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# Variations in soil microbial biomass and N availability due to residue and tillage management in a dryland rice agroecosystem

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**Abstract**

Seasonal changes in the levels of soil microbial biomass C (MBC) and N (MBN), N-mineralization rate and available-N concentration were studied in rice–barley supporting tropical dryland (rainfed) agroecosystem under six combinations of tillage (conventional, minimum and zero tillage) and crop residue manipulation (retained or removed) conditions. Highest levels of soil MBC and MBN (368–503 and 38.2–59.7 μg $g^{-1}$, respectively) were obtained in minimum tillage residue retained (MT+R) treatment and lowest levels (214–264 and 20.3–27.1 μg $g^{-1}$, respectively) in conventional tillage residue removed (CT−R, control) treatment. Along with residue retention tillage reduction from conventional to zero increased the levels of MBC and MBN (36–82 and 29–104% over control, respectively). The proportion of MBC and MBN in soil organic C and total N contents increased significantly in all treatments compared to control. This increase (28% in case of C and 33% N) was maximum in MT+R and minimum (10% for C and N both) in minimum tillage residue removed (MT−R) treatment. In all treatments concentrations of N in microbial biomass were greater at seedling stage, thereafter these concentrations decreased drastically (21–38%) at grain-forming stage of both crops. In residue removed treatments, N-mineralization rates were maximum during the seedling stage of crops and then decreased through the crop maturity. In residue retained treatments, however, N-mineralization rates were lower than in residue removed treatments at seedling stage of both crops. At grain-forming stage in all instances the N-mineralization rates in residue retained treatments considerably exceeded the rates in corresponding residue removed treatments. Tillage reduction and residue retention both increased the proportion of organic C and total N present in soil organic matter as microbial biomass. Microbial immobilization of available-N during the early phase of crops and its pulsed release later during the period of greater N demand of crops enhanced the degree of synchronization between crop demand and N supply. The maximum enhancement effects were recorded in the minimum tillage along with residue retained treatment. In the dryland agroecosystem studied, two management practices in combination proved more advantageous than either practice alone in maintaining soil fertility levels. For soil fertility amelioration in dryland agroecosystems with least dependence upon chemical fertilizer input, post-harvest retention of about 20 cm shoot biomass (accounting for 25–40% aboveground biomass) of previous crop and its incorporation in soil through minimum tillage in the succeeding crop is suggested, especially in the case of cereal. 

*Keywords:* Dryland agriculture; Tillage reduction; Microbial biomass; N-mineralization rate; Available N; Residue retention

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## 1. Introduction

Agroecosystems in the tropics are faced with the biological degradation of soils, which results in reduction in organic matter content due to decline in the amount of carbon input from biomass (Stewart and Robinson, 1997). In dryland (rainfed) agroecosystems excessive tillage and crop residue removal leads to water scarcity and low soil fertility, both responsible for decreased crop production (Singh and Singh, 1995). In dryland agriculture use of conservational tillage and organic inputs have been suggested as a method of 'low-input agriculture' to achieve sustainable crop production (Singh and Singh, 1993). Interest in the conservational tillage, an ecological approach to seed-bed preparation, has increased recently (from 15 to 38 million hectare over the last decade, CTIC, 1994) because of the potential of this practice to reduce soil erosion, conserve soil moisture and improve soil fertility. According to Blevins and Frye (1993) conservational tillage practices are responsible for temporary immobilization of fertilizer N and reduction in N availability to crops at early stages of growth. Thus, there is a need to understand the impact of practices combining tillage and residue input variations on the biological processes involved in the maintenance of soil fertility in relation to the sustainable crop production systems.

Microbial biomass, a small (1–5% by weight) but active fraction of soil organic matter is of particular concern in soil fertility considerations because it is more susceptible to management practices than the bulk organic matter (Janzen, 1987). Soil microbial biomass acts as a reservoir of critical nutrients (Smith and Paul, 1990) and is a major determinant for governing the nutrient availability and resource base for nutrient release, which finally reflect soil fertility levels. Microbes using the organic materials as an energy source compete with crop plants for available N. Microbial biomass temporarily accumulates available N and gradually releases it into soil with passage of time. Presence of low quality crop residues in association to fertilizer application will extend the time period of availability of N to the crop plants in dryland farming conditions through the initial immobilization of N in the microbial biomass. Addition of plant residues with high C:N ratio may facilitate transformation of fertilizer or soil N into a slowly available N source and thus may improve N use efficiency in dryland agroecosystems (Singh and Singh, 1995). Microbial biomass under upland field conditions may practically act as slow release fertilizer.

Last two decades have seen a great interest in the development of farming systems characterized by relatively inexpensive levels of inputs combined with a high efficiency of internal resource recycling (Woomer and Ingram, 1990). Organic materials like crop residues offer sustainable and ecologically sound alternatives for meeting the N requirement of crops. The suitability of crop residues as a source of N depends to a great extent on the mineralization of its N in relation to the crop demand. The decomposition of organic matter in soil and the accompanying mineralization and immobilization of inorganic N are key processes in the soil–plant N cycle (Watkins and Barraclough, 1996). Crop productivity is strongly influenced by nutrient availability in soil and the nutrient supply rate (N-mineralization) is a crucial process of nutrient dynamics (Binkely and Vitousek, 1989). The largest proportion of N is found in the soil organic matter and its availability to plant is dependent on its mineralization to ammonium-N which under favourable conditions may be nitrified to nitrate-N. However, the impact of conservational tillage and crop residue retention after harvest on the dynamics of microbial biomass, N-mineralization rate and available nutrients are poorly documented in tropical dryland agroecosystems. Such information may be helpful in developing sustainable crop production practices in dryland agroecosystems in India, which account for ca. 70% of the cultivated land in the country. Farmers in these regions require soil working and organic input management ecotechnology which gives reasonable increase in crop productivity within a short term.

This study addresses the following questions with respect to tropical rice–barley dryland agroecosystem when subjected to short term crop residue and tillage manipulation: (1) What is the impact of tillage and residue manipulation on the levels of microbial biomass C and N? (2) Whether the change in N-mineralization rate is associated with the changes in the levels of microbial biomass C and N under conditions of tillage and residue manipulation? (3) How does the amount of available-N change under tillage and residue manipulation? (4) How does the tillage and residue manipulation affect the N-mineralization?

## 2. Materials and methods

### *2.1. Study site*

This study was performed at the Dryland Farm at the Institute of Agricultural Sciences, Banaras Hindu University (25°18′ N latitude and 83°1′ E longitude, 76 m above the mean sea level). The region has a tropical moist sub-humid climate, characterized by strong seasonality with respect to temperature and precipitation. The year is divisible into a warm-wet rainy season (July–September), a cool-dry winter (November–February), and a hot-dry summer (April–June). October and March constitute transitional months between rainy and winter, and between winter and summer seasons, respectively. The summer is dry and hot with temperatures ranging between 35 and 45°C during the day. Warm conditions (25–35°C) and high relative humidity (70–91%) prevail during the rainy season. In the winter season temperature falls between 10 and 25°C. Of the total annual rainfall (ca. 1287 mm) more than 85% occurred within the rainy season (Fig. 1). The rainy and winter seasons are the major cropping seasons in this region where rice based crop rotation is most common. Rice (*Oryza sativa* var. NDR 118) was selected as the rainy season test crop and barley (*Hordeum vulgare* L. var. Joyti) as the winter season crop.

The soil of the Banaras Hindu University campus is characterized as Banaras Type III by Agarwal and Mehrotra (1952). It is an inceptisol with a flat topography, pale brown colour, and sandy loam texture.

### *2.2. Experimental design*

The experiment was designed to vary the amount of organic matter input through residue retention from previous crop to the succeeding crop, and the soil disturbance in the form of different tillage practices (viz. conventional tillage, minimum tillage and zero tillage). Rice was grown in a conventionally tilled field (65 m×45 m) during the rainy season in 1997. When the rice crop matured (November 1997) six treatments which replicated thrice (plot size 9 m×10 m) were established in a randomized block design. A strip of 1 m was left to separate treatment plots from each

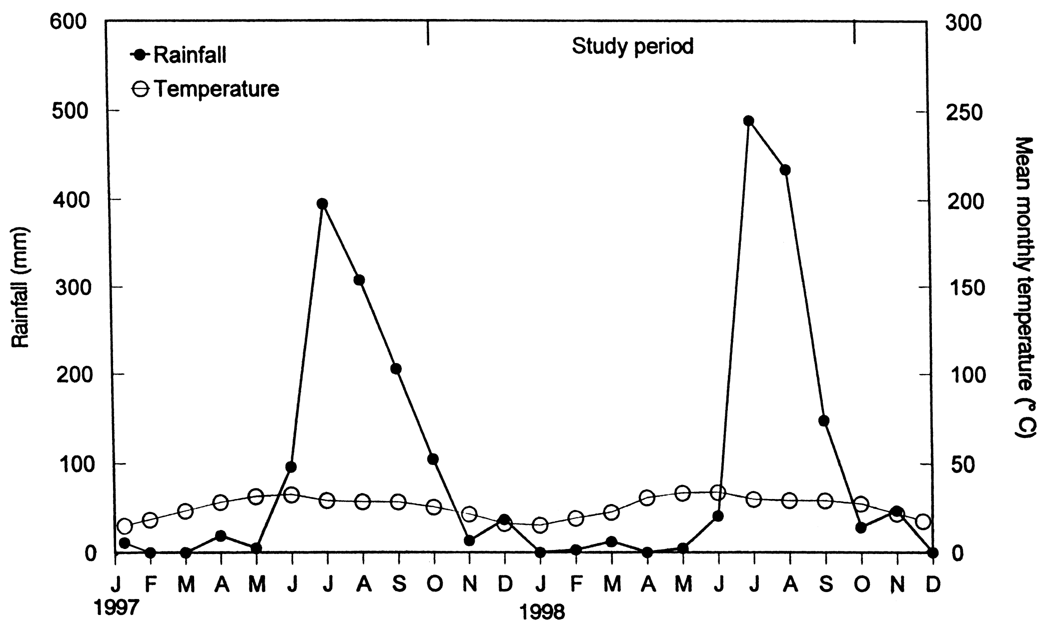


Fig. 1. Ombrothermic diagram for the study area. Solid circles represent rainfall and open circles show mean monthly temperature.

other. The assessment of initial soil fertility status (November 1997) showed that differences in organic C and total N contents between different replication blocks were not significant; the means (±S.E.) for the three blocks were: organic C 7855±80 μg $g^{-1}$, total N 872±8 μg $g^{-1}$.

The six treatments were: (1) conventional tillage (disked twice, cultivated once to 20 cm depth), and residue removed (CT−R); (2) conventional tillage (as above), and residue retained (CT+R); (3) minimum tillage (disked once, cultivated once up to 10 cm depth), and residue removed (MT−R); (4) minimum tillage (as above), and residue retained (MT+R); (5) zero tillage (no cultivation other than the disturbance caused by the planting tines), and residue removed (ZT−R); (6) zero tillage (as above), and residue retained (ZT+R). In the residue removed treatments harvesting of rice was done at the ground level, leaving no standing aboveground residue. However, in the residue retained treatments, rice was harvested 20 cm above the ground level leaving a portion of the rice aboveground residue standing in the plot. Rice residue retained in different plots was incorporated in the soil during tillage operations (either conventional or minimum) done before the sowing of barley (October 1997). In the case of zero tillage the rice residue standing in the plot was chopped at ground level and the cut material was left on the soil surface at the time when first tillage operation was being done in conventional and minimum tillage plots. When barley matured (April 1998) its harvesting was also done as in the preceding rice crop and the same six treatments with barley shoot residue were established for the succeeding rice crop.

The chemical composition and the amount of rice and barley residues retained in various treatments are given in Table 1. The quantity of residue retained corresponded to 35–40% of maturity aboveground biomass in rice and 42% (CT+R) to 52% biomass (ZT+R) in barley. The NPK chemical fertilizers (80 kg N $ha^{-1}$, 40 kg P $ha^{-1}$ and 30 kg K $ha^{-1}$ for rice crop and 60 kg N $ha^{-1}$, 40 kg P $ha^{-1}$ and 30 kg K $ha^{-1}$ for barley crop) were applied in all treatments at the time of crop sowing.

### 2.3. Soil collection

For the estimation of microbial biomass C and N, available-N and N-mineralization, soil samples (0–10 cm depth) were collected six times, once during seedling, grain-forming, and maturity stages of barley as well as rice crops. Three sub-samples of soil were collected from each replicate plot and composited. After removal of visible plant debris and fauna, soil was sieved through a 2 mm mesh screen. For physico-chemical analysis soil was collected after the harvest of rice (November 1998). Samples from different replicate plots of each treatment were analysed separately. Field moist samples were used for the determination of soil pH.

### 2.4. Soil physico-chemical analysis

Soil pH was determined by a pH meter using a glass electrode (1:5, soil:water) and water holding capacity by perforated circular brass boxes (Piper, 1966). Bulk density was determined using a metallic tube of known internal volume. Total organic carbon in soil

Table 1
Chemical composition of crop residues retained and their quantity in different treatments

| Chemical composition/amount | Crop residue | |
|---|---|---|
| | Rice | Barley |
| Carbon (%)[a] | 49.1±0.52 | 48.9±0.53 |
| Nitrogen (%)[b] | 0.602±0.025 | 0.622±0.020 |
| C:N ratio | 81.6 | 78.6 |
| Quantity of residue (kg $ha^{-1}$) | 6825±358 (in all residue retained treatments) | 5831±495 (in CT+R)[c]<br>6687±308 (in MT+R)[c]<br>3750±508 (in ZT+R)[c] |

[a] Determined as: loss in ignition/2 (McBrayer and Cromack, 1980).
[b] Micro-kjeldahl method (Jackson, 1958).
[c] Differences in the quantity of residue retained in various treatments were due to the variations in standing crop biomass.

was analysed following dichromate oxidation and back titration of unused dichromate (Kalembasa and Jenkinson, 1973). Total nitrogen was measured by the microkjeldahl method (Jackson, 1958).

### 2.5. Estimation of soil microbial biomass

MBC was measured by determining the organic carbon in chloroform fumigated and non-fumigated samples by dichromate digestion as described by Vance et al. (1987). Soil MBC was then estimated from the equation: MBC=2.64$E_C$ (Vance et al., 1987), where $E_C$ is the difference between carbon extracted from the $K_2SO_4$ extract of fumigated and non-fumigated soils, both expressed as μg C $g^{-1}$ oven dry soil. With the same $K_2SO_4$ soil extract, MBN was determined as total nitrogen using kjeldahl digestion procedure (Brookes et al., 1985). The flush of total N ($K_2SO_4$ extractable N from non-fumigated soil subtracted from that of fumigated soil) was divided by $K_N$ (fraction of biomass N extracted after chloroform fumigation) value of 0.54 (Brookes et al., 1985).

### 2.6. Determination of available-N and N-mineralization rate

Fresh field moist and sieved (2 mm) samples were used for the determination of nitrate-N and ammonium-N concentrations. Nitrate-N was measured by the phenol disulphonic acid method, using $CaSO_4$ as the extractant (Jackson, 1958). Ammonium-N was extracted by 2 M KCl and analysed by the phenate method (American Public Health Association, 1995). N-mineralization rate was measured by buried bag technique (Eno, 1960). Two sub-samples (ca. 150 g each) enclosed in sealed polyethylene bags were buried within 0–10 cm soil depth in each replication plot. Coarse roots and any large fragments of organic debris were removed in order to avoid any marked immobilization during incubation. At time zero (immediately after collection) and after 30 days of field incubation nitrate-N and ammonium-N were determined (as previously described). The increase in the concentration of ammonium-N plus nitrate-N after the field incubation was defined as net N-mineralization, the increase in ammonium-N as ammonification, and the increase in nitrate-N as nitrification. All the results are expressed on oven dry soil (105°C) basis.

### 2.7. Statistical analysis

Statistical analysis was done using SPSS/PC$^+$ software on microcomputer. Data were analysed through analysis of variance (ANOVA) and by correlation and regression to test treatment effects. Treatment means were compared using the LSD range test procedure at the 5% level of significance.

## 3. Results and discussion

### 3.1. Soil physico-chemical properties

Within a short term after one annual cycle water holding capacity, pH, and bulk density were affected by residue retention and tillage reduction but the effect of residue retention was greater than the effect of tillage reduction except in case of bulk density where the role of tillage reduction was prime (Table 2).

Tillage reduction (MT−R, ZT−R) did not significantly affect the organic C and total N levels in the soil (Table 2) which is poor in these respects. In contrast, in no-tillage systems Arshad et al. (1990) showed quantitative as well qualitative improvements in soil organic matter and reported about 26% higher organic C and total N in no-tilled soil than in conventionally tilled soil. An increase of 12–25% in organic C was reported under zero tillage compared to conventional tillage (Dick, 1983). In a study comparing 13 years of conventional tillage to zero tillage on a clay loam in southeastern United States, Beare et al. (1994) found 18% increase in soil organic C in zero tillage relative to conventional tillage. On the other hand, in all tillage variations in the present study residue retention tended to increase organic C and total N levels (cf. residue removed treatments). Such increase was more marked in CT+R (26% organic C and 36% total N) and MT+R (42% organic C and 53% total N). Residue retention in association with tillage reduction (MT+R, ZT+R) significantly increased soil organic C and total N contents over control. Much less increase was recorded in ZT+R (10% organic C, and 12% total N) than in MT+R treatment (42% organic C and 53% total N). Saffigna et al. (1989), however, in subtropical Australian vertisol showed 15–18% increase in soil organic C and total N due to combined effect of

Table 2
Changes in soil properties in various treatments after one annual cycle of crop growth (barley followed by rice); the values are mean±S.E.; treatment code: CT−R, conventional tillage and residue removed; CT+R, conventional tillage and residue retained; MT−R, minimum tillage and residue removed; MT+R, minimum tillage and residue retained; ZT−R, zero tillage and residue removed; ZT+R, zero tillage and residue retained

| Treatments | Soil properties | | | | | |
|---|---|---|---|---|---|---|
| | pH | Bulk density ($g\ cm^{-3}$) | WHC ($g\ kg^{-1}$) | Organic carbon ($\mu g\ g^{-1}$) | Total nitrogen ($\mu g\ g^{-1}$) | C/N ratio |
| CT−R | 6.85±0.018 | 1.27±0.006 | 412±2.6 | 7800±208 | 870±17 | 8.96 |
| CT+R | 6.76±0.014 | 1.24±0.007 | 423±1.9 | 9800±231 | 1180±13 | 8.30 |
| MT−R | 6.84±0.016 | 1.29±0.007 | 416±3.2 | 8200±153 | 915±6 | 8.95 |
| MT+R | 6.75±0.016 | 1.25±0.006 | 431±0.9 | 11100±173 | 1330±17 | 8.34 |
| ZT−R | 6.75±0.007 | 1.42±0.004 | 410±0.6 | 8100±154 | 889±5 | 9.10 |
| ZT+R | 6.72±0.008 | 1.40±0.004 | 414±2.4 | 8600±152 | 977±19 | 8.80 |
| LSD ($p$<0.05) | 0.04 | 0.04 | 9.1 | 683 | 54 | |

residue retention and zero tillage. Tillage operations accelerate organic matter decomposition, and greater amount of organic materials must be returned/added to the soil to maintain or build up its organic matter level. Combined effect of both these management practices (tillage reduction and residue retention) on the enhancement of soil organic C and total N was greater than the effect of either alone.

### 3.2. Soil microbial biomass

Over the two crop periods, the amount of MBC ranged widely: CT−R 214–264, CT+R 299–401, MT−R 241–295, MT+R 368–503, ZT−R 243–317, and ZT+R 283–343 $\mu g\ g^{-1}$dry soil (Fig. 2) suggesting significant role of residue retention and tillage practices on the levels of MBC in dryland agroecosystems.

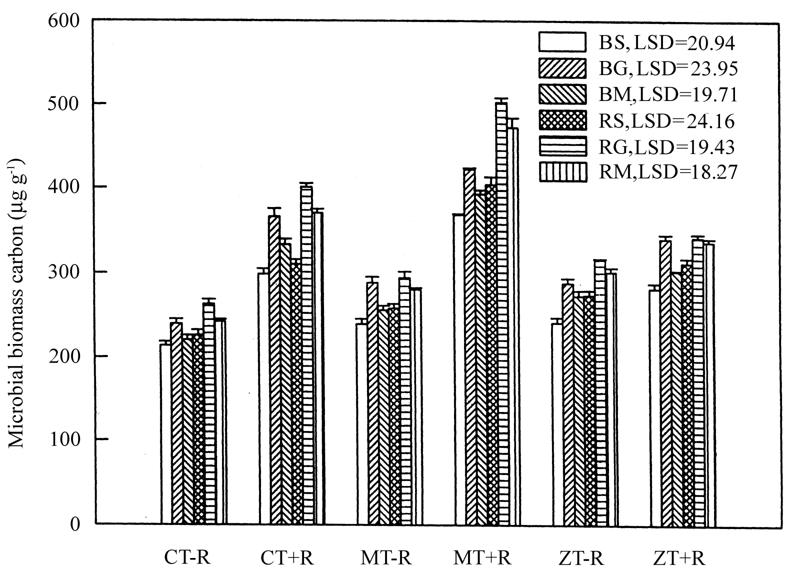


Fig. 2. Responses of soil microbial biomass carbon ($\mu g\ g^{-1}$) to different tillage and residue manipulation treatments during barley and rice crop periods in a dryland agroecosystem; code: BS, barley seedling stage; BG, barley grain-forming stage; BM, barley maturity stage; RS, rice seedling stage; RG, rice grain-forming stage; RM, rice maturity stage; LSD at $p$<0.05.

ANOVA for the two crop period data indicated significant differences in amount of MBC due to treatments ($F_{5,72}$=872, $p$<0.001) and crop stages ($F_{5,72}$= 159, $p$<0.001). The seasonal changes in MBC were essentially similar in all treatments. In both crop periods MBC significantly increased from the seedling to the grain-forming stage and then decreased slightly at crop maturity stage. During the annual cycle the maximum accumulation of MBC was recorded during the grain-forming stage of rice crop and minimum at the seedling stage of barley. Similar seasonal patterns of MBC, with increased amounts near flowering and lower concentrations at planting and harvest, have been reported by several authors (Collins et al., 1992; Singh and Singh, 1993; Franzluebbers et al., 1994). The increase in the level of MBC from the seedling to grain-forming stage of crops was probably a result of increased C input from the rhizosphere products to the soil before and during flowering (Martin and Kemp, 1980; Xu and Juma, 1993). When flushes of C were supplied into the soil in the form of crop residue or root, the microbial biomass increased in size until the substrate was depleted and then it decreased due to limitation of C (Singh and Singh, 1993). Pre-harvest root mortality and decomposition may also have contributed nutrients to the increased microbial biomass. The root biomass has been shown to decline considerably after grain-forming stage until the harvest in rice based dryland agroecosystems (Ghoshal and Singh, 1995).

On annual mean basis, residue retention alone increased MBC in CT+R treatment by 48% over control (CT−R) (Table 4). The effect of tillage reduction alone on MBC was marginal (15–20% increase over control in MT−R and ZT−R). The combined effect of residue retention and minimum tillage (MT+R, where the retained residue was incorporated due to tillage operation) increased MBC by 82% over control. However, in ZT+R treatment the surface application of retained residues (because of no tillage operation) increased MBC only by 36% over control. These residue induced MBC enhancements may be compared with 77% increase in MBC in straw+fertilizer treatment and 51% increase in straw alone treatment reported by Singh and Singh (1993). Saffigna et al. (1989) reported smaller increase (15–27%) in soil MBC following the incorporation of straw alone and in association with zero tillage in Australian soils. The microbial growth due to organic input such as straw application is mainly dependent on the increased availability of C in the soil. According to Schnurer et al. (1985) the decomposition rate of organic input is responsible for the variation in the level of microbial biomass. Although the quantity of microbial biomass is mainly related to C inputs, other mitigating factors can regulate the growth and activity of the native microflora (Smith and Paul, 1990).

During the two crop periods in different treatments, MBN ranged: CT−R 20.3–27.1, CT+R 32.8–44.0, MT−R 23.7–31.2, MT+R 38.2–59.7, ZT−R 24.1–29.6, and ZT+R 27.0–35.2 μg $g^{-1}$ dry soil (Fig. 3). ANOVA of this data suggested significant differences in MBN due to treatments ($F_{5,72}$=1772, $p$<0.001) and crop stages ($F_{5,72}$=298, $p$<0.001). In contrast to MBC, the maximum accumulation of MBN occurred at the crop seedling stage in both crops, possibly due to immobilization of N during early phase of decomposition of residues. Significant decrease of MBN from the seedling to grain-forming stage of the crops may be related to the release of N which became easily available to meet the expanded demand of the growing crops. It is well known that bulk of N is taken up by the crops between seedling to grain-forming stages. The decrease in MBN from the seedling to grain-forming stage of crops has been reported in flood plains of South Central Texas (Franzluebbers et al., 1994) and in rice–lentil crop sequence in a dryland agroecosystem (Singh and Singh, 1993).

The amount of MBN increased significantly in the residue retained plots compared to the residue removed plots. Residue retention increased (60% over control) the level of MBN in conventional tillage treatment (CT+R) (Table 4). The combined effect of residue retention and minimum tillage (MT+R) considerably increased (104% over control) the level of soil MBN. However, the surface application of retained residue with zero tillage (ZT+R) increased the level of MBN only by 29% over control. The effect of tillage reduction alone (MT−R, ZT−R) on the level of MBN was less marked (11–16% increase over control). Singh and Singh (1993) reported 77 and 84% increase in the levels of MBN under straw+fertilizer and straw treatments, respectively, in a dryland rice based agroecosystems. In Australian vertisol, Saffigna et al. (1989) reported increases (18–22%)

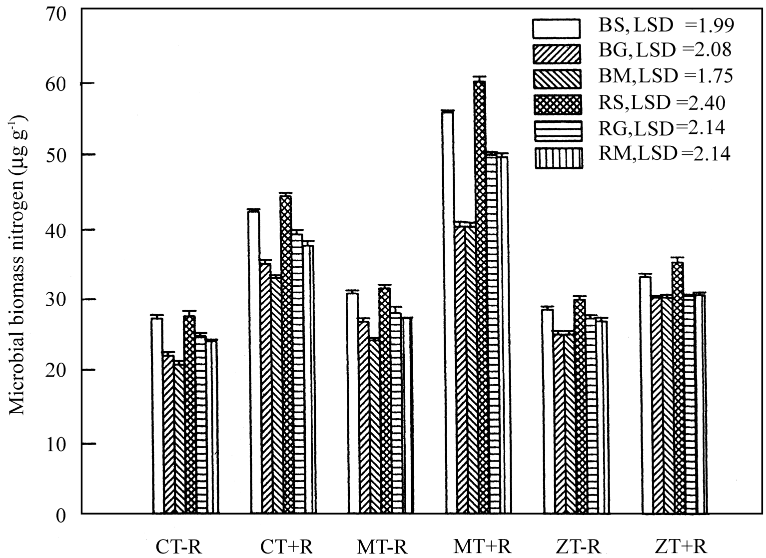


Fig. 3. Responses of soil microbial biomass nitrogen (µg $g^{-1}$) to different tillage and residue manipulation treatments during barley and rice crop periods in a dryland agroecosystem; code: same as in Fig. 2.

in the level of MBN due to residue retention alone and in combination with zero tillage.

Soil MBC and MBN were calculated as fractions of soil organic C and total N (organic C and total N values from Table 2 and annual mean values of MBC and MBN from Table 4). The proportions of MBC and MBN in soil organic C and total N contents increased significantly in all treatments compared to the control (CT−R). The increase (28% C and 33% N) was maximum in MT+R treatment and minimum (10% C and 10% N) in MT−R. This indicates that the effect of residue retention on the variations in the fraction of MBC and MBN to organic C and total N in the soil was primary and that of the tillage reduction was secondary. According to Anderson and Domsch (1989) the ratio of microbial biomass C to total C increased if the input of organic matter to the soil increased.

The concentration of N in the microbial biomass increased significantly in seedling stage in both crops (Table 3) in all treatments except the zero tillage (ZT+R, ZT−R). In barley and rice seedling stage

Table 3
Concentration of nitrogen in microbial biomass during different stages of barley and rice crop; values are mean ±S.E.; treatment code as in Table 2; crop stages code as in Fig. 2

| Treatments | Concentration (%) of N in microbial biomass[a] | | | | | | LSD ($P<0.05$) |
|---|---|---|---|---|---|---|---|
| | BS | BG | BM | RS | RG | RM | |
| CT−R | 6.26±0.25 | 4.48±0.19 | 4.58±0.19 | 5.96±0.09 | 4.59±0.02 | 4.83±0.01 | 0.595 |
| CT+R | 7.02±0.12 | 4.75±0.06 | 4.91±0.14 | 7.10±0.18 | 4.85±0.05 | 5.04±0.14 | 0.484 |
| MT−R | 6.32±0.06 | 4.55±0.07 | 4.57±0.07 | 6.01±0.07 | 4.67±0.04 | 4.76±0.04 | 0.241 |
| MT+R | 7.50±0.09 | 4.74±0.06 | 4.86±0.05 | 7.39±0.12 | 4.93±0.07 | 5.22±0.13 | 0.354 |
| ZT−R | 5.80±0.06 | 4.26±0.15 | 4.38±0.09 | 5.38±0.18 | 4.24±0.08 | 4.38±0.01 | 0.425 |
| ZT+R | 5.82±0.04 | 4.36±0.12 | 4.45±0.09 | 5.62±0.06 | 4.41±0.07 | 4.49±0.01 | 0.280 |
| LSD ($p<0.05$) | 0.486 | 0.454 | 0.452 | 0.483 | 0.232 | 0.312 | |

[a] Calculated by assuming that dry biomass contains 50% carbon (Brookes et al., 1984).

the concentration of N in microbial biomass increased significantly (12–24% increase over control) in CT+R and MT+R treatments. However, the concentration of N in microbial biomass in seedling stages decreased by 6–10% in ZT+R and ZT−R treatments relative to control. In all treatments the concentrations of N in microbial biomass were greater at the seedling stage and thereafter the concentrations decreased drastically (21–38%) at grain-forming stage in both crops. This decrease was, however, more pronounced in barley than in rice crop. This tendency of decreasing concentration of N in microbial biomass at grain-forming stage may be related to the synchronization of available N with crop demand in these dryland agroecosystem.

Retention of residue decreased the C:N ratio of soil microbial biomass under all tillage conditions (Table 4). The C:N ratio increased considerably in zero tillage treatments. It has been reported that when residue with wide C:N ratio is incorporated in the soil, a large proportion of the N required by the rapidly increasing microbial population comes directly from the straw (Ocio et al., 1991). Different C:N ratios occur as a result of changes in microbial population during the decomposition of incorporated straw (Tate et al., 1988). When the residue is incorporated into the soil food web changes. Surface placed straw is generally dominated by fungi, while residue incorporation shifts the food web towards bacterial dominance (Hendrix et al., 1986). The C:N ratio of fungal hyphae is often in the range 7–12 whereas that of bacteria is usually ranges 3–6 (Anderson and Domsch, 1989). Thus it is expected that with time, the crop residue retention will reduce the C:N ratio of the microbial biomass.

### 3.3. N-mineralization rate

In both crops quite different patterns of net N-mineralization rates were observed in residue retained (CT+R, MT+R, ZT+R) and removed (CT−R, MT−R, ZT−R) treatments (Fig. 4). In residue removed treatments, N-mineralization rates were maximum during the seedling stage of crops and then decreased through the crop maturity. In residue retained treatments the N-mineralization rates sharply increased from seedling to grain-forming stage and then declined considerably at maturity. In residue retained treatments, however, at seedling stage of both crops N-mineralization rates were lower than in residue removed treatments. At the grain-forming stage in all instances the N-mineralization rates in residue retained treatments considerably exceeded the rates in corresponding residue removed treatments. The levels of N-mineralization at maturity in both crops were always greater in residue retained treatments compared to residue removed treatments. This may be due to the difference in the amount of

Table 4
Effect of tillage and residue treatments on soil microbial biomass (C and N), N-mineralization rate (ammonification and nitrification) and available N (ammonium-N and nitrate-N); values are annual mean of six sampling dates±S.E.; treatment code as in Table 2

| Properties | Treatments | | | | | | LSD ($p$<0.05) |
|---|---|---|---|---|---|---|---|
| | CT−R | CT+R | MT−R | MT+R | ZT−R | ZT+R | |
| MBC[a] | 235±8.35 | 347±8.91 | 271±5.12 | 427±11.46 | 283±5.98 | 320±5.57 | 9.61 |
| MBN[a] | 23.9±0.63 | 38.3±0.96 | 27.7±0.64 | 48.7±1.86 | 26.6±0.49 | 30.9±0.64 | 0.91 |
| MBC:MBN ratio | 9.82±0.15 | 9.06±0.36 | 9.76±0.06 | 8.76±0.40 | 10.63±0.32 | 10.35±0.30 | 0.37 |
| N-mineralization[b] | 18.3±0.62 | 22.5±1.09 | 20.6±0.68 | 25.0±1.35 | 14.3±0.44 | 17.7±1.00 | 0.47 |
| Ammonification[b] | 14.8±0.49 | 18.5±1.02 | 16.8±0.58 | 20.6±1.21 | 12.4±0.35 | 15.5±0.94 | 0.54 |
| Nitrification[b] | 3.5±0.25 | 4.0±0.13 | 3.8±0.13 | 4.4±0.20 | 1.9±0.14 | 2.2±0.09 | 0.16 |
| Ammonification:nitrification | 4.23±0.08 | 4.62±0.10 | 4.42±0.02 | 4.68±0.11 | 6.52±0.04 | 7.04±0.14 | 0.35 |
| Available-N[a] | 12.0±0.31 | 14.7±0.74 | 13.0±0.91 | 16.1±0.68 | 7.8±0.60 | 8.9±0.43 | 5.29 |
| Ammonium-N[a] | 9.6±0.63 | 12.1±0.74 | 10.5±0.77 | 13.3±0.71 | 6.6±0.47 | 7.6±0.38 | 0.71 |
| Nitrate-N[a] | 2.4±0.24 | 2.6±0.15 | 2.5±0.19 | 2.8±0.09 | 1.2±0.13 | 1.3±0.07 | 0.18 |
| Ammonium-N:nitrate-N | 4.0±0.10 | 4.6±0.17 | 4.2±0.01 | 4.7±0.15 | 5.5±0.03 | 5.8±0.31 | 0.61 |

[a] Expressed as $\mu g\ g^{-1}$ soil.
[b] Expressed as $\mu g\ g^{-1}$ soil per month.

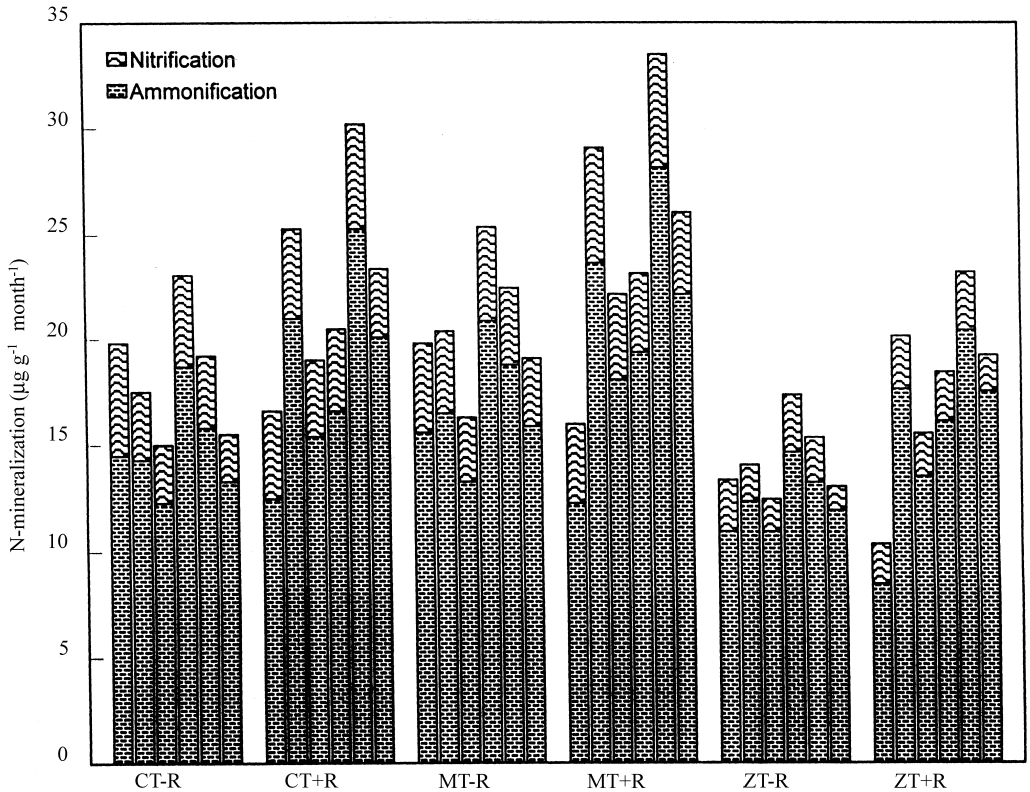


Fig. 4. Changes in N-mineralization rates (μg $g^{-1}$ per month) due to different tillage and residue manipulation treatments during barley and rice crop periods in a dryland agroecosystem; each bar cluster from left to right represents: barley seedling, barley grain-forming, barley maturity, rice seedling, rice grain-forming and rice maturity stages.

organic inputs (retention/removal of residues) and degree of incorporation of crop residue as a result of different tillage practices. Nitrogen release from the crop residue depends on microbial immobilization/mineralization of N as influenced by crop residue type, placement, and degree of incorporation in soil (Aulakh et al., 1991). Retention of crop residue with wide C:N ratio showed a slow initial N release or initial lag phase followed by a rapid N release phase and subsequent lowering of rate of N-mineralization. The initial lag phase seems to have occurred because of immobilization of N in microbial biomass.

In this study the N-mineralization rate was dominated by the ammonification which accounted for 73–92% of the total N-mineralization in this study. A marked seasonality was observed in N-mineralization rate; for instance, wet period crop (rice) showed higher rates of N-mineralization in soil than the dry period crop (barley) (Fig. 4). In wet period among the several factors responsible for highest N-mineralization rates higher soil moisture levels seem to be the chief determinant. Rewetting of a dry soil has been shown as a major factor for the acceleration of N-mineralization especially under semi-arid and subtropical conditions (Dalal and Mayer, 1986).

The maximum N-mineralization rate was observed in MT+R (39% increase over control) and the minimum in ZT−R treatment (23% decrease relative to control). It has been reported that incorporated crop residue has 1.5 times faster decomposition rates than surface applied crop residues and the residue incorporated in soil, immobilizes less and mineralizes more nutrients compared to surface placed residue (Holland and Coleman, 1987; Douglas and Rickman, 1992). In zero tillage accumulation of organic matter and nutrients such as N at or near the soil surface restricts N-mineralization rate in the soil (Chamen and Parkin, 1995).

On annual basis, residue retention alone (CT+R) increased (21%) the levels of N-mineralization compared to control (CT−R). The maximum N-mineralization rate was observed in MT+R treatment, whereas in the zero tillage either alone (ZT−R) or in combination of residue retention (ZT+R) the rate of N-mineralization rate decreased compared to control (Table 4). Interestingly the ammonification:nitrification ratio tended to rise from conventional tillage (CT−R, 4.23) to minimum tillage (MT−R, 4.42) and zero tillage (ZT−R, 6.52). Further, the ratio increased substantially in residue retained treatments compared to residue removed treatments. The degree of increase was substantially greater in ZT+R compared to CT+R and MT+R. The increased ammonification:nitrification ratio in residue retained treatments suggested that organic material input may possibly mitigate the effect of disturbance caused by tillage operations in terms of reduced nitrification in the system. Hoyt et al. (1980) reported greater proportion of soil nitrate-N to ammonium-N in conventional tillage compared to no-tillage and concluded that nitrification was inhibited in no-tillage soils. Commonly two mechanisms of nitrification inhibition in zero tillage are suggested; Acceleration of acidification of the soil surface in zero tillage (Blevins and Frye, 1993) perhaps inhibits nitrifiers in some cases, or substrate ($NH_4$) limitation to nitrifiers may be more severe in zero tillage due to less mineralization or less favourable spatial distribution. Doran (1980) pointed out that the microbial population is more anaerobic under no-tillage. Under such conditions slower mineralization and nitrification and greater immobilization and denitrification are expected. Soil compaction is also known to reduced N-mineralization rate from the added organic materials and increased N retention in microbial biomass and soil organic matter (Breland and Hansen, 1996).

### 3.4. Available N

Available-N (ammonium-N+nitrate-N) concentrations in soil varied considerably during the two crop periods. Seasonal variations in available N ranged: CT−R 7.4–16.2, CT+R 9.7–18.7, MT−R 9.7–19.7, MT+R 12.6–20.9, ZT−R 6.2–11.6, and ZT+R 7.6–12.6 μg $g^{-1}$ dry soil (Fig. 5). The maximum accumulation of available-N occurred during the seedling stages in both crops, excepting CT+R and MT+R treatments in barley. During the following period of active crop growth available-N in soil decreased due to enhanced plant uptake. In the present study, ammonium-N was the predominant form of available-N. The activity of the nitrifying bacteria in contrast to the diverse ammonifying microbes can be retarded by low water potential obtaining in dryland soil, resulting in high ammonium level (Dommergues et al., 1978). Ammonium dominance is expected to reduce nitrogen losses from these dryland agroecosystems. In both crops ammonium-N levels decreased substantially from seedling to the grain-forming stage and thereafter tended to increase at the time of crop maturity, particularly in CT+R and MT+R treatments. The reverse was, however true in case of ZT+R treatment. Pre-harvest increase in ammonium-N was pronounced in CT+R and MT+R treatments. In ZT−R treatment, however, consistent decrease in ammonium-N was noticed towards crop maturity (Fig. 5). Residue retained treatments broadly showed similar temporal trends for ammonium-N and nitrate-N as in residue removed treatments. The level of nitrate-N in two crops showed a distinct decrease from seedling to crop maturity stage with few exceptions. In CT+R and MT+R treatments the levels of nitrate-N were almost similar at three stages of rice crop.

On annual basis, residue retained treatments showed greater available N in comparison to residues removed treatments. Zero tillage alone (ZT−R) as well as in association to residue retention (ZT+R) decreased the levels of available N. One of the most crucial aspects of conservational tillage is management of N (Blevins and Frye, 1993) particularly in tropical dryland agroecosystems because tropical soils have generally low levels of available N (Singh and Singh, 1995). Applied N is likely to be immobilized to a greater extent under conservation tillage. The ratio of ammonium-N:nitrate-N increases along the gradient of decreasing tillage operations. The ratio further increases in the same sequences after residue retention (Table 4). Studies in the conservational tillage and residue placement show low levels of nitrate-N compared to ammonium-N in the soils (Standley et al., 1990; Thomas et al., 1990).

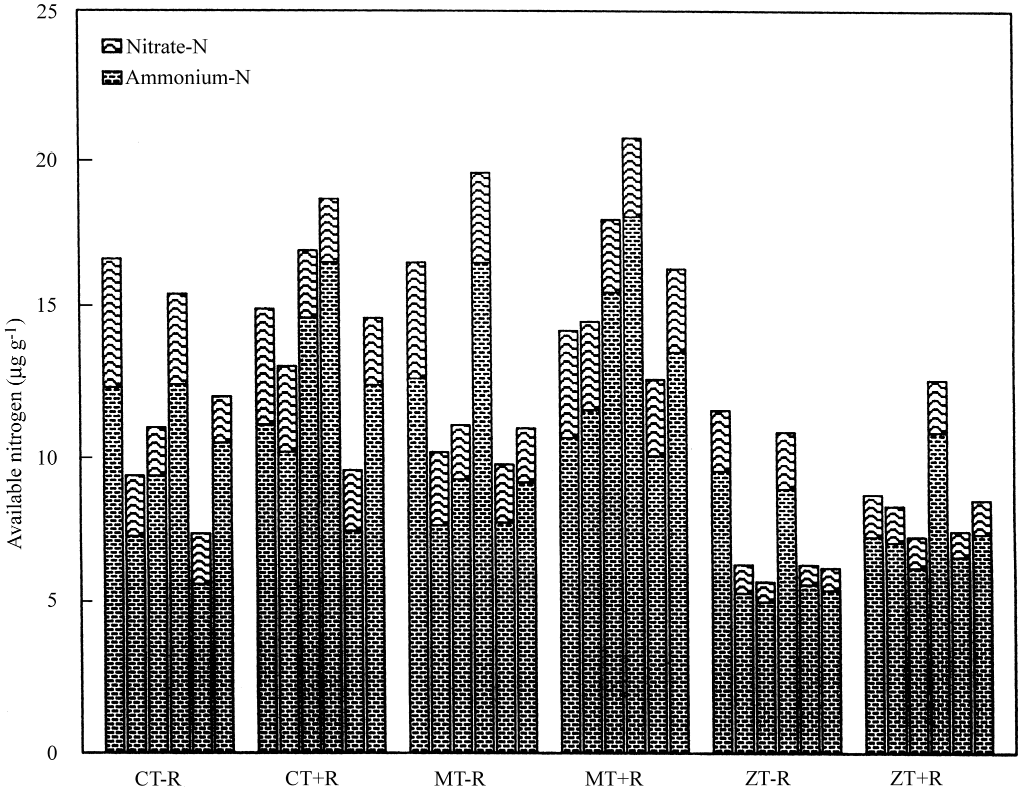


Fig. 5. Effect of different tillage and residue manipulation treatments in a dryland agroecosystem on the levels of available N (μg $g^{-1}$ soil) during barley and rice crop period; explanation of bar clusters, same as in Fig. 4.

### 3.5. Regression analysis of different soil properties

The seasonal changes in N-mineralization rate and available-N concentration were correlated with and regressed against corresponding soil parameters (MBC, MBN and concentration of N in microbial biomass) in different treatments. The relationships of concentration of N in microbial biomass with N-mineralization rate and available-N, which were better than other combinations examined, are reported in Table 5. Significant negative correlations ($r$=0.62–0.69, $p$=0.05–0.001) of concentration of N in microbial biomass with N-mineralization rate in residue retained treatments (CT+R, MT+R and ZT+R) contrasted with positive correlation ($r$=0.70, $p$=0.001 in CT−R) and weak positive correlations (in MT−R and ZT−R) of concentration of N in microbial biomass with N-mineralization in residue removed treatments. Negative correlations of concentration of N in microbial biomass with N-mineralization in residue retained treatments suggested a tendency of strong earlier immobilization of N in microbial biomass due to input of residue having wider C:N ratio, and its pulsed release in available form later at the time of greater crop demand. In residue removed treatments positive correlations suggested a gradual release of N in available form during the growth period of crop. Concentration of N in microbial biomass was strongly positively correlated with available-N in all treatments ($r$= 0.52–0.94, $p$=0.05–0.001). The degree of correlation was, however, significantly greater in residue removed condition then residue retained. This further suggested a better N synchronization in residue retained treatments compared to residue removed treatments.

Table 5
Correlations and regressions (based on six samplings and three replicates, $n$=18) reflecting relationships between concentration of N in microbial biomass (N in MB) and N-mineralization rate and available-N concentration in different tillage and residue treatments; treatment code as in Table 2

| Parameters/ treatments | $a$ | $b$±S.E. | $r$ | $p$ |
|---|---|---|---|---|
| N in MB[a] (X) vs available-N[b] (Y) | | | | |
| CT−R | −8.66 | 4.02±1.47 | 0.91 | 0.001 |
| CT+R | 6.03 | 1.54±0.63 | 0.52 | 0.05 |
| MT−R | −10.82 | 4.63±0.54 | 0.91 | 0.001 |
| MT+R | 11.45 | 0.80±0.55 | 0.34 | NS[c] |
| ZT−R | −9.45 | 3.64±0.33 | 0.94 | 0.001 |
| ZT+R | −0.14 | 1.86±0.55 | 0.65 | 0.05 |
| N in MB[a] (X) vs N-mineralization[d] (Y) | | | | |
| CT−R | 6.42 | 2.39±0.61 | 0.69 | 0.001 |
| CT+R | 37.55 | −2.68±0.85 | 0.62 | 0.05 |
| MT−R | 11.92 | 1.69±0.86 | 0.44 | NS[c] |
| MT+R | 43.44 | −3.19±0.84 | 0.69 | 0.001 |
| ZT−R | 10.93 | 0.73±0.69 | 0.25 | NS[c] |
| ZT+R | 38.32 | −4.20±1.27 | 0.64 | 0.05 |

[a] Expressed as %.
[b] Expressed as μg $g^{-1}$ dry soil.
[c] Not significant.
[d] Expressed as μg $g^{-1}$ per month.

## 4. Conclusion

Soil microbial biomass, the active fraction of soil organic matter which plays a central role in the flow of C and N in ecosystems responds rapidly to management practices, and serves as an index of soil fertility. In the presently studied rice–barley rotation tropical dryland agroecosystem, the practices of crop residue retention and tillage reduction in association with basal fertilizer application provided an increased supply of C and N which was reflected within a short term of one year in terms of increased levels of microbial biomass, N-mineralization rate and available-N concentration in soil. Residue retention and tillage reduction both increased the proportion of organic C and total N present in soil organic matter as microbial biomass. Microbial immobilization of available-N during the early phase of crops and its pulsed release later during the period of greater N demand of crops enhanced the degree of synchronization between crop demand and N supply. The maximum enhancement effects were recorded in the minimum tillage along with residue retained treatment. In the dryland agroecosystem studied, these two management practices in combination proved more advantageous than either practice alone in improving soil fertility levels. For soil fertility amelioration in dryland agroecosystems with least dependence upon chemical fertilizer input, based on this short term study post-harvest retention of about 20 cm high shoot biomass (accounting for ca. 25–40% aboveground biomass) of the previous crop, and its incorporation in soil through minimum tillage in the succeeding crop, is suggested, especially in the case of cereal crops.

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