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Impact of the addition of different plant residues on carbon–nitrogen content and nitrogen mineralization–immobilization turnover in a soil incubated under laboratory conditions

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Abstract

Application of plant residues as soil amendment may represent a valuable recycling strategy that affects on carbon (C) and nitrogen (N) cycling, soil properties improvement and plant growth promotion. The amount and rate of nutrient release from plant residues depend on their quality characteristics and biochemical composition. A laboratory incubation experiment was conducted for 120 days under controlled conditions (25 °C and 58 % water filled pore space (WFPS)) to quantify initial biochemical composition and N mineralization of leguminous and non-leguminous plant residues i.e. the roots, shoots and leaves of *Glycine max*, *Trifolium repens, Zea mays, Poplus euramericana, Rubinia pseudoacacia* and *Elagnus umbellate* incorporated into the soil at the rate of 200 mg residue N kg^{-1} soil. The diverse plant residues showed wide variation in total N, carbon, lignin, polyphenols and C / N ratio with higher polyphenol content in the leaves and higher lignin content in the roots. The shoot of *G. max* and the shoot and root of *T. repens* displayed continuous mineralization by releasing a maximum of 109.8, 74.8 and 72.5 mg N kg^{-1} and representing a 55, 37 and 36 % of added N being released from these resources. The roots of *G. max* and *Z. mays* and the shoot of *Z. mays* showed continuous negative values throughout the incubation showing net immobilization. After an initial immobilization, leaves of *P. euramericana*, *R. pseudoacacia* and *E. umbellate* exhibited net mineralization by releasing a maximum of 31.8, 63.1 and 65.1 mg N kg^{-1}, respectively and representing a 16, 32 and 33 % of added N being released. Nitrogen mineralization from all the treatments was positively correlated with the initial residue N contents ($r = 0.89$; $p \leq 0.01$), and negatively correlated with lignin content ($r = -0.84$; $p \leq 0.01$), C / N ratio ($r = -0.69$; $p \leq 0.05$), lignin / N ratio ($r = -0.68$; $p \leq 0.05$), polyphenol / N ratio ($r = -0.73$; $p \leq 0.05$) and ligin + polyphenol / N ratio ($r = -0.70$; $p \leq 0.05$) indicating a significant role of residue chemical composition and quality in regulating N transformations and cycling in soil. The present study indicates that incorporation of plant residues strongly modify the mineralization-immobilization

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turnover (MIT) of soil that can be taken into account to develop synchronization between net N mineralization and crop demand in order to maximize N delivery and minimize N losses.

1 Introduction

Application of organic materials as soil amendments is an important management strategy that can improve and uplift soil quality characteristics and alter the nutrient cycling through mineralization or immobilization turnover of added materials (Khalil et al., 2005; Baldi and Toselli, 2014). Use of local organic materials derived either from livestock or plants have been attaining worldwide support to improve the fertility and productivity potential of degraded and nutrient poor soils (Huang et al., 2004). Indeed, plant residues and animal manures are potentially important sources of nutrients for crop production in smallholder agriculture. However, the Hindu Kash Himalayan (HKH) regions including the State of Azad Jammu and Kashmir have a wide diversity of leguminous species and non-leguminous plants compared to the livestock production. Hence, use of plant residues as organic nutrient source is relatively simple for the farmers compared to the manures application. Incorporating plant residues into agricultural soils can sustain organic carbon content, improve soil physical properties, enhance biological activities, and increase nutrient availability (Hadas et al., 2004; Cayuela et al., 2009). In the short-term, incorporation of plant residues provides the energy and nutrients for microbial growth and activity, and act as a driving force for the mineralization-immobilization processes in the soil and a source of nitrogen (N) for plants (Jansson and Persson, 1982). In the long-term, incorporation of crop residues is important for the maintenance of organic carbon (C) and N stock in the nutrient pool of arable soils (Rasmussen and Parton, 1994).

Incorporation of crop residues provides readily available C and N to soils depending upon the decomposition rates and synchrony of nutrient mineralization (Murungu et al., 2011). The N availability from these residues depending on the amount

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of N mineralized or immobilized during decomposition. However, previous studies demonstrated that the decomposition and nutrient release rates of residues is often regulated by environmental factors, such as temperature and soil moisture, and biochemical composition of plant materials and their interaction (Abiven et al., 2005; Khalil et al., 2005). The biochemical composition or quality parameters such as total N concentration, lignin (LG), polyphenols (PP), carbon : nitrogen (C / N) ratio, LG / N, PP / N and (LG + PP) / N ratios are considered useful indicators controlled decomposition and N release of added residues (Nakhone and Tabatabai, 2008; Vahdat et al., 2011; Abera et al., 2012). However, it has not been clearly established that which of these variables correlate the best with N mineralization of plant residues (Nakhone and Tabatabai, 2008) as contrasting results have been reported in the literature (Nourbakhsh and Dick, 2005). It has been reported that N released from leguminous tree leaves indicated that the (lignin + polyphenol) : N ratio was the most important factor in predicting N mineralization (Mafongoya et al., 1998). On the other hand, Frankenberger and Abdelmagid (1985) suggested that lignin content of the legumes is not a good predictor of the N mineralization. Handayanto et al. (1994) suggested that the N concentration or lignin : N ratio of the leaves were not good indicators of N release for agroforestry materials. Palm and Sanchez (1991) attributed the differences in N mineralization rates of various tropical legumes was due to polyphenols. Handayanto et al. (1994) found however, that the total N content of plant residues was not correlated with rates of N released under non-limiting N condition.

Earlier studies clearly demonstrated the beneficial effects of plant residues to soil-plant systems (Huang et al., 2004; Cayuela et al., 2009; Khalil et al., 2005; Baldi and Toselli, 2014). However, still there is a scope to explore the possibilities for achieving maximum benefits in term of rate, time and amount of N released. For example, the synchronization of net N mineralization with plant/crop growth is desirable to maximize N delivery for the crop and minimize N losses. Abiven et al. (2005) reported that one of the tools to achieve synchronization is the use of plant residues with different nature and qualities. Application of residues with high C / N ratio results in immediate net

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N immobilization while residues with low C / N ratio results in net N mineralization showing that mineralization-immobilization turnover (MIT) can be influenced differently by chemical components of added plant materials. To achieve this target, combination of legumes and non-legumes plant materials or different plant components of the same plant species i.e. root, shoot and leaves can be tested.

The present work aims to examine the initial biochemical composition and quality characteristics of on farm available plant residues and to quantify the N release potential (mineralization) of these residues added to a soil incubated under controlled conditions (25 °C) in the laboratory at Rawalakot Azad Jammu and Kashmir, Pakistan.

2 Materials and methods

2.1 Soil sampling

The soil used in this study was collected from an arable field located at the research farm, Faculty of Agriculture, the University of Poonch, Rawalakot Azad Jammu and Kashmir, Pakistan. The study area located at latitude 33°51′32.18″ N, longitude 73°45′34.93″ E and an elevation of 5374 feet above the sea level. The soil in the study site was clay loam in texture, Humic Lithic Eutrudepts (Inceptosols) (Ali et al., 2006). Soil samples were collected from 0–15 cm depth at random from five different locations and mixed well to get a composite sample. The field fresh soil was passed through a 4 mm sieve to eliminate coarse rock and plant material, thoroughly mixed to ensure uniformity and stored at 4 °C before use (not more than 2 wk). A subsample of about 0.5 kg was taken, air dried, and passed through a 2 mm sieve and used for the determination of physical and chemical characteristics. Samples analysis showed that the soil contained 6.1 g kg^{-1} organic C, 0.58 g kg^{-1} total N and the pH was 7.2.

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2.2 Collection of plant residues

Six predominant on farm available plant species were selected. There were ten residue treatments i.e. *G. max* shoot, *G. max* root *T. repens* shoot, *T. repens* root, *Z. mays* shoot, *Z. mays* root, *P. euramericana* leaves, *R. pseudoacacia* leaves, and *E. umbellata* leaves. Plant samples / residues were collected at different timings in the year 2012. *Glycine max* and *Trifolium repens* samples were collected from the field before flowering (summer) while *Zea mays* samples were taken one week before crop harvest. The tree leaves were sampled late in fall. Plant residues were washed with running tap water, rinsed three times with distilled water, dried at 65 °C for 48 h, milled and passed through a 1 mm sieve. Triplicate samples of plant residue were taken and analyzed for their C, N, lignin and polyphenol concentration. Total N contents of the residues were determined by Kjeldhal digestion of distillation method (Bremner and Mulvaney, 1982). Wet digestion method was used for organic C analysis (Nelson and Sommers, 1982). The lignin content was determined using Van Soest methods (Van Soest et al., 1991). Soluble polyphenols were extracted in hot water (100 °C, 1 h) and determined by colorimetery using Folin–Denis reagent.

2.3 Laboratory incubation

The incubation methods used in this study was followed by the methods used in our previous studies (Abbasi et al., 2011; Abbasi and Khizar, 2012). Briefly, about hundred grams of soil already stored in the refrigerator at 4 °C was weighed and transferred into 200 mL glass jars. The initial moisture content of soil was 28 % (w/w) that was increased by adding distilled water to achieve a final water filled pore space (WFPS) of 58 %. Plant residues were weighed and added into the jars at the rate equivalent to 200 mg N kg^{-1}. After adding residues, all the jars were weighed and their weight was recorded. Altogether, a total of 300 jars (10 treatments × 10 incubation timings × 3 replications) were arranged in a completely randomized design and incubated under controlled conditions at 25 °C. A soil without adding any amendment

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was also used as a control. The incubation timings were 0, 7, 14, 21, 28, 42, 60, 80, 100 and 120 days. Soil moisture was checked/adjusted after every two days by weighing the glass jars and adding the required amount of distilled water when the loss was greater than 0.05 g.

2.4 Soil extraction and analysis

Samples of all ten treatments were analyzed for total mineral nitrogen (TMN) as described earlier (Abbasi and Khizar, 2012). Initial concentration of TMN (NH_4^+–N + NO_3^-–N) at day 0 was determined by extracting soil samples with 200 mL of 1 mol KCl added directly to the flask immediately after incorporation of each N source. Thereafter, triplicate samples from each treatment were removed randomly from the incubator at different incubation timings and extracted by shaking for one hour with 200 mL of 1 mol KCl followed by filtration. The total mineral N of the extract were determined by using the steam distillation and titration method (Keeney and Nelson, 1982). Net cumulative N mineralized (NCNM) from different plant residue treatments was calculated following the method described earlier (Sistani et al., 2008).

2.5 Statistical analysis

All data were statistically analyzed by multifactorial analysis of variance (ANOVA) using the software package MSTATC Version 3.1 (1990). Least significant differences (LSD) was used as post-hoc test to indicate significant variations within the values of either treatments or time intervals. Correlation coefficient used between the studied variables was calculated using SPSS 20 software. A probability level of $p \leq 0.05$ was considered significant (Steel and Torrie, 1980).

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3 Results and discussion

3.1 Chemical composition of the residues – residues quality

The initial biochemical composition and quality characteristics of various plant residues are summarized in Table 1. The N content of the plant residues ranged from 4.0 g kg^{-1} for the *Z. mays* roots to 35.2 g kg^{-1} for the *G. max* shoot. A significant difference in N content among different residues was observed and *G. max* shoot, *R. pseudoacacia* and *E. umbellate* leaves exhibited significantly ($p \leq 0.05$) higher N compared to the remaining treatments. The total C contents varied from 397 g kg^{-1} for the *T. repens* shoot to 486 g kg^{-1} for the *Z. mays* root. The C contents in *Z. mays* shoot and root were significantly higher than the C contents of the remaining plant materials. The amended materials had a wide range of C / N ratio varied from 12.1 for the *R. pseudoacacia* and *E. umbellate* leaves to 121.5 for the *Z. mays* roots. The lignin content varied from a minimum of 11 g kg^{-1} in the *G. max* shoot to a maximum of 48 g kg^{-1} in the *Z. mays* roots, significantly higher than the lignin content of other amendments. A minimum polyphenol contents of 31.1 g kg^{-1} were present in *G. max* shoot while a maximum of 53.8 g kg^{-1} in the *P. euramericana* leaves. The variation among different amendments was significant ($p \leq 0.05$) (Table 1). The LG / N, PP / N and LG + PP / N ratios were highest in the *Z. mays* root while the lowest values were recorded for the *G. max* shoot. Generally, total N contents of the legume residues were higher compared to the non-legumes. Similarities could be observed between the same organs of the different species i.e. all the roots were characterized by high C, LG and PP contents and lower N concentration. Leaves were particularly rich in PP and total N. The differences in the concentration of quality characteristics of residues according to plant components i.e. shoot, root and leaves had been reported earlier (Abiven et al., 2005; Nourbakhsh and Dick, 2005). It has been reported that high lignin content in root was due to presence of suberin in the roots and its ability to form complex barriers when associated with lignin (Abiven et al., 2005). Plant residues used in this study provided a wide range of contrasted chemical composition and significant variation in quality characteristics

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because of the difference in: (i) type of species i.e. leguminous and non-leguminous, trees and crops; and (ii) plant components/organs i.e. shoot, root and leaves.

3.2 Nitrogen mineralization

Results indicated that the control soil without any amendment released a maximum concentration of 77.7 mg N kg^{-1} at day 100 compared to 13.7 mg kg^{-1} at the start showing a substantial release of N into mineral N pool (Table 2). Expressed as the total N initially present, the net N mineralized during the incubation was 14 %. The mineralization of native soil N observed here was in accordance with our previous study where a maximum of 90 mg kg^{-1} mineral N was released from the control soil representing 16 % of the initial N of the soil (Abbasi and Khizar, 2012). Among different plant materials added, shoot of *G. max* and shoot and root of *T. repenes* exhibited a continuous increase in TMN (except *T. repenes* roots for few initial samplings) during incubation and displayed significantly ($p \leq 0.05$) higher N mineralization compared to the remaining treatments. The maximum TMN released from these amendments varied between 150 and 189 mg kg^{-1}. Shoot of *G. max* displayed the highest TMN throughout the incubation. Averaged across timings, TMN released from *G. max* shoot was 112 mg kg^{-1} compared to 78 and 64 mg kg^{-1} released by *T. repenes* shoot and root, respectively. In contrast, incorporation of *G. max* root and *Z. mays* shoot and root resulted in a constant decrease in TMN and the maximum values ranged between 32 to 49 mg kg^{-1} compared to 78 mg kg^{-1} in the control treatment. On the other hand, after initial negative values till day 14 and 21, leaves of *P. euramericana, R. pseudoacacia* and *E. umbellate* continuously increased TMN till the end ranged between 107 and 140 mg kg^{-1} (highest values).

3.3 Net cumulative N mineralization

Nitrogen mineralization of added plant residues was determined on the basis of net cumulative N mineralized (NCNM). The N mineralization from *G. max* and *T.*

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repenes shoot showed positive values throughout the incubation ranged between 24 to 110 mg kg^{-1} for *G. max* and 5 to 75 mg kg^{-1} for *T. repenes* (Fig. 1). Considering the NCNM at the end day 120, the net N mineralized as percentage of total N applied from *G. max* and *T. repenes* shoot was 54 and 21 %, respectively. The percent of N mineralized from *G. max* added shoot had been reported previously ranged from 39 to 43 % of applied N residues (Nakhone and Tabatabai, 2008). On the other hand, the NCNM from *G. max* roots, *Z. mays* shoot and *Z. mays* roots exhibited negative values throughout the incubation indicating net immobilization. Among the three residues, *Z. mays* roots displayed higher negative values leading to higher immobilization. Roots of *G. max,* and leaves of *P. euramericana, R. pseudoacacia* and *E. umbellate* showed four phases of mineralization-immobilization turnover (MIT): initial negative values from day 7 to 21, slow mineralization from day 21 to 60, a rapid mineralization during 60 and 80 days, declining in net during 100 and 120 days. The net N mineralized as percentage of total N applied from roots of *G. max,* and leaves of *P. euramericana, R. pseudoacacia* and *E. umbellate* was 16, 8, 21, 21 % respectively. Net nitrogen mineralization (% of added N) from different organic materials during 110 days of incubation was in the range between −35 % in *T. aestivum* (wheat) residues to 81 % in *T. repen* (white clover) residues (Kumar and Goh, 2003). Similarly, a 44, 38 and 35 % of N added had been released from the leaves of peanut, pigeonpea and hairy indigo, respectively (Thippayarugs et al., 2008).

All legumes (except *G. max* root) exhibited the highest NCNM (average 30 % of added plant N residues) compared to non-legumes (17 %). Similarly, the cereal crop *Z. mayz* shoot and root exhibited net immobilization compared to net mineralization observed in the legumes and tree leaves. The plant components also showed variation in NCNM. For example, shoot of *G. max* and *T. repens* mineralized an average of 74 mg N kg^{-1} compared to 4 mg N kg^{-1} from the roots. Likewise, leaves of forest trees showed higher NCNM compared to the roots of legumes and non-legumes crop.

The shoot of *G. max* and *T. repens* exhibited the highest NCNM without any negative value during incubation because of high N concentration and low C / N ratio. However,

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it is interesting to note that the total N concentration of the leaves of *R. pseudoacacia* and *E. umbellate* was higher and C / N ratio was lower compared to the *T. repens* shoot but the net mineralization (averaged) of *T. repens* shoot was higher (47 and 58 %) compared to the leaves of *R. pseudoacacia* and *E. umbellate*, respectively. The low mineralization in leaves in spite of high N content and low C / N ratio was attributed to higher concentration of LG, PP, LG / N, PP / N and LG + PP / N. These results demonstrated the role of other factors in addition to total N and C / N ratio affecting plant residues decomposition and N mineralization kinetics. As indicated in a previous study (Trinsoutrot et al., 2000) the net accumulation (whether positive or negative) of mineral N in soil during decomposition of organic residues is directly related to the residue N content. However, our results clearly indicated that N was not the only factor affecting the mineralization of added residues but some additional quality characteristics also influenced MIT of plant residues. Likewise, the total N content and C / N ratio of the leaves of *R. pseudoacacia* and *E. umbellate* were at par with *G. max* shoot but the net mineralization of *G. max* shoot was 3-fold higher. It had been reported that organic materials with similar C / N ratios may mineralize different amounts of N because of differences in composition that are not reflected by the C / N ratio (e.g. different lignin contents) (Mohanty et al., 2011).

Similarly, roots of *G. Max* and *Z. mays* showed net immobilization while roots of *T. repens* displayed fast decomposition and net N release pattern. This discrepancy in root MIT was mainly due to high N concentration, low C / N ratio; low LG and PP contents of the roots of *T. repens*. The N turnover shown by *T. repens* roots confirmed the strong below-ground N dynamics and residual effect of *T. repens* if grown in the soil.

Among the leaves of different trees tested, leaves of *R. pseudoacacia* and *Eumbellate* released a substantial amount of N into mineral N pool. Leaf residues have been described as high quality litter materials in terms of high N and low-lignin contents (Thippayarugs et al., 2008), have been found to decompose easily and release mineral N substantially (Mtambanengwe and Kirchmann, 1995) as observed in our study.

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However, *P. euramericana* leaves exhibited higher net immobilization (for a longer period) and lower net mineralization. The variation was again due to disparity in the biochemical composition. The low N content, high C / N ratio and high PP content may have been largely responsible for the slow decomposition and low net mineralization of *P. euramericana* leaves. These results inferred that the same plant components may not necessarily be shown similar decomposition and mineralization turnover because of variation in biochemical composition.

3.4 Pattern and trend of N mineralization

The patterns of N mineralization varied among plant residues and plant components. After incorporation into soil and during incubation, the added residues exhibited three main patterns of cumulative net mineralization (Fig. 2): (i) a pattern of the continuous and rapid release of net N throughout the incubation without showing any negative value indicating net mineralization. This pattern of mineralization was shown by the *G. max* shoot and *T. repens* shoot; (ii) a pattern shown by the *T. repens* roots, and leaves of *P. euramericana*, *R. pseudoacacia* and *E. umbellate* indicated initial negative values of net cumulative immobilization for variable periods followed by slow and then a rapid release of N indicating immobilization-mineralization turn-over; (iii) a pattern showed continuous negative values throughout the incubation indicating net N immobilization as seen in case of the *G. max* root and the *Z. mays* shoot and the root. The MIT and N released pattern by plant residues observed here was in accordance with that reported earlier in both leguminous and non-leguminous plant residues (Kumar and Goh, 2003).

The N mineralization trend over time showed wide variation (Fig. 3a). These results highlighted the time taken for releasing N into mineral N pool by the added plant residues. Results showed initial lag phase where most of the applied residues endured immobilization with little mineralization only from *G. max* and *T. repenes* shoot was shown during 0 to 21 days of incubation. The rapid mineralization phase occurred from day 28 to day 80. Thereafter, a declining phase of mineralization started in the later part of the incubation at day 100 to day 120.

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3.5 Changes in soil organic matter

In order to examine the changes in soil organic matter (SOM) in response to added plant residues, comparison between the SOM at the start at day 0 with those recorded at the end of incubation on day 120 had been shown (Fig. 3b). Soil organic matter contents of all the treatments recorded at day 120 was lower than that recorded at day 0. The unaccounted SOM ranged between 32 and 67 % compared to that recorded at day 0. The decreasing trend of SOM was substantially higher for the treatments showing mineralization (54–67 %) compared to those showing immobilization (32–38 %). By the end at day 120, the loss of SOM was in the order: *T. repens* shoot > *E. umbellate* leaves > *T. repens* root = *R. pseudoacacia* leaves > *P. euramericana* > *G. max* shoot > *Z. mays* shoot > *Z. mays* root = *G. max* root. The SOM turnover observed here was coincided with net mineralization. In the initial lag phase when mineralization was either very low or displayed negative values, on average only 8 % of the initial SOM had been utilized (7–21 days). The SOM utilization during 28–80 days when mineralization was rapid was 31 % of the initial amount while 43 % of initial SOM was utilized in the later part of incubation (100 and 120 days) when mineralization start showing declining trend.

3.6 Relationship between cumulative N mineralization and residues quality characteristics

Results of the study showed highly significant positive correlation between N mineralization i.e. NCNM and plant residue N concentrations ($r = 0.89$; $P \leq 0.01$) (Table 3). In contrast, a negative significant correlations existed between NCNM and LG ($r = -0.84$; $P \leq 0.01$), NCNM and C / N ratio ($r = -0.69$; $P \leq 0.05$), NCNM and LG / N ratio ($r = -0.68$; $P \leq 0.05$), NCNM and PP : N ratio ($r = -0.73$; $P \leq 0.05$) and NCNM and LG + PP / N ratio ($r = -0.70$; $P \leq 0.05$). The correlation between N mineralization and PP was non-significant at a $p < 0.05$. The significant positive correlation between net rates of N mineralization and residues N concentration

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observed is consistent with other studies (Nourbakhsh and Dick, 2005; Vahdat et al., 2011). It had been reported that N availability may control the decomposition of plant residues, particularly those with low N content such as cereals when the N requirements of the soil decomposers are not met by the residue or soil N contents (Vahdat et al., 2011). A negative correlation was also observed between net N mineralization and C / N ratio of the plant materials. Previously total N contents and C / N ratio were considered adequate for predicting the net N mineralization of crop residue. However, the latest studies including the present work highlighted the role of other quality characteristics including LG and PP affecting net mineralization of plant residues. The closer relationship between net mineralization with residue lignin contents ($r = -0.84$; $P \leq 0.01$) than that of C / N ratio ($r = -0.69$; $P \leq 0.05$) recorded in this study was in accordance with previous findings (Müller et al., 1988; Vahdat et al., 2011). The highly significant positive correlation between net N mineralization and the residue N content ($r = 0.89$; $P \leq 0.01$) confirm the previous results (Nourbakhsh and Dick, 2005; Vahdat et al., 2011) indicating that residue N concentration can be considered a better tool to predict mineralization of added organic residues compared to the C / N ratio.

4 Conclusions

The experiment showed that soil amended with plant residues displayed wide variation of net N mineralization depended upon the plant species and plant components/organs. The decomposition and N released potential of added materials were largely related to their biochemical composition. Overall, in addition to residues N concentration and C / N ratio, LG contents of plant residues also appeared an important factor predicting the net N mineralization. Due to high N concentrations and low C / N ratio and LG contents, shoots of *G. max and L. repens* found superior over other added residues regarding the rate and amount of N released. Similarly, leaves of *R. pseudoacacia* and *E. umbellate* also exhibited a substantial net mineralization

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potential in spite of the initial immobilization. These two plant types therefore can produce high quality residues and thus have the potential to promote N cycling in agro-ecosystems. In contrast, incorporation of *Z. mays* shoot and roots and *G. max* roots resulted in continuous net immobilization. Hence, the added residues displayed both mineralization-immobilization turn-over in soil that can be used as an important N management strategy in soil-plant systems. Plant residues showing rapid mineralization can be used for early N demands of a crop while residues having high C / N ratio and LG contents immobilize N thus can help to counter the N loss generally observed due to rapid ammonification-nitrification turn over.

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Table 1. Biochemical composition of the plant residues used in the experiment (each value is the mean of three replications). Different letters in each column show significant differences among different treatments at a $p < 0.05$.

Plant residues	Plant organs	Total N	Total C	Lignin (LG)	Polyphenols (PP)	C / N	LG / N	PP / N	LG + PP / N
		g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}				
Glycine max	Shoot	35.2a	447c	11f	13.1f	12.7	0.3	0.4	0.7
Glycine max	Root	12.8e	466b	29d	26.9d	36.4	2.3	2.1	4.4
Zea Mays	Shoot	9.6f	472ab	41b	29.5cd	49.2	4.3	3.1	7.3
Zea Mays	Root	4.0g	486a	48a	31.4c	121.5	12.0	7.9	19.9
Trifolium repenes.	Shoot	27.4b	397g	13f	18.0e	14.4	0.4	0.6	1.1
Trifolium repenes	Root	16.0d	423de	21e	20.2e	26.4	1.3	1.2	2.5
Poplus euramericana	Leaves	20.8c	435cd	34c	53.8a	20.9	1.6	2.6	4.2
Rubinia pseudoacacia	Leaves	33.3a	404fg	28d	32.3c	12.1	0.8	1.0	1.8
Elagnus umbellate	Leaves	34.7a	418ef	32cd	38.7b	12.1	0.9	1.1	2.0
LSD (0.05)	–	3.14	14.16	4.53	3.77				

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Table 2. Changes in the concentration of total mineral N (TMN) of a soil amended with different plant residues and incubated at 25 °C under controlled laboratory conditions.

Treatments	Days after plant residues addition										LSD
	0	7	14	21	28	42	60	80	100	120	($p \leq 0.05$)
	mg N kg^{-1} soil										
T_0	13.7	13.9	12.9	17.1	30.9	65.9	63.1	75.6	77.7	51.7	2.88
T_1	14.8	39.2	49.2	76.8	96.7	158.1	165.2	174.1	188.7	160.9	7.90
T_2	13.7	8.1	5.2	8.3	11.8	13.8	28.4	50.4	49.4	27.7	8.15
T_3	13.7	7.4	6.2	6.9	10.5	23.1	21.2	36.1	46.7	21.0	5.34
T_4	14.3	7.4	9.4	7.7	8.8	15.3	22.2	21.4	32.4	26.4	4.30
T_5	14.1	19.0	21.6	55.5	62.5	86.8	127.6	150.8	145.8	93.3	7.31
T_6	15.5	8.2	5.2	23.9	34.0	85.3	98.0	149.9	130.2	85.8	9.46
T_7	13.0	5.7	4.1	8.6	22.6	55.5	73.1	106.8	87.3	66.9	8.39
T_8	13.9	7.4	9.2	23.6	46.6	91.3	111.0	138.9	127.8	93.7	7.83
T_9	12.9	9.4	14.5	25.3	51.1	80.1	92.7	140.0	116.4	93.5	6.88
LSD ($p \leq 0.05$)	2.43	4.77	3.12	5.11	7.63	8.23	6.87	9.23	8.27	7.34	

T_0 = control; T_1 = *Glycine max* shoot, T_2 = *G. max* root; T_3 = *Zea mays* shoot, T_4 = *Z. mays* root; T_5 = *Trifolium repens* shoot; T_6 = *T. repens* root; T_7 = *Poplus euramericana* leaves; T_8 = *Rubinia pseudoacacia* leaves; T_9 = *Elagnus* umbellate leaves incubated under controlled laboratory conditions. LSD represents the least significant difference ($p \leq 0.05$) among incubation periods (within rows) and among the treatments (within column).

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Table 3. Pearson linear correlation coefficients between initial quality characteristics of the plant residues and net N mineralization

	N_{min}	TN	LG	PP	C : N	LG : N	PP : N
TN	0.89**						
LG	−0.84**	−0.66*					
PP	−0.42 ns	−0.10 ns	0.62*				
C : N	−0.69*	−0.80**	0.73*	0.07 ns			
LG : N	−0.68*	−0.76**	0.77**	0.14 ns	0.99**		
PP : N	−0.73*	−0.77**	0.82**	0.29 ns	0.99**	0.98**	
LG + PP : N	−0.70*	−0.76**	0.79**	0.19 ns	0.99**	1.00**	0.99**

** And * represent significant level at $p \leq 0.01$ and $p \leq 0.05$, respectively; ns means non-significant at a $p < 0.05$ N_{min}, N mineralization; TN, total nitrogen; LG, lignin; PP, Polyphenols.

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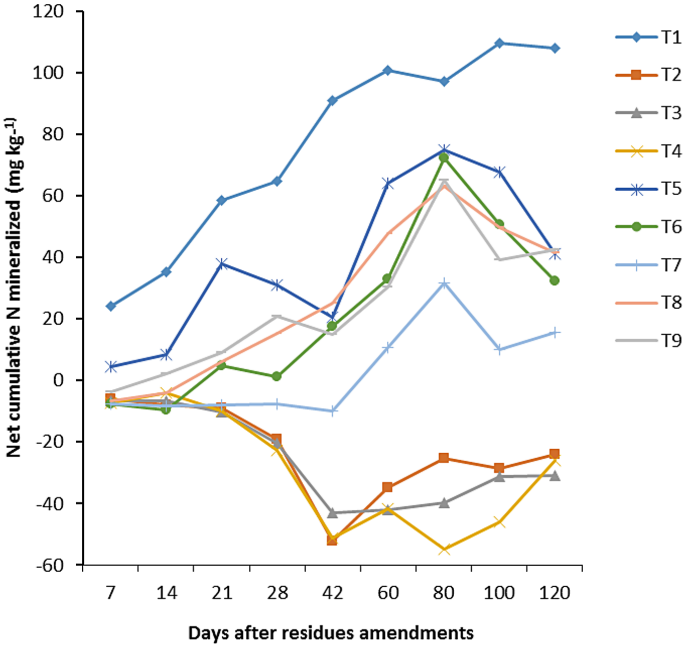

Figure 1. Net cumulative N mineralized (NCNM) from the added plant residues at different incubation periods. The legends at the top represent T_1 = *Glycine max* shoot, T_2 = *G. max* root; T_3 = *Zea mays* shoot, T_4 = *Z. mays* root; T_5 = *Trifolium repens* shoot; T_6 = *T. repens* root; T_7 = *Poplus euramericana* leaves; T_8 = *Rubinia pseudoacacia* leaves; T_9 = *Elagnus umbellate* leaves.

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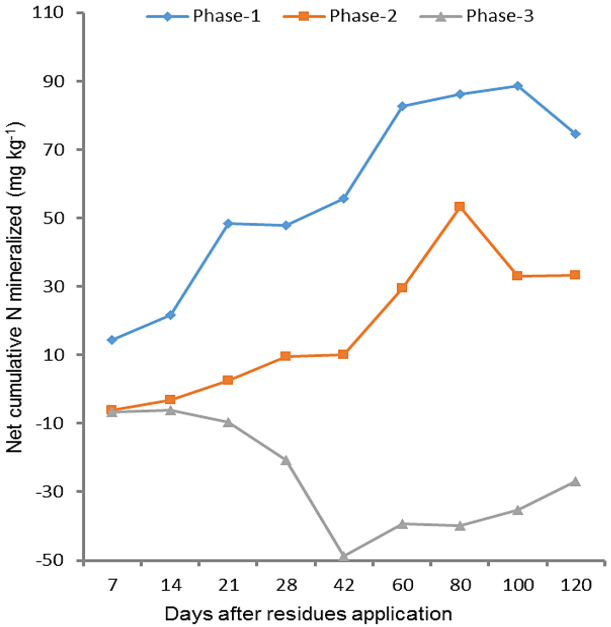

Figure 2. The mineralization–immobilization turnover (MIT) of added plant residues representing three phases during 120 days incubation.

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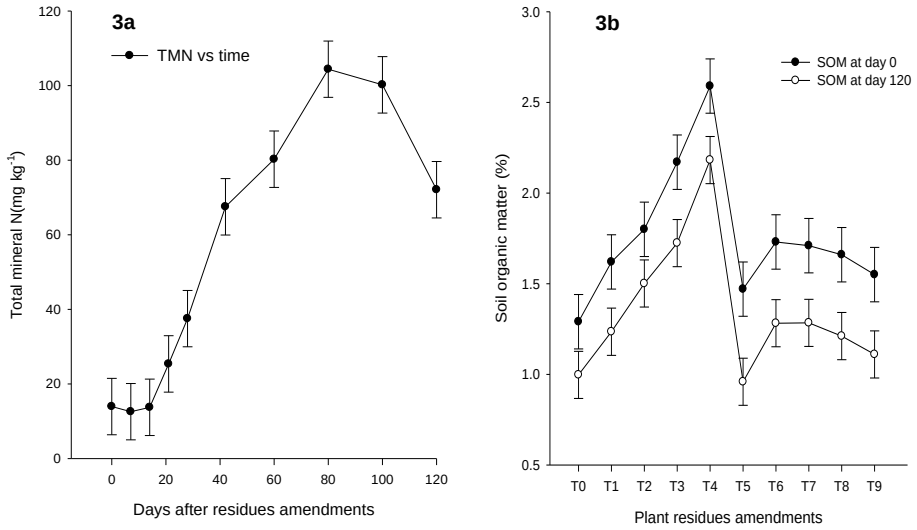

Figure 3. Mineralization trend of added plant residues across timings **(a)** and soil organic matter (SOM) turnover of different plant residues **(b)** recorded at the start of the experiment at day 0 and at the end of incubation at day 120. Vertical line on each major line represents the LSD ($P \leq 0.05$) between incubation periods and between each treatment, respectively.

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