (*i.e.* 400g/m^2) forming a 2 cm thick straw layer on the soil surface. In the other six plots, where the chemical weeding was a treatment, Ethoxysulfuron 20 + fenoxaprop 69 g a.i./l (Tiller® Gold) was applied at a rate of 0.5 L/ha (dilution- 15 ml of herbicide in 16 L of water) at 10-14 days after sowing (the date of herbicide application was adjusted between 10-14 days according to prevailing condition of the atmosphere in the season).

All plots received the same rate of inorganic fertilizers as recommended by the Department of Agriculture in Sri Lanka [8]. The rate of NPK application was 120 - 40 - 40 kg of N, P_2O_5 and K_2O per ha respectively. All the P_2O_5, 20 kg/ha of K_2O and 5 kg/ha of N were applied at the time of crop establishment. The remaining N was applied at 14 days after sowing (DAS) (35 kg/ha), 35 DAS (55 kg/ha) and at panicle initiation stage (25 kg/ha). The rest of K_2O (20 kg/ha) was applied at panicle initiation stage. To provide NPK, commercially available fertilizers of Urea (46% N), Triple super phosphate (45% P_2O_5) and Muriate of potash (60% K_2O) were used. All plots were irrigated at 5 day intervals and the water level was always kept at 2-3 cm above soil surface at the time of irrigation, until crop maturity.

Measurements

To determine the initial soil fertility status, soil samples were taken from the undisturbed lowland paddy land. Ten soil samples from the top 10 cm layer were taken in May 2009, before land preparation. All soil samples were randomly collected from ten sampling points and mixed thoroughly to a 1 kg composite sample. The soil sample was air dried by spreading out in a clean, warm, dry area for three days and kept in the laboratory until their analysis. An undisturbed soil sample was also taken from the top soil (0-10 cm), for determination of bulk density.

Thereafter, soils were sampled prior to the application of inorganic fertilizers at planting, 35 DAS, panicle initiation and harvesting stages during each season. Composite sampling was done at all sampling dates, where 4-5 sub-samples were collected randomly from selected locations in plots, and the subsamples were composited for analysis. Soil samples were air-dried by spreading out in a clean, warm, dry area, and air drying for two to three days. The air dried soil samples were subjected to analysis - Soil pH using a 1:2.5 soil water ratio, total nitrogen by Kjeldahl distillation [9], available phosphorous by Olsen method[10], extractable potassium by Ammonium bi-carbonate ($NaHCO_3$) extraction and flame photometry and organic matter content by Walkey and Black method[11].

Statistical Analysis

The comparison of treatments was done on a seasonal basis (dry season and wet season). Prior to the detailed analysis, the seasonal data were tested for equal variances and DS and WS data were pooled. Analysis of variance was carried out for the data collected using the SAS statistical analytical package (Version 8.12, SAS Institute, Cary, NC). The Duncan's test was used for mean separation when the treatment effects were significant.

Results

Soil Properties Prior to Experiment

Soil pH, total N, available- P, and extractable- K of the site prior to crop establishment were, 7.2±0.21, 0.28%±0.004%, 10±0.81 ppm and 62±0.47 ppm respectively. The top soil (0-10 cm) bulk density was 1.4 t / m^3.

Total Soil Nitrogen

Total soil N (%) content was significanltly ($p<0.05$) influenced by the season with higher values in the wet season at initial, 35 days of sowing and harvesting stages. The total soil N (%) content was not statistically significant among treatments at all dates of sampling in both seasons (Table 1).

Table 1. Total nitrogen content in soil as affected by season, method of crop establishment and rice straw mulch

	Total Nitrogen content (%)							
	Initial		35 DAS		PI		Harvesting	
Trt / Season	DS	WS	DS	WS	DS	WS	DS	WS
DDSR+UW	0.33 a	0.36 a	0.32 a	0.46 a	0.39 a	0.38 a	0.34 a	0.41 a
DDSR+RSM	0.32 a	0.36 a	0.32 a	0.44 a	0.39 a	0.36 a	0.34 a	0.41 a
DDSR+C	0.34 a	0.39 a	0.38 a	0.46 a	0.42 a	0.40 a	0.38 a	0.36 a
WDSR+UW	0.30 a	0.36 a	0.37 a	0.43 a	0.40 a	0.35 a	0.38 a	0.38 a
WDSR+RSM	0.37 a	0.35 a	0.36 a	0.41 a	0.39 a	0.35 a	0.33 a	0.42 a
WDSR+C	0.32 a	0.36 a	0.34 a	0.41 a	0.35 a	0.34 a	0.35 a	0.36 a
Seasonal Average	0.33 b	0.36 a	0.35 b	0.44 a	0.39 a	0.36 a	0.35 b	0.39 a

DDSR, dry- direct seeded rice; WDSR, wet- direct seeded rice; UW, non-weeding; C, chemical; RSM, rice straw mulch; DS, dry season; WS, wet season; DAS, days after sowing; Trt, treatment. In a column, values followed by a common letter are not significantly different at 5% probability. In the last row, values for the seasonal average followed by a common letter are not significantly different at 5% probability.

Available Phosphorous

The available P content in soil was significantly influenced ($p<0.05$) by the season at planting, panicle initiation and harvesting stages and the values were greater in WS than in the DS. Among treatments, in WS, a significantly low available P content was seen in WDSR+RSM at 35 days after sowing, panicle initiation and harvesting stages. Although the available P content was numerically lower in WDSR+RSM in DS, it was not statistically significant from the other treatments (Table 2). Thus, a reduction of available P stock was observed in rice straw treated WDSR plots in both seasons. It could be due to a significant increase in plant biomass (757.7 g/m2 in WS and 839.7 g/m2 in DS at 50% heading stage) in WDSR+RSM treatment compared to other treatments. In terms of establishment method, the available P stocks were greater in the DDSR method, than in the WDSR method at the time of harvesting in both seasons (Table 2). The difference between DDSR and WDSR methods for available P contents were significant at P=0.0149 at the time of harvesting.

Extractable Potassium

The seasonal effect for extractable potassium (K) content in soil was significant ($p<0.05$) at 35 days after sowing, harvesting and a significantly higher extractable soil potassium (K) content was observed in the WS. The application of rice straw mulch had a pronounced impact on soil extractable K content in WDSR and DDSR methods in both seasons (Table 3). The release of K from rice straw along with inorganic fertilizers in DS occurred within 35 days of mulching was greater (15 ppm), when compared to the period from 35 days after sowing to panicle initiation (10.44 ppm) in WDSR+RSM. A similar comparison in WS revealed the occurrence of K release (30.7 ppm) within initial 35 days of mulching and 4 ppm from 35 days after sowing to panicle initiation in WDSR+RSM. Thus, greater release of K into the soil environment could be observed due to rice straw mulching in the initial 35 days of application than in the period from 35 days of sowing to panicle initiation in both seasons. Compared to the straw mulched plots, the values of K release were less in non-mulched plots. For example, in WDSR+C, the widely adopted practice in lowland rice culture in Sri Lanka, the K release was 1.5 ppm and 8.6 ppm, respectively for 0-35 days after sowing and 35days of sowing to panicle initiation in DS. In WS, the respective values were 1.8 ppm and 20.2 ppm.

The increment in extractable soil K content was greater until panicle initiation in rice straw treated WDSR plots than in the non-mulched plots. In non-mulched plots, the soil extractable K content was reduced from crop establishment up to 35 days after sowing. Thereafter, an enhancement of extractable K content was observed with the application of the second top dressing of N at 35 days of sowing.

The percent increase of soil extractable K stocks due to rice straw mulch at two important stages (*i.e.* panicle initiation and harvesting) were calculated in DDSR and WDSR methods in both seasons by considering the WDSR+C; the present practice in Sri Lanka as the standard treatment. The enhancements of 43 % and 23% in soil K, respectively in panicle initiation and harvesting in DS were recorded in WDSR+RSM. In DDSR+RSM, the respective values for same season were 15% in both panicle initiation and harvesting stages. A similar comparison for WS illustrated a higher percentage value of soil extractable K stock enhancement than in the DS. For example, the K enhancements in soil were 19% and 53% in WDSR+RSM and 15 % and 44 % in DDSR+RSM, respectively for panicle initiation and harvesting stages in the WS. Thus, the percentage values revealed that the K stock build up in soil was greater in WDSR+RSM than in the DDSR+RSM at panicle initiation and harvesting stages in both seasons.

Table 2. Available P content in soil as affected by season, method of crop establishment and rice straw mulch.

Available P content in soil (ppm)								
	Initial		35 DAS		PI		Harvesting	
Trt. / Season	DS	WS	DS	WS	DS	WS	DS	WS
DDSR+UW	11.8 a	15.1 a	12.3 a	22.5 a	17.0 a	19.0 ab	19.1 a	22.3 ab
DDSR+RSM	12.8 a	16.3 a	8.8 b	24.3 a	15.0 a	19.8 ab	20.0 a	25.1 a
DDSR+C	11.6 a	15.0 a	8.8 b	22.8 a	14.6 a	23.8 a	16.1 a	21.2 ab
WDSR+UW	12.0 a	16.5 a	9.0 ab	19.1 ab	15.1 a	23.3 a	17.0 a	19.0 b
WDSR+RSM	11.1 a	15.3 a	9.0 ab	15.8 b	12.3 a	16.0 b	15.3 a	16.8 b
WDSR+C	12.5 a	16.1 a	9.1 ab	20.1 ab	17.0 a	24.1 a	17.3 a	19.3 ab
Seasonal Average	11.9 b	15.8 a	9.5 b	20.7 a	15.2 b	21.0 a	17.5 a	20.6 a

DDSR, dry- direct seeded rice; WDSR, wet- direct seeded rice; UW, non-weeding; C, chemical; RSM, rice straw mulch; DS, dry season: WS, Wet season; DAS, days after sowing; Trt, treatment. In a column, values followed by a common letter are not significantly different at 5 % probability. In the last row, values for the seasonal average followed by a common letter are not significantly different at 5% probability.

Table 3. Extractable K content in soil as affected by season, method of crop establishment and rice straw mulch.

Extractable K content in soil (ppm)								
	Initial		35 DAS		PI		Harvesting	
Trt. / Season	DS	WS	DS	WS	DS	WS	DS	WS
DDSR+UW	78.6 a	77.6 ab	65.16 c	74.3 c	90.5 b	86.3 b	81.6 abc	90.3 bc
DDSR+RSM	90.5 a	90.16 a	85.66 ab	97.6 b	87.5 b	115.0 a	91.0 ab	109.6 ab
DDSR+C	77.6 a	72.0 b	68.50 bc	74.4 c	87.6 b	80.8 b	73.3 c	76.8 cd
WDSR+UW	63.5 a	80.16 ab	61.50 c	71.6 c	76.8 b	82.0 b	74.6 a	68.1 d
WDSR+RSM	86.6 a	84.3 ab	102.16 a	115.0 a	112.6 a	119 a	96.8 a	116.0 a
WDSR+C	66.0 a	77.8 ab	67.50 bc	79.6 c	76.1 b	99.8 ab	78.6 bc	75.8 cd
Seasonal Average	77.1 a	83.3 a	75.1 b	85.4 a	88.5 a	97.2 a	82.7 b	89.4 a

DDSR, dry- direct seeded rice; WDSR, wet- direct seeded rice; RSM, rice straw mulch; DS, dry season: WS, Wet season; DAS, days after sowing; Trt, treatment .In a column, values followed by a common letter are not significantly different at 5% probability. In the last row, values for the seasonal average followed by a common letter are not significantly different at 5% probability.

Soil Organic Matter Content (SOM)

The SOM content increased marginally at the time of harvesting in both seasons (Table 4). At the time of harvesting the soil organic matter content was significantly higher ($p<0.05$) in WS than in the DS. However, within four cropping cycles, there was no significant influence by rice straw mulch (RSM) on SOM content.

Table 4. Organic matter content in soil as affected by season, method of crop establishment and rice straw mulch.

	Soil organic matter content (ppm)							
	Initial		35 DAS		PI		Harvesting	
Trt. / Season	DS	WS	DS	WS	DS	WS	DS	WS
DDSR+UW	3.2 a	3.6 ab	4.2 a	4.0 a	4.7 a	3.9 a	3.7 a	4.6 a
DDSR+RSM	3.1 a	3.8 ab	4.1 a	4.0 a	4.3 ab	3.3 ab	3.8 a	4.3 a
DDSR+C	2.9 ab	3.9 a	3.5 a	3.7 a	4.3 ab	3.8 a	3.6 a	4.5 a
WDSR+UW	2.6 b	3.1 b	3.7 a	2.96 a	4.3 ab	3.0 b	3.3 a	4.5 a
WDSR+RSM	3.0 ab	3.4 ab	3.6 a	4.0 a	4.0 ab	3.8 a	3.2 a	4.7 a
WDSR+C	2.8 ab	3.5 ab	3.9 a	3.2 a	3.8 b	3.2 b	3.6 a	4.4 a
Seasonal Average	2.9 b	3.6 a	3.8 a	3.6 a	4.2 a	3.5 b	3.5 b	4.5 a

DDSR, dry- direct seeded rice; WDSR, wet- direct seeded rice; UW, non-weeding; C, chemical; RSM, rice straw mulch; DS, dry season: WS, Wet season; DAS, days after sowing; Trt, treatment. In a column, values followed by a common letter are not significantly different at 5 % probability. In the last row, values for the seasonal average followed by a common letter are not significantly different at 5% probability.

Discussion

At the rate of 4 t /ha of straw mulching, the extractable K content was heavily influenced. The K build-up in soil at panicle initiation stage in WDSR+RSM treatment (112.6 ppm) was significant than the WDSR+C (76.1 ppm) in DS. Similarly, in WS a greater increase in soil K content in WDSR+RSM (119.6 ppm) than the WDSR+C (99.8 ppm) at panicle initiation stage was recorded. This trend did not change at the time of harvesting as indicated by a higher level of soil K stock in rice straw treated plots than in the plots, that received inorganic fertilizers only. Previous studies also found that the crop residues contain large quantities of potassium, and their recycling can markedly increase K availability in soils[12-14]. The release of K by straw was greater in the initial 35 days of application in both seasons. Among the crop growing seasons, the amount of K release was greater in WS than that in the DS.

Since addition of rice straw mulch at the rate of 4t/ha enhanced the soil K stocks, it may be possible to reduce the amount of K added through inorganic fertilizers in an integrated approach. However, further studies are needed to determine the exact quantity of inorganic fertilizer that can be reduced in integrated system management of rice straw mulch and inorganic fertilizers in lowland rice culture.

The N fertilization may have an influence on the availability of K in soil. As indicated in a study [15] in the short-term, K concentration in the soil solution may increase following NH_4^+ fertilization, whereas long-term NH_4^+ fertilization have depleted exchangeable and non-exchangeable K in soil. In this study, an enhancement of soil exchangeable K content after N fertilization at 35 days of sowing was clearly observed.

The study revealed that the total nitrogen content was not affected significantly by treatments. In general, residues with low C:N ratio tend to exhibit net N mineralization, while residues with high C:N ratio exhibit immobilization [16]. Hence, in farming systems where the straw remains in the field after harvest, rapid decomposition is important to minimize negative effects on the following crop caused by N immobilization [17,18]. A study indicated that the yield depression following straw incorporation has been mitigated by adding inorganic N [19]. In this study, inorganic N applied as recommended by the Department of Agriculture in Sri Lanka was sufficient to mitigate the problem of N immobilization in treatment with rice straw mulch in both wet and dry direct seeding methods.

In this study, the seasonal effect on total nitrogen content was significant, showing high total nitrogen content in WS than in the DS. It is well recognized that temperature is one of the most important driving forces of ammonia volatilization from soils[20-22]. Therefore, it is expected that ammonia volatilization from paddy soils in DS, which is characterized by the prevalence of high temperatures, may be higher than in the WS.

In both seasons, even though statistically not significant, WDSR+RSM had lower values of available P. Thus, it indicated that the P depletion was greater in rice straw treated WDSR method in both seasons. Previous research reported that the availability of soil phosphorus is enhanced by adding organic matter, due to chelating of polyvalent cations by organic acids and other decaying products[23-25]. In general, the phosphorus compounds act as energy currency within the plants and involve in wide range of plant processes from permitting cell division to developing good root system[26]. This study clearly showed the enhancement of early root growth in rice straw treated WDSR plots (data are not shown). Thus, the extensively developed root system, in rice straw treated plots could be utilized greater available P, leading to depletion of P stocks to a greater extent than in the non-mulched plots.

The changes in SOM content were very little within the four cropping cycles of this study. This is consistent with a study conducted under tropical warm conditions, which showed that in 12- and 14-year studies of incorporation of wheat residue, where SOM changed very little[27]. In contrast, some studies have confirmed positive increases in organic matter with application of residues[28] indicating that decomposition of plant residues added to the soil is an important component in the turnover of organic C. However, this depends on several conditions; plants, soil, management (*e.g.* soil tillage) and climate. This study was carried out in four seasons (*i*.e. two DS's and two WS's) which are climatically different due to the prevalence of hot conditions in DS.

Studies have shown that warmer temperatures and high moisture result in higher organic matter decomposition[28-30]. This study also revealed a lower SOM accumulation in warmer DS than in the WS at the time of harvesting.

Conclusion

A better understanding of plant nutrients in soil in relation to productivity is immensely important to develop sustainable rice production systems in the low country dry zone of Sri Lanka. Although a fertilizer subsidy is granted for rice at present, effective utilization of both organic and inorganic fertilizers are required for sustainable soil health. The recycling of rice straw, which is available in abundance, has a potential to return a considerable amount of plant nutrients to the soil. The study indicated that the integrated use of inorganic fertilizers and rice straw mulching helps the K build up in soil. Thus, there is potential to reduce the amount of mineral K added through inorganic fertilizers in this integrated system. Thus, heavy reliance on K fertilizer (*i.e.* Muriate of potash) could be reduced in rice farming and the foreign exchange for importation of K fertilizers could be saved.

However, further studies are needed to determine the exact quantity of K that can be reduced from inorganic fertilizers in integrated rice systems. Although the rice straw has a high C: N ratio, immobilization of N could be avoided with the application of inorganic nitrogen at the recommended rate. The P depletion was greater in rice straw treated WDSR plots compared to no mulch plots. The SOM changes were minor during 2 years of treatment application. Therefore, this study illustrated the possibility of soil K build up in wet-direct seeded lowland rice, without immobilization of nitrogen by integrated system management of inorganic fertilizers and rice straw mulch.

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References

1. Weerakoon WMW, Mutunayaka MMP, Bandara C, Rao AN, Bhandari DC, *et al.* Direct-seeded rice culture in Sri Lanka. *Field Crops Research* 2011; 121: 53-63.

2. Gawai PP, Pawar VS. Integrated nutrient management in sorghum (*Sorghum bicolor*) – chickpea (*Cicer arietinum*) cropping sequence under irrigated conditions. *Indian Journal of Agronomy* 2006; 51: 17-20.

3. Dobermann A, Fairhurst TH. "Rice: Nutrient Disorders & Nutrient Management." Potash & Phosphate Institute (PPI), Potash & Phosphate Institute of Canada (PPIC) and International Rice Research Institute (IRRI), East & South Asia Programs of PPI and PPIC, Singapore 2000.

4. Mary B, Recous S, Darwis D, Robin D. Interactions between decomposition of plant residues and nitrogen cycling in soil. *Plant and Soil* 1996; 181: 71-82.

5. Doran JW, Smith MS. Organic matter management and utilization of soil and fertility nutrients. In: Follet RF *et al.*, (Eds). *Soil Ferttility and Organic Matter as Critical Components of Production Systems. ASA Spec. Pub. 19*, Madison, WI: ASA, SSSA, and CSSA, 1987: 51-70.

6. Central Bank of Sri Lanka. Central Economic and social statistics, agriculture, fertilizers, 2000-2009. Colombo: Central Bank of Sri Lanka, 2011. 52 p.

7. Duminda DMS, Amerasekara MGTS, Jinadasa DM, Karunarathne KN, Vidyarathna DD. Characterization of soil physical and chemical properties along an undulating terrain of Radish Brown Earth and Low Humic Gley soils at Puliyankulama, Anuradhapura. Proceedings of RUSL - Research Symposium, FMAS, Saliyapura.2010: 1-5.

8. Sri Lanka rice knowledge bank [internet]. [Available from: http://www.knowledgebank.irri.org/sriLanka/index.html. (Accessed on: 02/02/2009)

9. Van Ranst E, Verloo M, Demeyer A, Pauwels JM. *Manuals for the Soil Chemistry and Fertility Laboratory*. Gent, Belgium: University of Gent, 1999.

10. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular 939 Washington D.C.:U.S. Government Printing Office, 1954.

11. Walkley A, Black IA. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 1934; 37: 29-37.

12. Ning CG, Hu TG. The role of straw-covering in crop production and soil management. *Better Crops International* 1990; 6(2): 6-7.

13. Patil MN, Zade KB, Naphade KT, Kharkar PT. Decomposition of organic materials in soil in relation to nutrient mineralization. *Journal of Maharashtra Agriculture Universities* 1993; 18: 348-51.

14. Chatterjee BN, Mondal SS. Potassium nutrition under intensive cropping. *Journal of Potassium Research* 1996; 12: 358-64.

15. Milford GFJ, Johnston AE. Potassium and Nitrogen Interactions in Crop Production. Proceedings 615 International Fertilizers Society, York, UK.2007.

16. Qian P, Schoenau J. Availability of nitrogen in solid manure amendments with different C:N ratios. *Canadian Journal of Soil Science* 2002; 82: 219-25.

17. Chesire MV, Bedrock C., Williams BL, Chapman, SJ, Solntseva I, *et al*. The immobilization of nitrogen by straw decomposition in soil. *European Journal of Soil Science* 1999; 50: 329-41.

18. Henriksen TM, Breland TA. Evaluation of criteria for describing crop residues degradability in a model of carbon and nitrogen turnover in soil. *Soil Biology and Biochemistry* 1999; 31: 1135-49.

19. Azam F, Lodhi A, Ashraf M. Availability of soil and fertilizer N to wetland rice following wheat straw amendment. *Biology and Fertility of Soils* 1991; 11: 97-100.

20. Olesen, JE, Sommer SG. Modeling effects of wind speed and surface cover on ammonia volatilization from stored pig slurry. *Journal of Agricultural Science* 1993:27:2567-574.

21. He ZL, Alva AK, Calvert DV, Bank DJ. Ammonia volatilization from different fertilizer sources and effects of temperature and soil pH. *Soil Science* 1999; 164: 750-58.

22. Liu GD, Li YC, Alva AK. Temperature quotients of ammonia emission of different nitrogen sources applied to four agricultural soils. *Soil Science Society of America Journal* 2007; 71: 1482-89.

23. Jama B, Rob AS, Buresh RJ. Agronomic and economic evaluation of organic and inorganic sources of phosphorus in Western Kenya. *Agronomy Journal* 1997; 89: 597-604.

24. Reddy SS, Reddy VC, Ananda MC, Sivaraj B. Direct effect of fertilizers and residual effect of organic manures on yield and nutrient uptake of maize (*Zea mays* L.) in groundnut-maize cropping system. *Crop Research* 2005; 29: 390-95.

25. Mohanty S, Paikaray NK, Rajan AR. Availability and uptake of phosphorus from organic manures in groundnut (*Arachis hypogeal* L.)-corn (*Zea mays* L.) sequence using radio tracer technique. *Geoderma* 2006; 133: 225-30.

26. Meena S, Senthilvalavan P, Malarkodi M, Kaleeswari RK. Residual effect of phosphorus from organic manures in sunflower-assessment using radio tracer technique. *Research Journal of Agriculture and Biological Sciences* 2007; 3: 377-79.

27. Adetunji MT. Organic residue management, soil nutrient changes and maize yield in a humid tropical Ultisol. *Nutrient Cycling Agroecosystems* 1997; 47: 189-95.

28. Swift MJ, Heal OW, Anderson JM. *Decomposition in terrestrial ecosystems. Studies in Ecology, Vol. 5*.Berkeley, CA: University of California Press,1979.

29. Preston CM, Trofymow JA, Group CIDEW. Variability in litter quality and its relationship to litter decay in Canadian forests. *Canadian Journal of Botany* 2000; 78: 1269-87.

30. Baker III T, Lockaby G, Conner WH, Meier CE, Stanturf JA, *et al*. Leaf Litter Decomposition and Nutrient Dynamics in Four Southern Forested Floodplain Communities. *Soil Science Society of America Journal* 2001; 65(4): 1334-347.