SOILS, SEC 2 • GLOBAL CHANGE, ENVIRON RISK ASSESS, SUSTAINABLE LAND USE • RESEARCH ARTICLE

Dynamics of soil extractable carbon and nitrogen under different cover crop residues

Xiaoqi Zhou · Chengrong Chen · Hanwen Wu · Zhihong Xu

Abstract

Purpose Cover crop residue is generally applied to improve soil quality and crop productivity. Improved understanding of dynamics of soil extractable organic carbon (EOC) and nitrogen (EON) under cover crops is useful for developing effective agronomic management and nitrogen (N) fertilization strategies.

Materials and methods Dynamics of soil extractable inorganic and organic carbon (C) and N pools were investigated under six cover crop treatments, which included two legume crops (capello woolly pod vetch and field pea), three non-legume crops (wheat, Saia oat and Indian mustard), and a nil-crop control (CK) in southeastern Australia. Cover crops at anthesis were crimp-rolled onto the soil surface in October 2009. Soil and crop residue samples were taken over the periods October–December (2009) and March–May (2010), respectively, to examine remaining crop residue biomass, soil NH_4^+-N and NO_3^--N as well as EOC and EON concentrations using extraction methods of 2 M KCl and hot water. Additionally, soil net N mineralization rates were measured for soil samples collected in May 2010.

Results and discussion The CK treatment had the highest soil inorganic N ($NH_4^+-N+NO_3^--N$) at the sampling time in December 2009 but decreased greatly with sampling time. The cover crop treatments had greater soil EOC and EON concentrations than the CK treatment. However, no significant differences in soil NH_4^+-N, NO_3^--N, EOC, EON, and ratios of EOC to EON were found between the legume and non-legume cover crop treatments across the sampling times, which were supported by the similar results of soil net N mineralization rates among the treatments. Stepwise multiple regression analyses indicated that soil EOC in the hot water extracts was mainly affected by soil total C ($R^2=0.654$, $P<0.001$), while the crop residue biomass determined soil EON in the hot water extracts ($R^2=0.591$, $P<0.001$).

Conclusions The cover crop treatments had lower loss of soil inorganic N compared with the CK treatment across the sampling times. The legume and non-legume cover crop treatments did not significantly differ in soil EOC and EON pools across the sampling times. In addition, the decomposition of cover crop residues had more influence on soil EON than the decomposition of soil organic matter (SOM), which indicated less N fertilization under cover crop residues. On the other hand, the decomposition of SOM exerted more influence on soil EOC across the sampling times among the treatments, implying different C and N cycling under cover crops.

Keywords Cover crop · Crop residue · Legume · Non-legume · Soil extractable organic C · Soil extractable organic N · Soil inorganic N

X. Zhou (✉) · Z. Xu
Environmental Futures Centre, School of Biomolecular and Physical Sciences, Griffith University,
Nathan 4111, Australia
e-mail: zhou318@yahoo.com.cn

C. Chen (✉)
Environmental Futures Centre, Griffith School of Environment, Griffith University,
Nathan 4111, Australia
e-mail: c.chen@griffith.edu.au

H. Wu
EH Graham Center, Wagga Wagga Agricultural Institute, Industry & Investment NSW, PMB,
Wagga Wagga, NSW 2650, Australia

1 Introduction

Cover crops are usually used to control weeds and to improve soil quality and crop productivity (Sainju et al. 2008). In general, after cover crop harvest, crop residues are retained on the soil surface, which not only reduces the impact of rain drops but also maintains soil moisture via decreasing soil evaporation (DuPont et al. 2009). More importantly, cover crops can increase soil extractable organic carbon (EOC) and nitrogen (EON) pools, an active fraction of soil organic matter (SOM), via the decomposition of crop residue biomass by microorganisms (Coppens et al. 2006; Ding et al. 2006). Many studies have reported that legume crops can fix N from the atmosphere and increase N input into the soils via root exudation and litter decomposition using ^{15}N labeling or natural abundance techniques (Bertin et al. 2003; Bilgo et al. 2007). However, Wichern et al. (2008) reviewed that similar amounts of N were released into the soils from legume crops in comparison with those from non-legume crops using ^{15}N natural abundances based on laboratory incubations. In fact, the effects of legume crops on soil N availability can be modified by many factors such as temperature and rainfall under field conditions. However, little is known about the effects of cover crop residue biomass on dynamics of soil EOC and EON pools under cover crop residues, which will be useful for developing effective agronomic management and N fertilization strategies.

Soil EOC and EON pools play important roles in nutrient cycling and provide a reservoir of nutrients for crop uptake (Ros et al. 2009; Xu et al. 2009). Soil EOC and EON pools are measured by various methods, and their concentrations vary with various extraction methods (e.g., 2 M KCl and hot water; Murphy et al. 2000; Ros et al. 2009). The pool sizes are more sensitive to management practices in comparison with SOM (Burton et al. 2007; Huang et al. 2008; Rui et al. 2011). In addition, soil EOC and EON pools can also be affected by environmental factors, such as soil moisture and temperature, which can be attributed to variations in soil microbial activity, an important factor determining the decomposition of crop residue biomass (Schmidt et al. 2007; Xiang et al. 2008). In the process of decomposition of crop residue biomass, most of the crop N is first broken down into smaller compounds such as soil EON (Schimel and Bennett 2004), which can be taken up by microorganisms (Geisseler et al. 2010). On the other hand, soil microorganisms can also contribute to soil EOC and EON pools via decomposing indigenous SOM (Chen and Xu 2008). Therefore, distinguishing the relative importance of crop residue biomass and SOM on soil EOC and EON pools will improve understanding of soil C cycling and N availability in agro-ecosystems.

To date, a few studies are available about the effects of cover crops on soil EOC and EON pools in temperate Australia in comparison with those in the other continents (Ros et al. 2009; Xiang et al. 2008). In this study, six cover crop treatments, i.e., two legume crops, three non-legume crops, and a nil-crop control, were selected to investigate the effects of cover crop residues on soil NH_4^+–N and NO_3^-–N, EOC, and EON over a period of May 2009 and May 2010. The objectives of this study were to examine (1) the dynamics of soil NH_4^+–N, NO_3^-–N, EOC, and EON between legume and non-legume cover crop treatments and (2) the relative importance of crop residue biomass and SOM to soil EOC and EON pools.

2 Materials and methods

2.1 Experimental site

The experimental site is located in the Wagga Wagga Agricultural Institute in NSW, southeastern Australia (147° 20′ E, 35°05′ S). The climate in this area is temperate with mean daily maximum temperatures ranging from 12.5 °C in July (mid winter) to 31.2 °C in January (mid summer). A meteorological station is maintained nearby the field experiment, and meteorological variables are measured daily, including air and soil temperatures, rainfall, and potential evaporation. Long-term records indicate mean annual rainfall of 550 mm, whereas 2009 was a dry year with 389 mm recorded and an extreme rainfall of 116.5 mm occurred on March 8, 2010 (Fig. 1). The soil is a Chromic Luvisol according to the FAO classification with 48.4±2.2 % sand, 19.5± 2.1 % silt, and 32.1±2.1 % clay. Soil bulk density and pH values are 1.29±0.18 g cm^{-3} and 5.01±0.08, respectively. Soil total organic C and N contents are 21.4±1.85 and 1.87± 0.16 g kg^{-1}, respectively (Zhou et al. 2011).
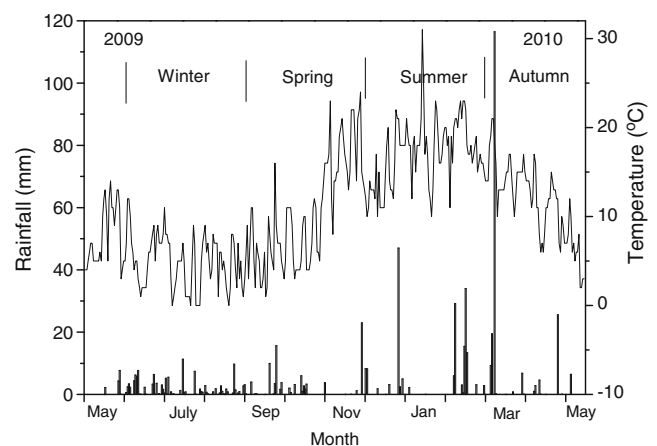

Fig. 1 Rainfall (*bars*) and mean air temperature (*line*) during the experimental period from May 2009 to May 2010 in Wagga Wagga, NSW, Australia

2.2 Field trial

The study site was cropped with winter wheat in 2005, and it has been fallowed prior to the experiment. The six cover crop treatments consisted of two legume crops, i.e., capello woolly pod vetch (*Vicia villosa*; designated as vetch) and field pea (*Pisum sativum*; designated as pea); three non-legume crops, i.e., wheat (*Triticum aestivum*), Saia oat (*Avena strigosa*; designated as oat), Indian mustard (*Brassica juncea*; designated as mustard); and a nil-crop treatment used as a control (CK). Treatments were arranged in a randomized complete block design with three replications. Each plot was 40 m^2 (4× 10 m) with a rowing space of 22 cm. The crop species were broadcast-seeded at 80, 80, 50, 100, and 5 kg ha^{-1} for wheat, oat, vetch, pea, and mustard, respectively, in late May 2009. Di-ammonium phosphate was applied at a rate of 80 kg ha^{-1} (including 20 kg N, 18 kg P, and 2–3 kg S ha^{-1}) for all plots at sowing (Zhou et al. 2011). Cover crops at anthesis were crimp-rolled on the soil surface in October 2009.

2.3 Soil and crop samplings

Soil and crop samples were collected in October and December 2009, and March and May 2010, respectively. The residue biomass of each cover crop was assessed by cutting at the ground level from two random quadrats of 1 m^2 in each plot. The aboveground biomass for each plot was then combined and oven-dried at 70 °C for 3 days. Soil samples were taken on the same day by taking five random cores (5-cm in diameter) to a depth of 10 cm in each plot. The five soil cores were immediately mixed thoroughly and kept in a cooler (about 4 ° C). After passing through 2-mm sieve, the soil samples were stored at 4 °C prior to analysis. The sub-samples were air-dried and stored at room temperature for hot water extraction.

2.4 Soil properties and crop C and N contents

Sand, silt, and clay contents were determined by the hydrometer method (Zhou et al. 2011). Soil moisture was determined after being oven-dried at 105 °C overnight. Soil pH was measured at a 1:2.5 dry soil/water ratio. Total C (TC) and total N (TN) of soil samples and crop C and N contents were determined using an Isoprime isotope ratio mass spectrometer with a Eurovector elemental analyzer (Isoprime-EuroEA 3000) (Zhou et al. 2010).

2.5 Soil inorganic N, extractable organic C and N

Two extraction methods were used to determine soil inorganic N, extractable organic C (EOC) and N (EON) (Zhou et al. 2012). For the KCl extracts, 5 g (dry weight equivalent) of field moist soil samples was extracted with 30 ml of 2 M KCl in an end-to-end shaker for 1 h and filtered through a Whatman no. 42 paper. Hot water extractable organic matter (HW) was measured by the method described by Zhou et al. (2011). Briefly, 5 g of air-dried samples were incubated at 70 °C for 16 h with 50 ml of distilled water in a centrifuge tube. After the tubes were shaken on an end-to-end shaker for 1 h and the soil–water suspension was centrifuged at 3,000 rpm for 30 min, the supernatant was filtered through a Whatman no. 42 paper and through 0.45-μm filter membrane. The concentration of inorganic N was measured on a Lachat Quickchem automated analyzer (Quick Chem method 10-107-064-D for NH_4^+ and 10107-04-1-H for NO_3^- and NO_2^-). Extractable inorganic N (EIN) was calculated as the sum of NO_3^-–N and NH_4^+–N. EOC and extractable total N (ETN) in the soil extracts were determined using Shimadzu TOC-$_{VCPH/CPN}$ analyzer (fitted with a TN unit). Soil EON was determined by subtracting EIN from ETN in the soil extracts for each sample (Chen et al. 2005).
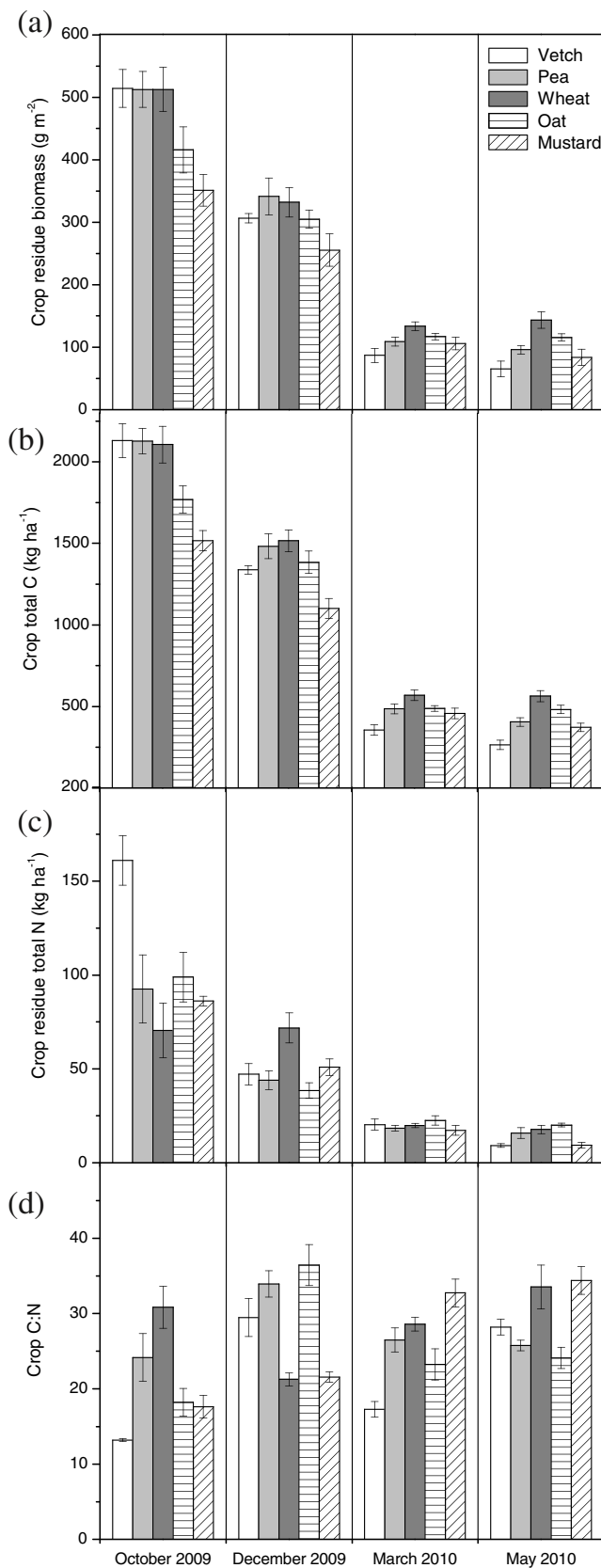
2.6 Soil net N mineralization rates

For the last batch of soils sampled in May 2010, soil net N mineralization rates were determined by a 7-day anaerobic incubation under laboratory conditions as described by Chen et al. (2002). Briefly, two portions of 5 g field moist soil samples were weighed, and one portion of them was added with 20 ml of distilled water and incubated at 40 °C for 7 days, extracted with 20 ml of 4 M KCl in an end-to-end shaker for 1 h, and then filtered through a Whatman no. 42 paper. The other portion of soil was directly extracted as above. Concentration of NH_4^+–N was measured on a Lachat Quickchem automated analyzer as described above.

Table 1 *F* values of the effects of sampling time (S) and treatment (T) on cover crop residue biomass, total C and N, as well as C/N ratios

	Crop residue biomass	Total C	Total N	C:N
Sampling time (S)	206.57***	192.23***	141.11***	6.51***
Treatment (T)	5.26**	4.39**	4.81***	3.26**
S×T	1.97*	0.18	6.91***	3.71***

*P<0.05; **P<0.01; ***P<0.001

(a)

(b)

(c)

(d)

2.7 Statistical analyses

All data were tested for normal distribution before other statistical analyses. Repeated measure analysis of variance was used to examine the effects of the cover crop treatments and sampling time on soil inorganic N, EOC and EON. In addition, two-way ANOVA was used to determine the main and interactive effects of the cover crop treatments and sampling times on soil physiochemical variables. One-way ANOVA was used to determine the differences in soil net N mineralization rates among the treatments. Pearson's correlation coefficients were determined to investigate relationships between soil inorganic N, EOC, and EON. To further investigate which variable has the greatest effect on soil EOC and EON, stepwise multiple regressions were conducted, with soil EOC and EON as the dependent variables, and soil moisture, pH, soil, and crop total C and N values as the independent variables. All statistical analyses were performed using SPSS 12.0 (SPSS Corp., USA).

3 Results

3.1 Cover crop residue biomass and C and N contents

Cover crop residue biomass, total C, total N, and C/N ratios were significantly affected by the sampling times and cover crop treatments ($P<0.05$; Table 1 and Fig. 2). At the beginning of the experiment, the vetch, pea, and wheat treatments had the highest residue biomass, which was significantly higher than that in the mustard treatment (351 ± 25 g m^{-2}). Crop residue biomass decreased significantly with sampling time (see Fig. 2a). Across the treatments, crop residue biomass decreased by 33 % in December 2009, 76 % in March 2010, and 78 % in May 2010, compared with the initial values in October 2009. A great loss of crop residue biomass occurred between December 2009 and March 2010, which coincided with the higher temperature and rainfall over this period (see Fig. 1). However, there were no significant differences in crop residue biomass between the two sampling times in March and May 2010 (see Fig. 2a).

Across the sampling times, there was a greater loss of crop residue biomass in the legume cover crop treatments than in the non-legume cover crop treatments (84 vs. 74 %). When sampled in May 2010, the crop residue biomass was the highest in the wheat treatment (143 ± 13 g m^{-2}), which was significantly higher than those in the vetch, pea, and mustard treatments (see Fig. 2a). The crop total C and N

Table 2 F values of the effects of sampling time (S) and treatment (T) on soil $NH_4^+–N$, $NO_3^-–N$, extractable organic C (EOC) and N (EON) concentrations, as well as ratios of EOC to EON in the KCl (KCl) and hot water (HW) extracts

	$NH_4^+–N_{KCl}$	$NO_3^-–N_{KCl}$	$NH_4^+–N_{HW}$	$NO_3^-–N_{HW}$	EOC_{KCl}	EON_{KCl}	EOC/EON_{KCl}	EOC_{HW}	EON_{HW}	EOC/EON_{HW}
Sampling time (S)	57.48***	114.32***	13.91***	37.89***	54.79***	102.12***	27.66***	91.76***	60.07***	17.88***
Treatment (T)	3.97*	35.41***	4.40*	38.13***	4.68*	10.22***	24.57***	5.91**	6.84**	7.49**
S×T	4.74*	3.86***	1.02	4.24***	0.98	1.42	22.83***	0.52	0.62	2.11*

*$P<0.05$; **$P<0.01$; ***$P<0.001$

showed the similar patterns to the crop residue biomass across the sampling times (see Table 1 and Fig. 2b, c). The vetch treatment had the lowest crop C/N ratio in comparison with the other treatments with the exception of sampling time in December 2009. The vetch treatment had significantly lower crop C/N ratio across the sampling times compared with the non-legume treatments, while the pea treatment had similar crop C/N ratios to the non-legume treatments (see Fig. 2d).

3.2 Dynamics of soil $NH_4^+–N$ and $NO_3^-–N$

Concentrations of $NH_4^+–N$ and $NO_3^-–N$ in the KCl and hot water extracts were significantly affected by the sampling times and cover crop treatments (Table 2 and Fig. 3). There were significant interactions between the sampling times and the

cover crop treatments on soil $NH_4^+–N_{KCl}$, $NO_3^-–N_{KCl}$ and $NO_3^-–N_{HW}$ contents (see Table 2). Soil $NH_4^+–N$ and $NO_3^-–N$ in the KCl (see Fig. 3a, b) and hot water extracts (see Fig. 3c, d) were similar to each other and represented consistent trends over time, which was evidenced by significant correlations between them ($r=0.29–0.91$, $P<0.01$; Table 3). Generally, the form of soil inorganic N was dominated by $NO_3^-–N$. Soil $NH_4^+–N$ and $NO_3^-–N$ concentrations in the two extracts were higher in December 2009 and March 2010 than in the other sampling times. At the beginning of the experiment, the control had the highest soil $NO_3^-–N$ contents, reached a peak in December 2009, and then decreased afterwards, resulting in no significant differences between all six treatments when sampled in May 2010 compared with the other treatments (see Fig. 3b, d). Similarly, soil $NH_4^+–N$ in the control decreased

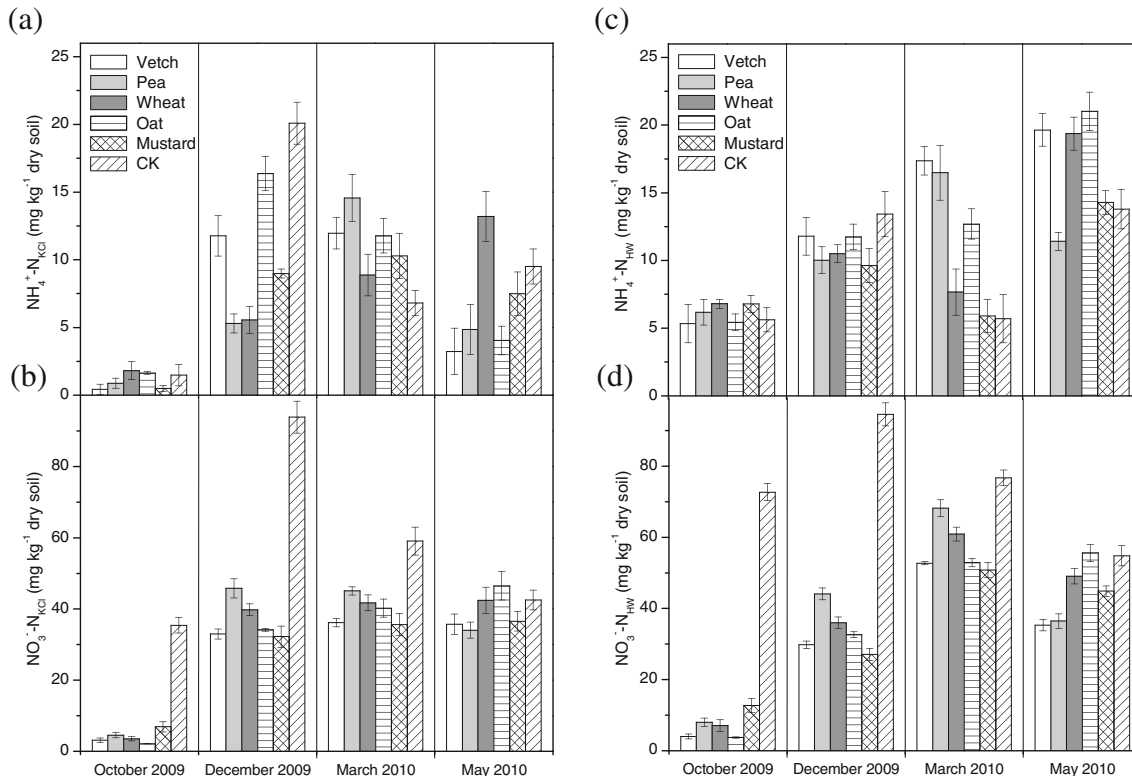**Fig. 3** Variations in soil $NH_4^+–N$ and $NO_3^-–N$ concentrations in the KCl (KCl; **a**, **b**) and hot water (HW; **c**, **d**) extracts between October 2009 and May 2010 under cover crops in southeastern Australia. Data represent mean and standard error ($n=3$)

Table 3 Pearson's correlation coefficients between soil NH_4^+–N, NO_3^-–N, extractable organic C (EOC) and N (EON) concentrations, as well as ratios of EOC to EON in the KCl (KCl) and hot water (HW) extracts

r	NH_4^+–N_{KCl}	NO_3^-–N_{KCl}	NH_4^+–N_{HW}	NO_3^-–N_{HW}	EOC_{KCl}	EON_{KCl}	EOC/EON_{KCl}	EOC_{HW}	EON_{HW}	EOC/EON_{HW}
NH_4^+–N_{KCl}	1									
NO_3^-–N_{KCl}	0.57***	1								
NH_4^+–N_{HW}	0.43***	0.29**	1							
NO_3^-–N_{HW}	0.49***	0.91***	0.56**	1						
EOC_{KCl}	0.50***	0.35***	0.42**	0.35**	1					
EON_{KCl}	0.39***	0.18	0.49***	0.38**	0.38**	1				
EOC/EON_{KCl}	−0.1	0.11	−0.14	0.33*	0.04	−0.55***	1			
EOC_{HW}	0.21	0.03	0.12	0.15	0.38**	0.83***	−0.41***	1		
EON_{HW}	0.25*	0.08	0.38*	0.17	0.17	0.84***	−0.54***	0.89***	1	
EOC/EON_{HW}	−0.03	0.07	−0.31*	0.13	0.13	−0.38***	0.65***	0.35*	−0.59***	1

*$P<0.05$; **$P<0.01$; ***$P<0.001$ ($n=72$)

greatly over the period December 2009–March 2010 (see Fig. 3a, c). Across the sampling times, the legume and non-legume cover crop treatments did not differ significantly in soil NH_4^+–N and NO_3^-–N, while the mustard treatment tended to be lower in soil NH_4^+–N compared with the other treatments. The variations in soil NH_4^+–N and NO_3^-–N within the legume cover crop treatments were to some extent larger than those within the legume and non-legume cover crop treatments (see Fig. 3).

3.3 Dynamics of soil extractable organic C and N pools

Concentrations of soil EOC, EON, and the ratios of EOC to EON in the KCl and hot water extracts changed greatly over time and were significantly affected by the sampling times and cover crop treatments (see Table 2 and Fig. 4). There were significant interactions between the sampling time and the cover crop treatments on soil EOC/EON_{KCl} and EOC/EON_{HW}, but not on soil EOC_{KCl}, EON_{KCl}, EOC_{HW}, and EON_{HW} (see Table 2). The two extraction methods (KCl and hot water extract) showed similar trends in soil EOC, EON, and the ratios of EOC to EON across the sampling times (see Fig. 4), which was evidenced by significant correlations between the two methods (all $P<0.05$; see Table 3).

Soil EOC and EON in the KCl and hot water extracts were higher in December 2009 and in March 2010 than in the other sampling times (see Fig. 4). Concentrations of soil EOC_{HW} were 6.1–8.9 times higher than those of EOC_{KCl}, while concentrations of soil EON_{HW} were 4.7–6.8 times higher than those of EON_{KCl}. In general, the CK treatment had higher EOC/EON_{KCl} and EOC/EON_{HW} in October and December 2009 in comparison with the other treatments. No significant differences were found in soil EOC and EON in the KCl and hot water extracts between the legume and non-legume crop treatments because of large variations across the sampling

times. The oat treatment had significantly higher soil EOC_{KCl} than the pea and wheat treatments (see Fig. 4a), while the wheat treatment had significantly higher soil EOC_{HW} than the pea and mustard treatments across the sampling times (see Fig. 4d). Significant differences were found in soil EON_{KCl} among the wheat, oat, and mustard treatments (see Fig. 4b), while no significant differences were found in soil EON_{HW} between the cover crop treatments across the sampling times (see Fig. 4e). The pea and oat treatments had significantly higher EOC/EON_{KCl} than the other cover crop treatments (see Fig. 4c), while no significant differences were found in EOC/EON_{HW} among the cover crop treatments across the sampling times (see Fig. 4f).

Concentrations of soil EOC_{KCl} were highly correlated with NH_4^+–N and NO_3^-–N in the KCl and hot water extracts ($r=0.35$–0.50, both $P<0.01$), while soil EON_{KCl} and EON_{HW} were highly correlated with NH_4^+–N_{KCl} ($r=0.25$–0.39, both $P<0.05$) and NH_4^+–N_{HW} ($r=0.38$–0.49, both $P<0.01$; see Table 3).

3.4 Soil net N mineralization rates

The CK treatment had the lowest soil net N mineralization rates, which was significantly lower than those in the vetch and oat treatments (Fig. 5). Among the cover crop treatments, the vetch treatment had significantly higher soil net N mineralization rates than the pea, wheat, and mustard treatments. However, no pronounced differences were found between the legume and non-legume cover crop treatments (see Fig. 5).

3.5 Factors influencing soil inorganic N, extractable organic C and N pools

Correlation analyses revealed that crop residue biomass, soil moisture, and pH were important factors affecting soil NH_4^+–

N, NO_3^-–N, EOC, and EON concentrations among the treatments across the sampling times. Cover crop residue biomass alone explained 17–58 % of the variations of soil NH_4^+–N and NO_3^-–N contents, while soil moisture alone explained 14–29 % and pH alone explained 13–20 % of them across the sampling times among the treatments (Table 4). Cover crop residue biomass, soil moisture, and pH alone explained 7–16 % of the variations in soil EON contents across the sampling

times among the treatments (all $P<0.05$). In addition, crop residue biomass alone explained 7 % of the variations of soil EOC_{HW}, while soil moisture alone explained 13 % of the variations of EOC_{KCl} across the sampling times (both $P<0.05$).

Stepwise multiple regression showed that EOC_{HW} was mainly affected by soil total C ($R^2=0.654$, $P<0.001$), while EON_{HW} mainly depended on crop residue biomass ($R^2=0.591$, $P<0.001$; Table 5).
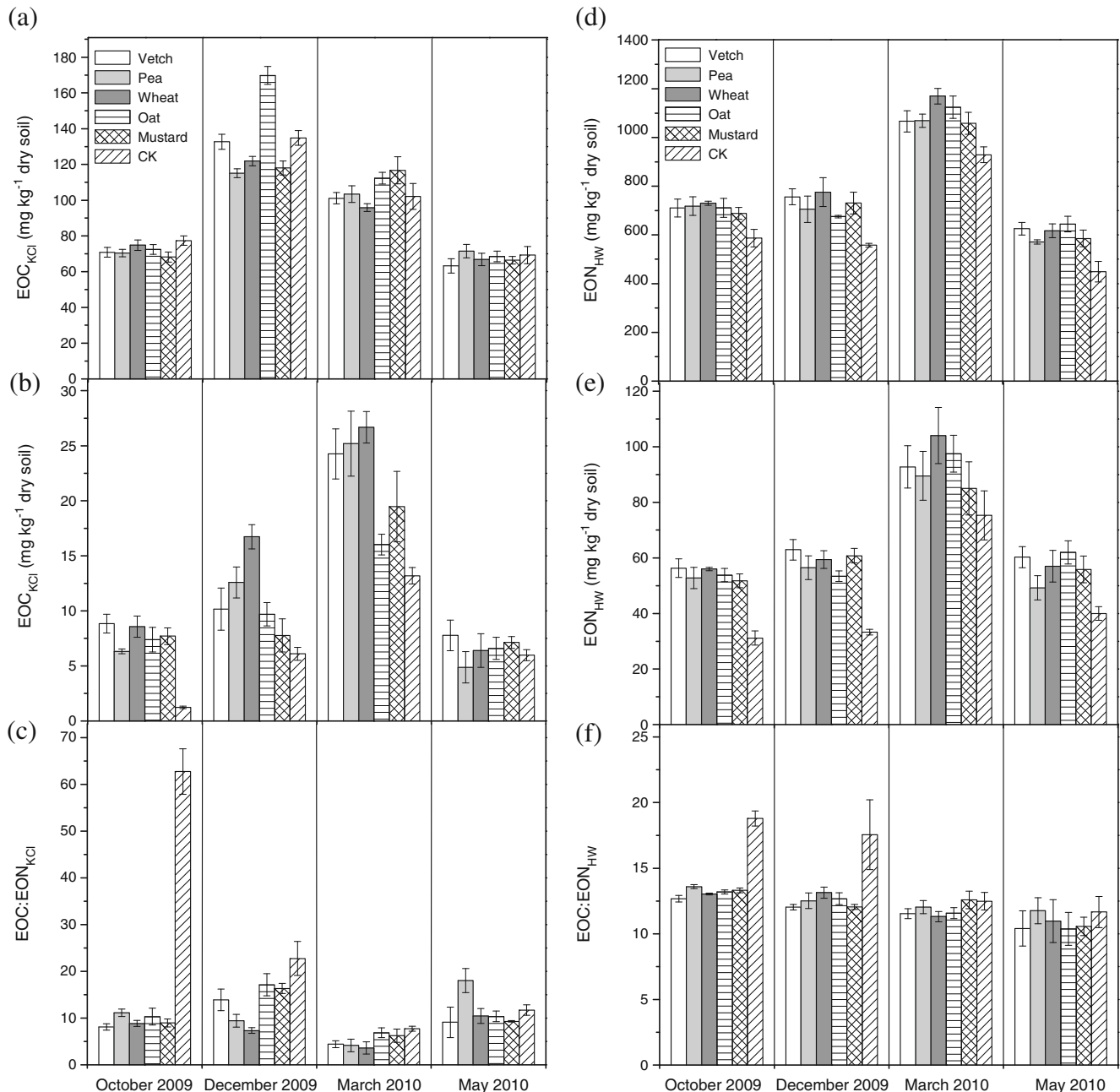

Fig. 4 Variations in soil extractable organic C (EOC) and N (EON) contents as well as ratios of EOC to EON in the KCl (KCl; **a–c**) and hot water (HW; **d–f**) extracts between October 2009 and May 2010 under cover crops in southeastern Australia. Data represent mean and standard error ($n=3$)
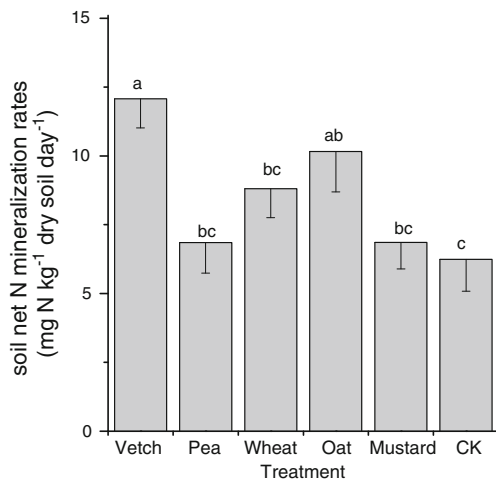
Fig. 5 Soil net N mineralization rates under cover crops sampled in May 2010. *Different letters* indicate significant differences at $P<0.05$ ($n=3$)

4 Discussion

4.1 Dynamics of soil inorganic N

At the sampling time in October 2009, the significantly higher concentrations of soil inorganic N in the CK treatment could be attributed to the lack of crop N uptake during the growing season (see Fig. 3). With the exception of a part of soil EON directly taken up by microorganisms, EON was first mineralized into NH_4^+–N and subsequently NO_3^-–N through nitrification (Ros et al. 2009; Schimel and Bennett 2004). During this period, any N released through mineralization was accumulated as NO_3^-–N, which could lead to the form of soil inorganic N dominated by NO_3^-–N across the sampling times (see Fig. 3). The CK treatment reached a peak in soil inorganic N in the summer compared with the other treatments and then decreased greatly in the autumn, which indicated a greater loss of N due to the absence of cover crop residues (see Fig. 3). Murphy et al. (2007) reported that soil inorganic N concentrations were closely associated with the changes in soil EON. In this study, however, significantly positive relationships were mainly found between soil NH_4^+–N and EON concentrations

across the treatments (see Table 3). The concentrations of soil inorganic N in the pea, wheat, and oat treatments were greater than in the other cover crop treatments across the sampling times (see Fig. 3), which could be due to greater losses of crop residue biomass via decomposition (see Fig. 2).

4.2 Dynamics of soil EOC and EON and net N mineralization rates

The application of cover crops could supply the crop C and N into the soils (Sainju et al. 2007). However, annual incorporation of total C and N under crop residue biomass did not substantially increase soil organic C and N contents (Bationo et al. 2007). For example, a study with 10-year mulch tillage was reported to increase soil organic C by 5.2 Mg ha^{-1} and total N by 0.41 Mg ha^{-1} in comparison with no-till treatment at 0–20 cm depth (Sainju et al. 2008). Similarly, a mixture of legume cover crops with residue biomass of 34.86–90.43 Mg ha^{-1} was found to increase soil organic C by 16.90–43.34 g kg^{-1} and total N by 0.97–3.07 Mg ha^{-1}, respectively, at 0–20 cm depth in a coconut plantation over a period of 12 years (Dinesh et al. 2006). In contrast, Rouw et al. (2010) reported that no-till system with a cover crop of 44.2 Mg dry weight per hectare reduced 133 g C m^{-2} at 0–40 cm depth over 4 years. In this study, we found that the incorporations of crop total C and N increased soil organic C by 0.07–0.56 Mg ha^{-1} and total N by 0.005–0.03 Mg ha^{-1} as compared with the nil-crop control during the experimental period (data not shown). However, no significant differences in soil organic C and total N were found among the treatments, although the additions of crop total C and N contents were 1.33–2.69 and 46.5–183 kg ha^{-1}, respectively.

Soil EOC and EON are very important for agricultural management practices since they act as a short-term reservoir of nutrient for microorganisms and crops, which is highly correlated with crop productivity (Bai et al. 2012; Chen and Xu 2008; Curtin et al. 2006). Changes in soil EOC and EON have been found to be closely associated with changes in temperature, soil moisture, and substrate availability (Liu et al. 2009; Murphy et al. 2007), resulting in

Table 4 Correlation coefficient among crop residue biomass, soil moisture and pH, as well as NH_4^+–N, NO_3^-–N, extractable organic C (EOC), and N (EON) concentrations in the KCl (KCl) and hot water (HW) extracts

R^2	NH_4^+–N_{KCl}	NO_3^-–N_{KCl}	NH_4^+–N_{HW}	NO_3^-–N_{HW}	EOC_{KCl}	EON_{KCl}	EOC_{HW}	EON_{HW}
Crop residue biomass	0.17**	0.52***	0.24***	0.58***	0.00	0.09*	0.07*	0.16**
Soil moisture	0.29***	0.33***	0.17**	0.14**	0.13**	0.16**	0.04	0.14**
pH	0.00	0.13**	0.13**	0.20***	0.15**	0.09*	0.15**	0.07*

*$P<0.05$; **$P<0.01$; ***$P<0.001$

Table 5 The dependency of soil extractable organic C (EOC) and N (EON) in the hot water (HW) extracts on soil and crop properties

Dependent	Factors in model	Coefficient	Incremental F values	R^2	Significance
EOC_{HW}	Soil TC	619.3	50.483	0.654	$P<0.001$
EON_{HW}	Crop residue biomass	−0.224	58.616	0.591	$P<0.001$

large variations in soil EOC and EON between the sampling dates (see Table 2 and Fig. 4). The pools of soil EOC and EON under the cover crops are derived from two main processes, i.e., (1) decomposition of SOM and belowground crop residues and (2) more mobile and labile soluble organic matter produced with season via the decomposition of aboveground crop residues. The increases in C and N input via the decomposition of cover crop residues led to greater soil EOC and EON in comparison with the CK treatment (see Fig. 4), which has also been found previously (Murphy et al. 2007; Sainju et al. 2007, 2008). No pronounced differences in soil EON were found between the legume (4.8–25.2 mg kg^{-1} dry soil) and non-legume (6.4–26.7 mg kg^{-1} dry soil) cover crop treatments across the sampling times (see Fig. 4). The main reasons for this are twofold. First, the large variations of soil EON between the cover crop treatments can mask the differences between the legume and non-legume cover crop treatments under field conditions (see Fig. 4). Second, legume crop can fix N from the atmosphere under field (Dinesh et al. 2006; Sainju et al. 2008) and laboratory conditions (Paterson 2003). However, Wichern et al. (2008) reviewed that similar amounts of N are released into the soils from legume and non-legume crops through rhizodeposition. No significant differences in soil N availability has been reported in an arid environment between legumes and non-legumes by measuring soil inorganic and organic N, net N mineralization rates, and substrate-induced respiration (Zhou et al. 2011). In addition, the large variations in soil EON among the treatments were also supported by the large changes in net N mineralization rates (see Fig. 5), which has been used as an index of soil potential N availability (Chen et al. 2002; Zhou et al. 2011). Lower soil net mineralization rates in the pea treatment indicated lower soil potential N availability (see Fig. 5).

Austin et al. (2004) reported that the ratios of EOC to EON had large impacts on the balance between N mineralization and immobilization. In general, the cover crop treatments had lower EOC/EON ratios than the CK treatment across the sampling time, which implied enough organic N for microbial N demands and higher organic N mineralization in the cover crop treatments. This speculation was supported by higher soil net N mineralization rates in the cover crop treatments sampled in May 2010 (see Fig. 5). In addition, a similar range of ratios of soil EOC/EON (7–17) was reported in grassland and woodland soils from Wales (Jones and Willett 2006), while Murphy et al. (2007) reported a significant fluctuation in ratios of EOC/EON between the sampling times and speculated that they would be correlated with the changes in soil inorganic N contents. In this study, significant fluctuations were found in ratios of EOC/EON in the KCl and hot water extracts (see Table 2). With the exception of the correlations between EOC/EON$_{KCl}$ with NH$_4^+$–N$_{HW}$ and NO$_3^-$–N$_{HW}$, as well as EOC/EON$_{HW}$ with NH$_4^+$–N$_{HW}$, no significant correlations were found between EOC/EON and soil inorganic N (see Table 3).

4.3 Relative importance of SOM and cover crop residues

A pathway of N utilization has been recently reviewed by Geisseler et al. (2010). However, little is known about the relative importance of the decompositions of crop residue biomass and SOM to soil EOC and EON pools, especially under field conditions. In this study, correlation analyses indicated that crop residue biomass alone accounted for 19 % of the changes in EOC$_{HW}$ and 24 % in EON$_{HW}$, respectively, across the sampling times. Soil total C played more important roles on the dynamics of EOC$_{HW}$ as compared with crop residue biomass, while crop residue biomass exerted more influences on soil EON$_{HW}$ than that of SOM (see Table 5). As soil EON acts as a reservoir of nutrient and can supply available N to crop growth, it means that less N fertilization is needed to the plot due to the higher EON concentrations as a result of cover crop residues, which will be useful for the effective management practices and environmental health (Chen and Xu 2008).

5 Conclusions

The cover crop treatments had lower soil inorganic N (NH$_4^+$–N+NO$_3^-$–N) compared with the CK treatment across the sampling times. The rapid or gradual decline of soil inorganic N in the CK treatment may indicate a great loss of N due to the absence of cover crop residues. No significant differences in soil EOC and EON pools were found between the legume and non-legume cover crop treatments, which were attributed to the large variations between the cover crops. In addition, the decomposition of cover crop residues had more influence on soil EON in the hot

water extracts than the decomposition of SOM, which indicated less N fertilization under cover crop residues. On the other hand, the decomposition of SOM exerted more influence on soil EOC in the hot water extracts across the sampling times among the treatments, implying different C and N cycling under cover crops.

References

Austin AT, Yahdjian L, Stark JM, Belnap J, Porporato A, Norton U, Ravetta DA, Schaeffer SM (2004) Water pulses and biogeochemical cycles in arid and semiarid ecosystems. Oecologia 141:221–235

Bai SH, Blumfield TJ, Xu ZH, Chen CR, Wild C (2012) Soil organic matter dynamics and nitrogen availability in response to site preparation and management during revegetation in tropical Central Queensland, Australia. J Soils Sediments 12:386–395

Bationo A, Kihara J, Vanlauwe B, Waswa B, Kimetu J (2007) Soil organic carbon dynamics, functions and management in West African agro-ecosystems. Agric Syst 94:13–25

Bertin C, Yan X, Weston LA (2003) The role of root exudates and allelochemicals in the rhizosphere. Plant Soil 256:67–83

Bilgo A, Masse D, Sall S, Serpantie G, Chotte JL, Hien V (2007) Chemical and microbial properties of semiarid tropical soils of short-term fallows in Burkina Faso, West Africa. Biol Fertil Soils 43:313–320

Burton J, Chen CR, Xu ZH, Ghadiri H (2007) Soluble organic nitrogen pools in adjacent native and plantation forests of subtropical Australia. Soil Biol Biochem 39:2723–2734

Chen CR, Xu ZH (2008) Analysis and behavior of soluble organic nitrogen in forest soils. J Soils Sediments 8:363–378

Chen CR, Xu ZH, Hughes JM (2002) Effects of nitrogen fertilization on soil nitrogen pools and microbial properties in a hoop pine (*Araucaria cunninghamii*) plantation in southeast Queensland, Australia. Biol Fertil Soils 36:276–283

Chen CR, Xu ZH, Zhang SL, Keay P (2005) Soluble organic nitrogen pools in forest soils of subtropical Australia. Plant Soil 277:285–297

Coppens F, Merckx R, Recous S (2006) Impact of crop residue location on carbon and nitrogen distribution in soil and in water-stable aggregates. Eur J Soil Sci 57:570–582

Curtin D, Wright CE, Beare MH, McCallum FM (2006) Hot water extractable nitrogen as an indicator of soil nitrogen availability. Soil Sci Soc Am J 70:1512–1521

Dinesh R, Suryanarayana MA, Chaudhuri SG, Sheeja TE, Shiva KN (2006) Long-term effects of leguminous cover crops on the biochemical and biological properties in the organic and mineral layers of soils of a coconut plantation. Eur J Soil Biol 42:147–157

Ding G, Liu X, Herbert S, Novak J, Amarasiriwardena D, Xing B (2006) Effect of cover crop management on soil organic matter. Geoderma 130:229–239

DuPont ST, Ferris H, Van Horn M (2009) Effects of cover crop quality and quantity on nematode-based soil food web and nutrient cycling. Appl Soil Ecol 41:157–167

Geisseler D, Horwarth WR, Joergensen RG, Ludwig B (2010) Pathways of nitrogen utilization by soil microorganisms—a review. Soil Biol Biochem 42:2058–2067

Huang ZQ, Xu ZH, Chen CR (2008) Effect of mulching on labile soil organic matter pools, microbial community functional diversity and nitrogen transformations in two hardwood plantations of subtropical Australia. Appl Soil Ecol 40:229–239

Jones DL, Willett VB (2006) Experimental evaluation of methods to quantify dissolved organic nitrogen (DON) and dissolved organic carbon (DOC) in soil. Soil Biol Biochem 38:991–999

Liu WX, Zhang Z, Wan SQ (2009) Predominant role of water in regulating soil and microbial respiration and their responses to climate change in a semiarid grassland. Glob Change Biol 15:184–195

Murphy DV, Macdonald AJ, Stockdale EA, Goulding KWT, Fortune S, Gaunt JL, Poulton PR, Wakefield JA, Webster CP, Wilmer WS (2000) Soluble organic nitrogen in agricultural soils. Biol Fertil Soils 30:374–387

Murphy DV, Stockdale EA, Poulton PR, Willison TW, Goulding KWT (2007) Seasonal dynamics of carbon and nitrogen pools and fluxes under continuous arable and ley-arable rotations in a temperate environment. Eur J Soil Sci 58:1410–1424

Paterson E (2003) Importance of rhizodeposition in the coupling of plant and microbial productivity. Eur J Soil Sci 54:741–750

Ros GH, Hoffland E, van Kessel C, Temminghoff EJM (2009) Extractable and dissolved soil organic nitrogen—a quantitative assessment. Soil Biol Biochem 41:1029–1039

Rouw A, Huon S, Soulileuth B, Jouquet P, Pierret A, Ribolzi O, Valentin C, Bourdon E, Chantharath B (2010) Possibilities of carbon and nitrogen sequestration under coventional tillage and no-till cover crop farming (Mekong valley, Laos). Agric Ecosyst Environ 136:148–161

Rui YC, Wang SP, Xu ZH, Wang YF, Chen CR, Zhou XQ, Kang XM, Lu SB, Hu YG, Lin QY, Luo CY (2011) Warming and grazing affect soil labile carbon and nitrogen pools differently in an alpine meadow of the Qinghai-Tibet Plateau in China. J Soils Sediments 11:903–914

Sainju UM, Schomberg HH, Singh BP, Whitehead WF, Tillman PG, Lachnicht-Weyers SL (2007) Cover crop effect on soil carbon fractions under conservation tillage cotton. Soil Till Res 96:205–218

Sainju UM, Senwo ZN, Nyakatawa EZ, Tazisong IA, Reddy KC (2008) Soil carbon and nitrogen sequestration as affected by long-term tillage, cropping systems, and nitrogen fertilizer sources. Agric Ecosyst Environ 127:234–240

Schimel JP, Bennett J (2004) Nitrogen mineralization: challenges of a changing paradigm. Ecology 85:591–602

Schmidt SK, Costello EK, Nemergut DR, Cleveland CC, Reed SC, Weintraub MN, Meyer AF, Martin AM (2007) Biogeochemical consequences of rapid microbial turnover and seasonal succession in soil. Ecology 88:1375–1385

Wichern F, Eberhardt E, Mayer J, Joergensen RG, Müller T (2008) Nitrogen rhizodeposition in agricultural crops: methods, estimates and future prospects. Soil Biol Biochem 40:30–48

Xiang S, Doyle A, Holden PA, Schimel JP (2008) Drying and rewetting effects on C and N mineralization and microbial activity in surface and subsurface California grassland soils. Soil Biol Biochem 40:2281–2289

Xu ZH, Chen CR, He JZ, Liu JX (2009) Trends and challenges in soil research 2009: linking global climate change to local long-term forest productivity. J Soils Sediments 9:83–88

Zhou XQ, Wang JZ, Hao YB, Wang YF (2010) Intermediate grazing intensities by sheep increase soil bacterial diversities in an Inner Mongolian steppe. Biol Fertil Soils 46:817–824

Zhou XQ, Liu X, Rui YC, Chen CR, Xu ZH (2011) Symbiotic nitrogen fixation and soil N availability under legume crops in an arid environment. J Soils Sediments 11:762–770

Zhou XQ, Wu HW, Koetz E, Xu ZH, Chen CR (2012) Soil labile carbon and nitrogen pools and microbial metabolic diversity under winter crops in an arid environment. Appl Soil Ecol 53:49–55