International Journal of Environment & Agricultural Science

P Kumar, et al., Int J Environ & Agri Sci 2017, 1: 1
1: 004

Reasearch

Lantana Camara Leaf Litter Mulching Improves Availability of Soil Nutrients And Yield of Rainfed Rice in Himalayan Mountains

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Abstract

In the Central Himalayan mountains in India, rainfed agriculture is the mainstay of local people. The rainfed crop fields are poor in soil fertility and crop yield, and require sustainable soil fertility management practices. Conventionally, huge amount of farm yard manure (FYM; consisting of nutrient poor leaf litter of the surrounding Oak and Pine forests) is applied in these crop fields to restore soil fertility. An experiment was therefore conducted to investigate the effect of leaf litter (Oak and Pine) mulching over the conventional practice (control; that involves use of FYM). Also, *Lantana camara* (a weed with high quality leaf residue) was tested as a sole mulch material and also mixing with Oak and Pine leaf litter in four (L_1-L_4) different combinations in the experimental plots.

Across the four mulch combinations, the L_4 (100% *Lantana* mulch) treated experimental plots recorded significantly greater soil organic carbon, phosphorus, NO_3-N, NH_4-N and N-mineralization as compared to control. Across all the mulch treatments the mean values of OC (range= 0.57-0.77%), total N (0.15-0.17%), total P (0.29-0.39%), NO_3-N (1.92-2.47 µg g^{-1} dry soil), NH_4-N (3.56-4.74 µg g^{-1} dry soil), N-mineralization (3.53-5.81 µg g^{-1} $month^{-1}$) varied significantly. Microbial biomass C was recorded highest in the L_4 (422.82 µg g^{-1} dry soil) and lowest in the L_1 treated plots (310.03 µg g^{-1} dry soil). Crop biomass (3627.2 vs. 2475.9 kg ha^{-1}) and rice grain yield (960.5 vs. 632.5 kg ha^{-1}) were found significantly greater in L_4 treated plots as compared to control. Thus, use of *Lantana* leaves as mulch, and mixing it with Oak and Pine leaves may be practiced for crop yield improvement and sustainable soil fertility management in the rainfed rice farming in the Central Himalayan mountains.

Keywords: *Lantana* Mulching; Rainfed Farming; Soil Physico-Chemical Properties; Microbial Biomass; N-Mineralization; Rice Yield

Introduction

Rice (*Oryza sativa* L) is the predominant staple food crop of nearly half of the world's population covering over 160 million ha area in the world producing more than 700 mt annually [1]. Worldwide, the area under rice cultivation is increasing fast due to ever increasing human demand. In intensively cultivated rice fields, the capacity of soil to supply plant-available nutrients may decline unless the soils are managed properly [2]. In order to enhance and /or maintain crop productivity, rice cultivators have become increasingly dependent on chemical N fertilizers. Recent observations of stagnant or declining yields under rice cropping with high levels of N fertilizer have raised concern about the long-term sustainability of rice yield. It has been reported that the efficiency of fertilizer use by rice is low due to large N losses through leaching [3]. Several studies have shown that the application of nitrogenous fertilizer to soils also frequently inhibits methane oxidation in soil, a process which constitutes a significant sink for atmospheric methane [4-6].

Optimization of C and N cycling through soil organic matter enhancement can improve soil fertility and crop yield while reducing the negative environmental impact [7,8]. The application of organic matter in the form of plant residues has long been known to improve the properties of soils, especially the soil organic matter content [9,10]. Soil organic matter, particularly its labile components (microbial biomass), play a key role in maintaining the fertility and structure of soils [11]. It is reported that applying organic matter residue in soil enhance yield of rice in comparison to FYM application [12,13]. Maximum effect of wheat residue inputs on microbial biomass and crop yield in dry land rice cultivation is reported [14]. Application of crop residue under reduced tillage has been frequently proposed as an alternative to soil fertility management to achieve higher crop yield, carbon sequestration and soil and water conservation [15-17]. Delaying incorporation of

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Sub Date: April 25, 2017, **Acc Date:** May 15, 2017, **Pub Date:** May 16, 2017.

Citation: P Kumar, M Pant and GCS Negi (2017) Lantana Camara Leaf Litter Mulching Improves Availability of Soil Nutrients And Yield of Rainfed Rice in Himalayan Mountains. Int J Environ & Agri Sci 1: 004.

crop residues to delay the release of NO_3 and hence reduce leaching has also been suggested [18].

In the Central Himalayan mountains in India, rainfed agriculture on tiny sloping terraces is the mainstay of the local people. Rainfed crop fields are characterized by low soil fertility, low soil moisture and low fertilizer input [19,20], that results into poor crop yield (0.1-1.3 t $ha^{-1}yr^{-1}$) [21]. Traditionally, huge quantities (≈ 1.7 t ha^{-1}) of FYM (that consists of leaf litter of Oak and Pine forests used for animal bedding and composted with cattle urine and dung) is applied for replenishment of soil fertility at the time of seed bed preparation every season. The high lignin and low N and P content in Oak and Pine litter (Table 1) decompose and release nutrients slowly in the temperate climate of the region [22,23], and leaching of nutrients due to rainfall-runoff leads to a nutrient poor soil (mean values of N=0.16%, P=0.06% and OC=1.21%) [24]. A high quality organic matter mulch (high N and P and low lignin containing *Lantana* leaves) was therefore considered to be useful to enhance the rate of decomposition and nutrient release when mixed with leaf litter of Oak and Pine, as has been reported earlier [25,26]. In this region studies on the use of *Lantana* (a weed that grows profusely around the croplands) as a mulch material has been found to restore soil fertility and moisture retention [27], enhance root growth, nutrient uptake and grain yield of maize and wheat [28,29]. It was found that mulching with Pine and *Lantana* leaves increased the P-use efficiency and yield of wheat [30]. Therefore, it was hypothesized that mulching *Lantana* leaves may provide a quick source of nutrients to the decomposer population and increases the nutrient release and improves the soil fertility and crop yield. The benefit of *Lantana* mulching may further improve the soil moisture [31], and hydraulic properties (soil aeration and water infiltration) of soil for wheat cultivation that become generally unfavorable after rice cropping [32,33]. Rice (*Oryza sativa* L.) followed by wheat (*Triticum aestivum*) is the major crop system in this region.

The objective of the present work was:

to evaluate the effect of application of different combinations of three type of leaf litter (Oak, Pine and *Lantana*) on soil fertility and yield of rice in rainfed condition to compare the traditional practice of crop cultivation and mulching to recommend suitable soil management practices for the rainfed farming in the Himalayan region.

Materials and Methods

Site Details

The experimental site is located at 29^0 38'N and 79^0 37'E; 1155 masl at Kosi-Katarmal, Almora that is a part of the western Himalaya, India. The region has a subtropical climate dominated by a typical monsoonal character. The year is divisible into a cold winter (November-February), a hot summer (April-June) and a wet and warm rainy season (July-September). During the two years of study (2006-2007), the mean annual rainfall was 723.7 mm (2006) and 1039 mm (2007), and the mean monthly minimum temperature was found ranging from a minimum of 0.35 ^{0}C to 20.18 ^{0}C (January) and a maximum of 12.0 ^{0}C to 31.31 ^{0}C (June).

The soils of the study area are sandy loam to loamy sand with a neutral reaction. At the start of experiment the mean values of various physico-chemical characteristics of the soil were as follows: water holding capacity (51.5%), bulk density (1.2 g cm^{-3}), sand (19.65%), silt (61.42%) and clay (17.12%). The pH (5.62), organic carbon (0.43%) total N, P and K were 0.102%, 0.062%, 0.56%, respectively. The C:N ratio was computed as 4.2. The mean nitrate-N values ranged from 1.0 to 1.02 µg/g, ammonium-N from 1.54 to 1.55 µg/g, available-P from 3.23 to 3.26 µg/g and available-K from 0.92-0.95 µg/g. The rate of N-mineralization in the soils of the study area has been reported ranging from 17.1-31.1 µg g^{-1} $month^{-1}$ [34].

Table 1. Litter nutrient concentration in different treatments of mulching.

* Source: [71]

Nutrient	Litter nutrient concentration (%)				
	Oak	Pine	*Lantana*	FYM	LSD
C	48.50±0.15	50.20±0.38	40.25±0.35	25.50±0.30	1.004
N	1.10±0.05	0.80±0.04	1.30±0.03	0.72±0.02	1.121
P	0.06±0.010	0.036±0.009	0.257±0.006	0.08±0.002	0.024
K	0.22±0.020	0.279±0.002	1.23±0.26	0.45±0.021	0.064
C:N	44.09±2.04	60.48±2.63	30.96±0.81	35.40±0.93	5.782
Lignin*	17.54±0.05	28.60±0.11	6.30±0.10	21.50*	6.136
Polyphenol:N*	7.46	3.76	4.73	0.42	-

±Standard error

Experimental Design

Thirty nine experimental plots (size 5 x 5 m^2 and slope <5°) were prepared at the above site. Mulch material (leaf litter of Oak and Pine trees and mature leaves of *Lantana*) was collected from the nearby forests and sun dried. Four mulch treatments (L_1-L_4) with nine replicate plots each were established in May 2006, in a randomized block design. The study and the same plots were allocated to the same treatments in the following year (2007). The quantity of mulch materials applied to the experimental plots of 25 m^2 (surface mulching) just after sowing rice crop in late May 2006 was as follows: L_1 (25% Oak= 1.22 kg, 25% Pine=1.63 kg and 50% *Lantana*=2.07 kg), L_2 (33% Oak=1.62 kg, 33% Pine=2.14 kg and 33% *Lantana*=1.37 kg), L_3 (12.5% Oak= 0.612 kg, 12.5% Pine= 0.812 kg and 75% *Lantana*= 3.11kg) and L_4 (100% *Lantana*=4.116 kg). In addition, three control (conventional tillage; CT) plots were maintained as conventional practice of crop cultivation in the region that involved FYM application (7.5 kg/plot). The amount of mulch material applied to each of the experimental plots was equated in terms of N input through FYM (@ 1.7 t/ha); this is equivalent to 21.6 kg N ha^{-1}. The C:N ratio of the mulch materials was computed as: L_1 (39.6), L_2 (42.9), L_3 (35.4) and L_4 (30.9). The seed input was @ 100-120 kg /ha as followed in the local conventional practices.

Soil Characteristics

Physico-chemical characteristics of the soil of the experimental plots were analyzed at the initiation of this experiment (prior to sowing the rice crop in May) and just after crop harvesting (October). Soil pH was measured by using electronic pH meter (1:2.5; soil: water ratio) and water holding capacity by perforated circular brass box. The organic C content was analyzed by Walkley-Black method [35]. Soil was digested by using mixture of H_2SO_4, H_2O_2, Selenium powder and Lithium Sulphate for the analysis of total N, P and K [36]. Total P was determined colorimetrically by the pH adjustment method [37]. Total K was determined by using a flame photometer (Systronics Mediflame 128).

Available N and N-Mineralization

Available N and N-mineralization rates were estimated in May, July and September in both the years of study period. N-Mineralization was measured by buried bag technique [38,39]. Field moist soil samples (150 g each) collected from each plot were enclosed in air sealed polyethylene bags and incubated in the respective soils at a 10 cm depth. Coarse roots and large fragments of organic debris were removed to avoid any marked immobilization during incubation. NO_3-N and NH_4-N were determined immediately after soil collection and after 30 days of field incubation. Nitrification is a process that increases NO_3-N during incubation. The increase in the concentration of NH_4-N plus NO_3-N over the course of field incubation is defined as net N-mineralization. NO_3-N was measured by the phenol disulphonic acid method after extraction by $CaSO_4$ [40]. NH_4-N was extracted in 2 M KCl and analyzed by the phenate method [41]. Alkaline sodium bicarbonate ($NaHCO_3$-Pi) was determined by the ammonium molybdate -Stannous chloride method [40].

Soil Microbial Biomass

Soil microbial biomass C, N and P was determined using field moist soil (>15 cm depth; sieved <2 mm) at bimonthly interval (May, July and September) in both years of study period, following fumigation-extraction method [42-44]. Soil was incubated prior to the measurement of microbial biomass C. For microbial biomass C analysis, 50 g soil fumigated with $CHCl_3$ for 10-20 hr. $CHCl_3$ was subsequently removed by evacuation and the soil was then extracted with 0.5 M K_2SO_4 (1:4, soil: extractant) for 30 minutes. Unfumigated soil was also extracted in the same way. Organic C in the soil extracts was measured by dichromate digestion [44]. Microbial biomass carbon (MBC) was then estimated from the equation; MBC = 2.64 Ec [44]; where Ec is the difference between C extracted from the fumigated and nonfumigated treatments, both expressed as μg C per gram oven dry soil [43]. Microbial biomass N (MBN) was determined using the same K_2SO_4 extract used for MBC analysis. Soil extract was analyzed for total N using the Kjeldahl digestion procedure. The flush of N (K_2SO_4-extractable N in unfumigated soil subtracted from the fumigated soil) was divided by the k_N (fraction of biomass N extracted after $CHCl_3$ fumigation) value of 0.54 [43]. For microbial biomass P estimation both fumigated and unfumigated soils were extracted with 0.5M $NaHCO_3$ solution (pH 8.5) for 30 minute. Inorganic P (P_i) in the $NaHCO_3$ extracts of fumigated and un fumigated soils was determined by the ammonium molybdate-stannous chloride method [45]. Microbial P was calculated by dividing the flush of P_i ($NaHCO_3$-P_i in fumigated soil minus that in the unfumigated soil) by a k_P value of 0.40 assuming that 40% of the soil microbial biomass was released as Pi by $CHCl_3$ [42].

Plant Biomass and Grain Yield

Crop yield was determined by total harvest method. Crop biomass of each of the 39 plots was harvested manually at the time of crop maturity. Grain and straw of the two crops was separated manually, oven dried and weighed component wise for each of the 39 plots, and the yield was converted into kg ha^{-1}. Data were subjected to multifactorial ANOVA. Differences between treatments were analyzed using Tukey's HSD as a range test. All analyses were done using a SPSS Statistical Software [46].

Results and Discussion

Total Soil Nutrients

The mean annual values for total soil nutrients of the rice planted experimental plots (control) and the different types of mulch treated soils (L_1-L_4) for the two study years are presented in Table 2. The 100% *Lantana* mulched plots (L_4 treatment) recorded a significantly greater OC and total P. However, the total N was not found significantly different. Similarly, the L_3 mulched plots (with 75% *Lantana*) also recorded significantly greater soil OC. ANOVA showed that mulching significantly affected pH ($F_{4,78}$ =3.103, P =0.021), OC ($F_{4,78}$ =114.9, P =0.000) and total P ($F_{4,78}$ =24.4, P =0.000) content of soil, but its effect on total N ($F_{4,78}$ = 1.396, P = 0.245) was not significant. The year X mulch interaction was significant for pH ($F_{4,78}$ = 8.928, P = 0.000) but insignificant for OC ($F_{4,78}$ = 1.448, P = 0.228), total N ($F_{4,78}$ = 0.464, P = 0.762) and total P ($F_{4,78}$ = 2.045, P = 0.098).

Available Soil Nutrients

The decomposition of added residue releases nutrient elements in plant available forms. In this experiment the mean annual concentration (across sampling months and two study years) of NO_3-N, NH_4-N and N-mineralization was found significantly high (P < 0.000) under L_3 and L_4 treatment plots. The rate of N-mineralization was highest in L_4 treatment plots and lowest in L_2 treatment plots (3.53 vs. 5.81 µg g^{-1} $month^{-1}$) (Table 3).

Seasonal values of available forms of N and N-mineralization across all the mulch treatments for the two study years are presented in Figure 1.

ANOVA showed highly significant effect of residue quality on available N pool (NO_3-N + NH_4-N) in the soils and on rates of

Table 2. Physico-chemical properties of soil under different treatments of mulching during two years of study. Values are mean ±1 across the sampling dates in each year.

Parameters	Year	Control	L_1	L_2	L_3	L_4
pH	2006	5.50 ± 0.003^{a,b}	5.55 ± 0.028^{a}	5.56 ± 0.022^{a,b}	5.68 ± 0.050^{b}	5.58 ± 0.025^{a,b}
	2007	5.64 ± 0.02^{b,d}	5.52 ± 0.009^{a}	5.59 ± 0.010^{b}	5.50 ± 0.011^{a,c}	5.46 ± 0.010^{c}
	Mean	5.57 ± 0.03^{a}	5.53 ± 0.015^{a}	5.58 ± 0.013^{a}	5.59 ± 0.033^{a}	5.52 ± 0.019^{a}
Organic C (%)	2006	0.55 ± 0.006^{a}	0.57 ± 0.005^{a}	0.55± 0.004^{a}	0.64 ± 0.013^{b}	0.77 ± 0.024^{c}
	2007	0.61 ±0.006^{a}	0.61 ± 0.006^{a}	0.59 ± 0.004^{a}	0.68 ± 0.008^{b}	0.78 ± 0.011^{c}
	Mean	0.58 ± 0.015^{a}	0.59 ± 0.006^{a}	0.57 ± 0.006^{a}	0.66 ± 0.009^{b}	0.77 ± 0.013^{c}
Total N (%)	2006	0.20 ± 0.018^{a}	0.20 ± 0.010^{a}	0.20 ± 0.012^{a}	0.22 ± 0.009^{a}	0.21 ± 0.010^{a}
	2007	0.10 ± 0.001^{b}	0.11± 0.00^{a}	0.10 ± 0.001^{a}	0.11 ± 0.002^{a}	0.11 ± 0.001^{a}
	Mean	0.15 ± 0.025^{a}	0.16 ± 0.013^{a}	0.15 ± 0.013^{a}	0.17 ± 0.014^{a}	0.16 ± 0.013^{a}
Total P (%)	2006	0.23 ± 0.015^{a}	0.36 ± 0.016^{a}	0.38± 0.029^{a}	0.36 ± 0.028^{a}	0.32 ± 0.011^{b}
	2007	0.34 ± 0.005^{e}	0.38 ± 0.010^{a}	0.39 ± 0.016^{b}	0.41 ± 0.009^{a}	0.38 ± 0.010^{d}
	Mean	0.29 ± 0.026^{c}	0.37 ±0.009^{a}	0.39 ± 0.016^{a,c}	0.38 ± 0.016^{a}	0.35 ± 0.011^{b}
C:N ratio	2006	4.69 ± 0.134^{a}	3.85 ± 0.729^{a}	4.53 ± 0.359^{a}	4.79 ± 0.307^{a}	4.23 ± 0.298^{a}
	2007	6.26 ± 0.134^{b}	5.67 ± 0.060^{a}	5.63 ± 0.060^{a}	6.10 ± 0.106^{b}	6.97 ± 0.103^{c}
	Mean	5.48 ± 0.361^{a}	4.76 ± 0.418^{a}	5.08 ± 0.221^{a}	5.44 ± 0.224^{a}	5.60 ± 0.366^{a}

±Standard error

Values in a row suffixed with different letters are significantly different from each other (Tukey's HSD, P<0.05)

Table 3. Available N (µg g^{-1}), N-mineralization (µg g^{-1} $month^{-1}$) and microbial biomass (µg g^{-1}) in the soil under different treatments of mulching. Values are mean ±1 across the two years of study.

Parameters	CT	L_1	L_2	L_3	L_4
Nitrate-N	1.92 ± 0.16^{a}	2.10 ± 0.09^{a,b}	1.99 ± 0.09^{a}	2.32 ± 0.12^{b}	2.47 ± 0.12^{b}
Ammonium-N	3.56 ± 0.24^{a}	4.02 ± 0.19^{a}	3.78 ± 0.17^{a}	4.41 ± 0.19^{a,b}	4.74 ± 0.19^{b}
N-mineralization	4.13 ± 0.22^{a,b}	4.15 ± 0.16^{a}	3.53 ± 0.19^{a}	5.01 ± 0.20^{b}	5.81 ± 0.20^{c}
MBC	355.59 ± 7.72^{a,b,c}	310.03 ± 6.02^{a}	349.87 ± 4.44^{b}	370.08 ± 7.11^{c}	422.80 ±14.92^{d}
MBN	43.37 ± 2.13^{a}	45.48 ± 0.94^{a}	43.25 ± 0.79^{a}	46.92 ± 0.95^{a}	53.46 ± 1.98^{b}
MBP	13.29 ± 0.57^{a}	13.30 ± 0.23^{a}	12.98 ± 0.32^{a,c}	14.23 ± 0.26^{c}	15.02 ± 0.27^{b}

±Standard error; Values in a row suffixed with different letters are significantly different from each other (Tukey's HSD, P<0.05)

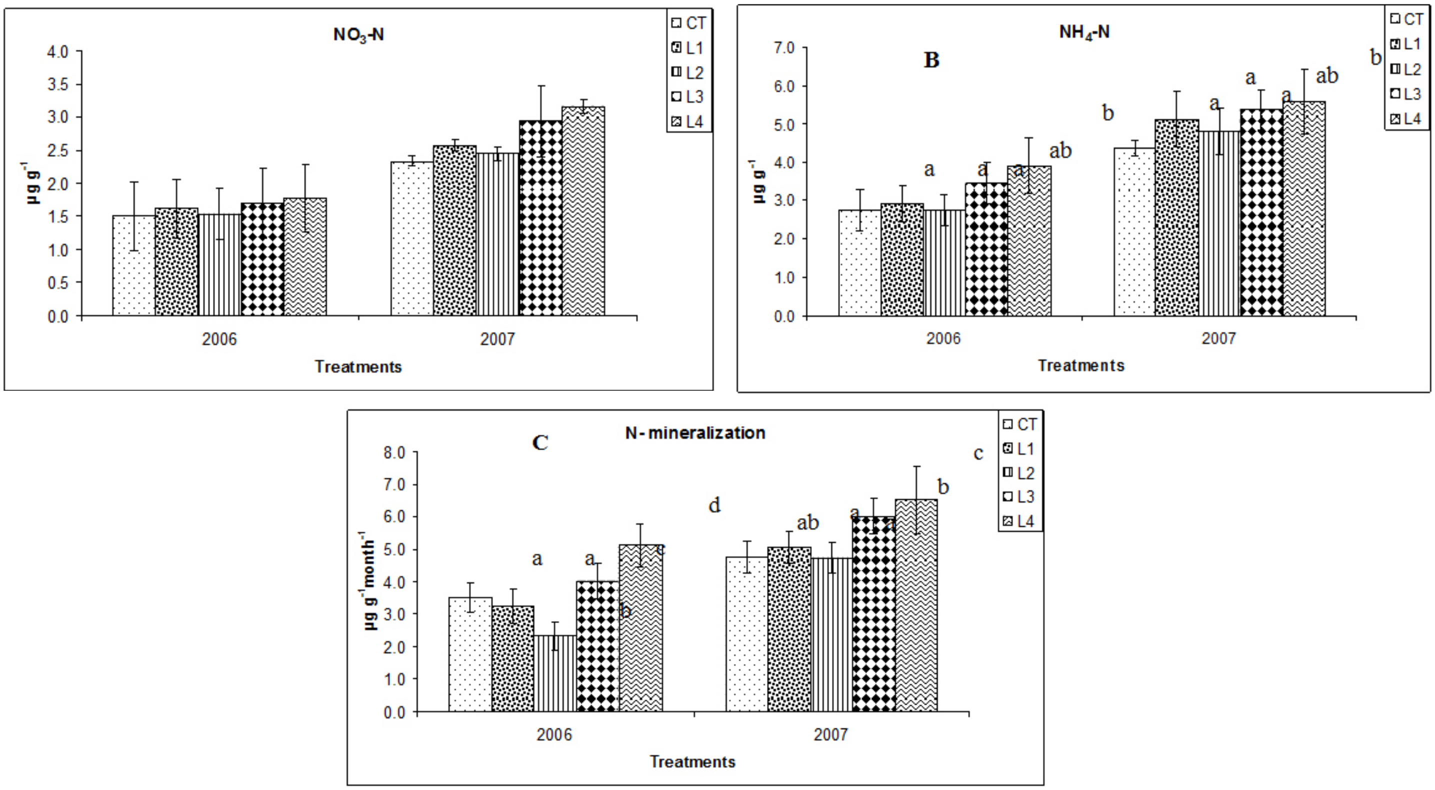

Fig. 1 (A, B, C). Soil NO_3-N, NH_4-N and N-mineralization due to different mulch applications in experimental plots under rainfed rice crop across two years of study. Treatments that differ significantly (P <0.05) are indicated by different letters over the bars.

its supply (i.e., net N-mineralization) (Table 4). Effect of months and year was significant for NO_3-N and NH_4-N, and the rate of N-mineralization was generally higher during the second year of study (Figure 1). ANOVA indicated significant differences in NO_3-N and NH_4-N concentration due to the type of mulch, and due to sampling month (Table 4). Similarly year X month, year X mulch and month X mulch interaction was significant for both NO_3-N and NH_4-N concentrations (Table 4).

The positive effect of *Lantana* mulch on OC and total P in the soil of experimental plots as recorded in this experiment is in conformity with earlier reports [47-51]. The total N in soil for L_4 and L_3 treatments was also found higher (although not significant) than control plots. The OC and N values were among the lowest for L_2 treatment plots (high proportion of Oak and Pine litter). Evidently organic matter mineralization was lower in L_2 treated plots. The L_2 treatment contains greater proportion of Pine litter, which is a poor quality organic resource with low N and high C:N ratio and decompose slowly [23]. Surface mulching of residues has been widely known for improving the soil nutrient status, particularly

Table 4. Summary of ANOVA for effect of mulch materials on available N (µg g^{-1}), N-mineralization (µg g^{-1} $month^{-1}$) and microbial biomass C, N and P (µg g^{-1}) in soil.

Source of variance	df	Nitrate-N	Ammonium-N	N-mineralization	MBC	MBN	MBP
Year	1	495.8**	1939.8**	773.1**	92.8**	431.1**	808.9**
Month	2	143.0**	566.8**	328.8**	267.2**	712.3**	60.0**
Mulch	4	25.6**	110.2**	219.7**	227.5**	198.9**	55.9**
Year x Month	2	133.5**	297.5**	19.150**	80.8**	539.5**	69.3**
Year x Mulch	4	7.437**	12.3**	12.305**	114.9**	51.6**	5.2**
Month x Mulch	8	3.351**	10.6**	7.926**	42.2**	49.1**	2.0*
Year x Month x Mulch	8	4.209**	6.623**	8.558**	47.8**	37.6**	2.5*
Residual	234						

** significant at 0.01; * significant at 0.05

in the top 10 cm of soil [52,53]. In dry land rice the application of wheat straw mulch enhanced the soil C [54]. However, insignificant increase in soil organic C, total N and total P has also been reported [55]. Other studies have also reported the soil N enrichment by residue incorporation in rice fields [56,57] that depends upon C:N ratio of applied residue [58]. In a tropical dry land ecosystem it was reported that organic residue management increases soil N-mineralization rate, N availability and microbial biomass in rice-barley rotation [59]. In the Cerrado region of Brazil it was reported that under the direct seeding mulch-based cropping the soil N-mineralization increased with about 2.0 kg N $ha^{-1}yr^{-1}$ [16]. Increases in total soil N stocks; thereby also increasing the pool of mineralizable-N has also been reported [60,61]. This supports our observation that N rich plant residues are promising alternatives to mineral fertilizers in rice and other crops [62]. It can be pointed out that the residue with high C:N ratio, as tested in this experiment (L_1 and L_2 treatments) may not be desirable to supplement soil nutrients to support crop growth as they immobilize N during decomposition [63]. Thus it can be hypothesized that application of residues, particularly with a low C: N ratio, may eventually lead to an increase in soil nutrients (both total and available forms), and this practice can be encouraged over traditionally practiced FYM application (control) to achieve higher soil fertility.

Microbial Biomass

Mean annual soil microbial biomass was recorded significantly greater (P<0.000) in L_4 treated experimental plots, followed by L_3 treatment in both the study years (Figure 2; Table 3). Trends were similar for the total mean value of MBC, MBN and MBP and the values ranged from 310.03 to 422.82 µg g^{-1}, 43.25 to 53.46 µg g^{-1}, and 12.98 to 15.02 µg g^{-1}, respectively. In general, microbial biomass was found higher in 2006. ANOVA indicated significant differences in MBC, MBN and MBP due to treatment, month, and year X month, year X treatment, month X treatment and year X month X treatment (Table 4). We found that microbial biomass varied with the chemical quality of organic residue inputs (representing same level of N input but widely varying in absolute amount of C). Higher microbial biomass in soils amended with wheat straw compared with non-amended soils has been observed [64] . Also, a four-fold increase in soil microbial N after incubation with added substrates has been reported [45]. It is reported that when straw is incorporated in soil a large proportion of the N required by the rapidly increasing microbial population comes directly from the straw [65]. These results confirm the hypothesis prevailing in literature that most labile fraction of soil organic matter, the soil microbial biomass, can be manipulated by varying the residue quality input in the soil [66]. In rice and barley crops it was found that residue placement increased MBC by about (40%) and MBN by 59-61% over the control [11]. They further recorded that residue retention significantly increased grain yield compared with when the residue was removed.

Crop Yield

The effect of improved soil fertility was evident in the yield of rice crop both in terms of grain yield and residue yield (Table 5). The L_4 treatment plots recorded significantly higher grain yield (34% more relative to control) as compared to other mulch treatments. The total yield (grain + straw) was also significantly greater for L_3 and L_4 treatments where the proportion of *Lantana* was 75 and 100%, respectively. ANOVA indicated significant differences in total crop biomass ($F_{4,78}$ =10.2, P = 0.000), grain yield ($F_{4,78}$ = 11.1, P = 0.000) and residue yield ($F_{4, 78}$ = 5.4, P = 0.001) due to mulch treatment. Effect of year was also significant on total crop biomass ($F_{1,78}$ = 68.308, P = 0.000), residue yield ($F_{1,78}$ = 15.677, P = 0.000) and grain yield ($F_{1,78}$ = 222.8, P = 0.000), and the values were higher for the second year of study (2007).

The increase in rice yield likely results from increased plant available N during decomposition of mulch material and from

Table 5. Crop biomass at maturity and grain yield of rice crop as under different treatments of mulching. Values are mean ± 1 SE (g m^{-2}).

Parameter	Year	Control	L_1	L_2	L_3	L_4
Grain yield	2006	384.9 ± 32.2^a	390.6 ± 35.9^a	476.6 ± 47.2^a	517.6 ± 55.7^a	771.6 ± 102.2^b
	2007	880.1 ± 33.7^c	1014.7 ± 14.3^a	1004.2 ± 9.3^c	1060.2 ± 15.1^a	1149.4 ± 14.4^b
	Mean	632.5 ± 112.7^a	702.7 ± 78.0a	740.4 ± 68.1^a	788.9 ± 71.5^a	960.5 ± 67.9^b
Crop residue	2006	1466.7 ± 266.7^a	1733.3 ± 115.5^a	1955.6 ± 215.5^a	2400.0 ± 339.9^a	2533.3 ± 326.6^a
	2007	2220.0 ± 27.2^a	2521.6 ± 14.4^a	2350.8 ± 25.3^a	2941.5 ± 16.4^b	2800.1 ± 52.1^b
	Mean	1843.3 ± 206.7^a	2127.5 ± 111.0^a	2153.2 ± 115.6^{a,b}	2670.7 ± 177.7^{b,c}	2666.7 ± 163.7^c
Total yield	2006	1851.6 ± 298.8^{a,c}	2123.9 ± 118.1^a	2432.1 ± 211.4^a	2917.6 ± 324.7^a	3304.9 ± 299.9^b
	2007	3100.1 ± 60.9^e	3536.3 ± 24.8^a	3355.1 ± 31.3^b	4001.7 ± 15.1^c	3949.5 ± 53.8^d
	Mean	2475.9 ± 310.7^a	2830.1 ± 181.0^a	2893.6 ± 152.5^a	3459.6 ± 205.3^b	3627.2 ± 167.2^b

Values in a row suffixed with different letters are significantly different from each other (Tukey's HSD, P< 0.05)

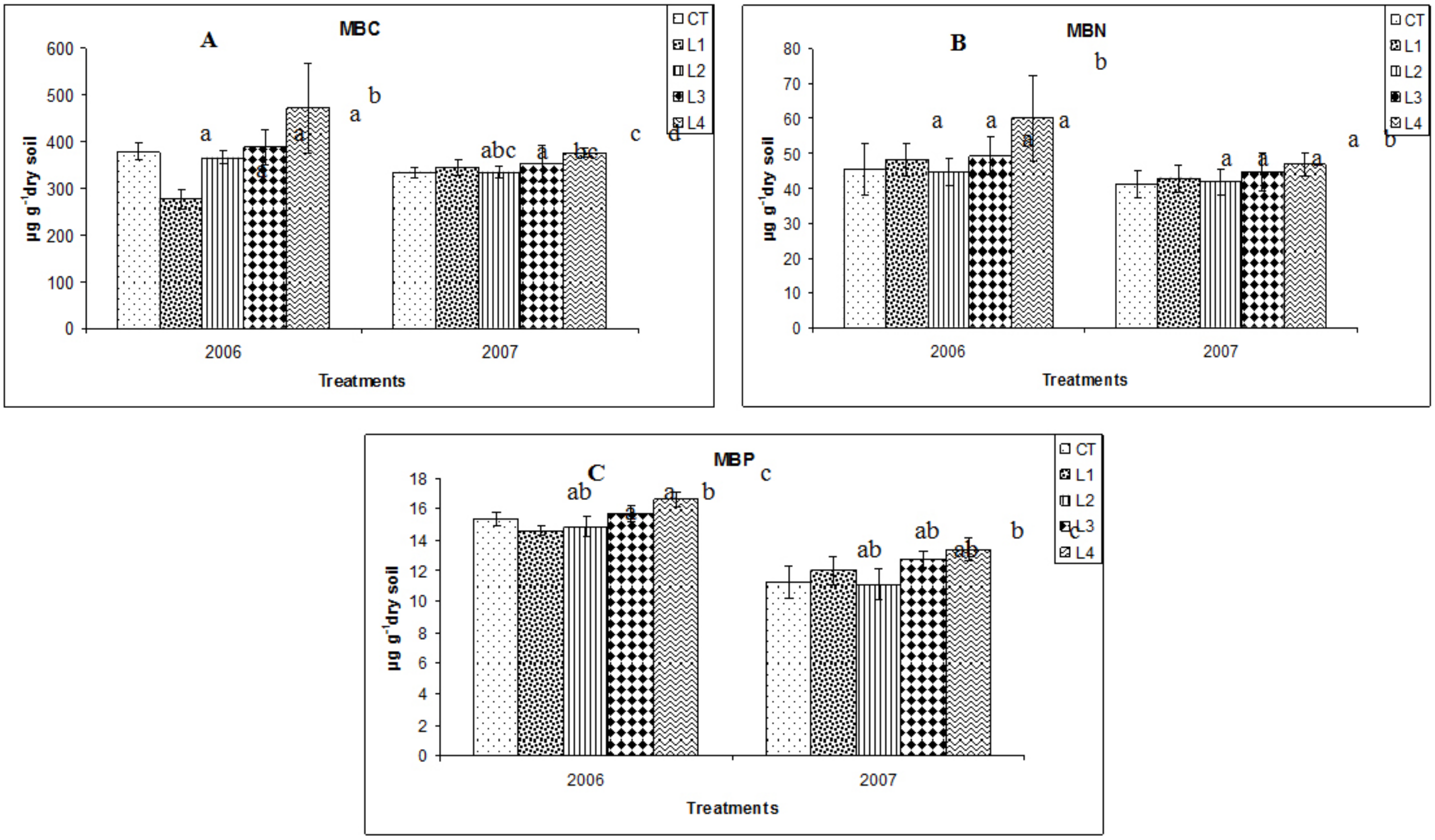

Fig. 2 (A, B, C). Soil microbial biomass C, N and P due to different mulch applications in experimental plots under rainfed rice crop across two years of study. Treatments that differ significantly (P <0.05) are indicated by different letters over the bars.

factors besides N supply rather than from a net increase in total soil N [67]. Total yield in L_4 mulch treated plots was recorded significantly higher because of high nutrient availability in these plots due to increased microbial biomass, a readily available source for nutrient mineralization. Further, a higher crop yield in 2007 was presumably due to the higher amounts of available forms of N in 2007 (Figure 1). It can be pointed out that mixing *Lantana* (a soft leaf species) must have accelerated the decomposition and nutrient release also in the L_3 treated plots thus resulting into greater crop yield. A strong positive correlation ($P < 0.001$) of grain yield with NO_3-N (r= 0.583), NH_4-N (r= 0.652) and N-mineralization (r= 0.614) was found. Similar to our findings, a high grain yield of maize (3 t ha^{-1}) was achieved by applying *Crotolaria juncea* (@4 t C ha^{-1}) relative to the control on a sandy soil in Zimbabwe [68]. Increase in rice yields by applying *Lantana* mulch is also reported [69]. The long-term effect of *Lantana* studied by [70], [29] and [32] in Northwest India found that mulching improves soil water retention and transmission properties in wheat-rice cropping pattern. Thus using *Lantana* mulch will enable us to enhance grain yield of rainfed rice and reduce our dependency on inorganic fertilizers. It can be concluded that application of *Lantana* leaves (that has high N and a low C:N ratio as compared to traditionally used Oak and Pine leaves) @ 1.7 t ha^{-1} yr^{-1} (dry matter basis) presents a suitable alternative of soil fertility management in the rainfed rice cropfields to achieve greater yield.

Acknowledgements

This study was funded by DST, Govt. of India, New Delhi (Grant No. SP/SO/PS-30/2002). Thanks are due to Dr. P.P. Dhyani, Director of the Institute for providing necessary facilities to carry out this work.

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