# Soil microbial metabolism and invertase activity under crop rotation and no-tillage in North China

**J.L. Hu, A.N. Zhu, J.H. Wang, J. Dai, J.T. Wang, R.R. Chen, X.G. Lin**

*State Key Laboratory of Soil and Sustainable Agriculture, Joint Open Laboratory of Soil and the Environment, Hong Kong Baptist University and Institute of Soil Science, Chinese Academy of Sciences, Nanjing, P.R. China*

**ABSTRACT**

Soil samples were collected at both jointing and maturing stages of maize and wheat to compare the effects of 4-year no-tillage (NT) and conventional tillage (CT) on seasonal variations of microbial biomass carbon (C), metabolic quotient, and invertase activity in a sandy loam soil in North China. Soil invertase activity significantly increased ($P < 0.05$) from summer to spring of the next year and then significantly decreased ($P < 0.05$) from spring to summer. With a delay of about 3 months, soil microbial biomass C and basal respiration altered in a similar pattern, while microbial metabolic quotient changed on the contrary. Compared with CT, the NT practice significantly increased ($P < 0.05$) soil organic C content, and tended to result in higher soil microbial biomass C and invertase activity, as well as lower soil microbial metabolic quotient, especially at the jointing stage of maize. Our results indicated that NT might play an important role in the improvement of soil microbial efficiency, especially at the maize seedling season.

**Keywords**: basal respiration; metabolic quotient; microbial biomass; seasonal variation; soil organic carbon

Microbes play crucial roles in geochemical cycling and ecosystem functioning. Microbial biomass, metabolism, and enzymes are often measured to provide immediate information about small changes in soils (Hu et al. 2011). It is commonly known that carbon (C) is a key factor governing soil microorganism growth (Grayston et al. 1998). Testing invertase activity could monitor soil's long-term productivity (Bogdevitch and Mikhailouskaya 2009), while soil respiration is valuable for understanding total microbial activities (Fernandes et al. 2005), and microbial metabolic quotient is an indicator of ecosystem disturbance and development (Wardle and Ghani 1995).

No tillage (NT) seems to be superior to conventional tillage (CT) for conserving soil and water, and for increasing C deposits into soil (Alvear et al. 2005). Reduction in physical disturbance may slow organic matter decomposition and thereby contribute to longevity of microbes (Yang et al. 2012b). Nevertheless, long-term NT may also result in surface soil hardening and a more limited $O_2$ supply for microbes (Álvaro-Fuentes et al. 2008). In that case, long-term field experiments are urgent to improve our knowledge of changes in microbial parameters with various tillage practices, and investigating their seasonal dynamics may help to ensure an opportunity for popularizing NT.

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The sustainable utilization of agricultural soil in the North China Plain (NCP) may affect China's food security. In this study, one 4-year field management experiment was selected to determine the seasonal dynamics of soil microbial parameters under different tillage treatments. The aims of this study were to evaluate the effects of NT on soil microbial biomass, invertase activity, basal respiration, and metabolic quotient, and to compare the dynamical responses at jointing and maturing stages of rotated crops.

## MATERIAL AND METHODS

**Experimental site**. It was part of the State Experimental Station for Agro-Ecology, Fengqiu County (35°00'N, 114°24'E), Henan province, China. This area has a mean annual temperature of 13.9°C and a mean annual precipitation of 615 mm. The lowest and highest mean monthly values are –1.0°C in January and 27.2°C in July, respectively, and two-thirds of the precipitation falls during June–September. The soil was derived from alluvial sediments of the Yellow River and was classified as an Aquic Inceptisol, with a sandy loam texture (containing 90 and 218 g/kg of clay and silt, respectively) in the plough layer and loam in the subsoil. The NT experiment was conducted in a well-drained field. Maize (*Zea mays* L.) was sown in June and harvested in late September. Then wheat (*Triticum aestivum* L.) was sown in October and harvested in early June. In June 2006, 2 tillage treatments (CT and NT) with 4 replicates were established in completely randomized blocks in 8 plots (each 14 × 6.5 m). Detailed information on field design was described by Yang et al. (2012a). Each plot received the same tillage management every year since 2006.

**Soil sampling**. On 27 June and 20 September 2009, and 31 March and 8 June 2010, at the jointing and maturing stages of maize and wheat, respectively, soil samples were collected from 16 points at the depth of 0–15 cm from each plot, and then mixed and homogenized by sieving through a 2-mm mesh sieve. Each sample was divided into 2 portions: fresh soil samples were used for the analysis of microbiological parameters, while dried and ground soil samples were used for the analysis of chemical properties.

**Soil chemical analysis**. Soil pH was determined with a glass electrode using a soil-to-water ratio of 1:2.5; organic C and total N were determined by dichromate oxidation and Kjeldahl digestion, respectively; available P was extracted by sodium bicarbonate and determined using the molybdenum blue method; available K was extracted by ammonium acetate and determined by flame photometry (Lu 1999).

**Soil microbiological determination**. Microbial biomass C was determined using chloroform fumigation extraction; invertase activity was analyzed using constant temperature incubation; basal respiration was determined using sealed incubation-alkali absorption (Lin 2010). Metabolic quotient was calculated as the ratio of basal respiration to microbial biomass C (Anderson and Domsch 1990). All these results were expressed on an oven-dried basis of soil weight (105°C, 24 h).

**Statistical analysis**. Analysis of variance (ANOVA) analysis and Pearson's correlation analysis were carried out with SPSS (version 10.0, Chicago, USA). Significance of the parameters was tested using the least significant difference multiple range test at $P < 0.05$ after one-way ANOVA.

## RESULTS

**Soil pH, organic C, and nutrient contents**. Soil pH significantly ($P < 0.05$) increased from maize jointing to maturing stages and thereby wheat jointing stage, but significantly ($P < 0.05$) decreased from wheat jointing to maturing stages (Table 1). Soil available K also significantly ($P < 0.05$) decreased from wheat jointing to maturing stages. There were no remarkable changes of soil organic C, total N, and available P from CT or NT treatments, except for a significant ($P < 0.05$) decrease of available P from maize jointing to maturing stages. Compared with CT, NT significantly ($P < 0.05$) increased soil organic C at all 4 sampling times, and tended to increase soil total N as well, but had no significant effects on soil pH, and available P and K, except for a significantly ($P < 0.05$) higher available P at maize jointing stage.

**Soil microbial biomass and invertase activity**. Soil microbial biomass C tended to decrease from maize jointing to maturing stages, but significantly increased ($P < 0.05$) from maize maturing stage to wheat jointing and thereby maturing stages (Figure 1a). Soil invertase activity significantly increased ($P < 0.05$) from maize jointing to maturing stages and thereby to wheat jointing stage, but significantly decreased ($P < 0.05$) from wheat joint-

Table 1. Soil chemical properties in conventional tillage (CT) and no tillage (NT) treatments at jointing and maturing stages of maize and wheat

| Sampling date | Treatment | pH | Organic C | Total N | Available P | Available K |
|---|---|---|---|---|---|---|
| | | | (g/kg) | | (mg/kg) | |
| 27 June | CT | 8.22 ± 0.04$^{c}$ | 5.86 ± 0.24$^{c}$ | 0.69 ± 0.09$^{ab}$ | 10.5 ± 1.4$^{b}$ | 93 ± 4$^{a}$ |
| | NT | 8.20 ± 0.03$^{c}$ | 6.66 ± 0.19$^{ab}$ | 0.75 ± 0.04$^{a}$ | 17.4 ± 3.6$^{a}$ | 98 ± 12$^{a}$ |
| 20 September | CT | 8.35 ± 0.05$^{b}$ | 5.85 ± 0.33$^{c}$ | 0.71 ± 0.04$^{ab}$ | 5.1 ± 2.3$^{b}$ | 90 ± 2$^{a}$ |
| | NT | 8.34 ± 0.06$^{b}$ | 6.48 ± 0.50$^{ab}$ | 0.73 ± 0.06$^{a}$ | 5.1 ± 0.6$^{b}$ | 99 ± 4$^{a}$ |
| 31 March | CT | 8.75 ± 0.08$^{a}$ | 5.94 ± 0.13$^{c}$ | 0.64 ± 0.02$^{b}$ | 8.7 ± 1.6$^{b}$ | 85 ± 5$^{a}$ |
| | NT | 8.70 ± 0.02$^{a}$ | 6.46 ± 0.34$^{ab}$ | 0.70 ± 0.03$^{ab}$ | 9.6 ± 4.6$^{b}$ | 87 ± 5$^{a}$ |
| 8 June | CT | 8.41 ± 0.04$^{b}$ | 6.19 ± 0.05$^{bc}$ | 0.72 ± 0.03$^{ab}$ | 5.7 ± 2.2$^{b}$ | 62 ± 16$^{b}$ |
| | NT | 8.39 ± 0.04$^{b}$ | 6.74 ± 0.24$^{a}$ | 0.73 ± 0.05$^{a}$ | 8.8 ± 6.7$^{b}$ | 59 ± 5$^{b}$ |

Data are mean values with standard deviation. Data within a column followed by different letters indicate a significant ($P < 0.05$) difference

ing to maturing stages (Figure 1b). Compared with CT, NT only tended to increase microbial biomass C at the maize season, and significantly increased ($P < 0.05$) invertase activity at its jointing stage.

**Soil basal respiration and microbial metabolic quotient**. There were no significant seasonal dynamics of soil basal respiration (Figure 2a) and microbial metabolic quotient (Figure 2b). NT also had no significant effects on soil basal respiration compared to CT, while microbial metabolic quotient was always lower under NT. The highest metabolic quotient was recorded in CT at maize maturing stage, and the two lowest ones were recorded in NT at maize jointing stage and wheat maturing stage.

**Correlation among measured parameters**. Soil microbial biomass C significantly correlated ($P < 0.05$) to basal respiration and negatively but closely correlated ($P < 0.01$) to microbial metabolic quotient, which also negatively but closely correlated ($P < 0.05$) to organic C (Table 2). Invertase activity significantly correlated ($P < 0.05$) to soil pH. Invertase can decompose complex organic compounds into subunits assimilated by microbes, leading to delayed changes of microbiological parameters. As might have been expected, earlier

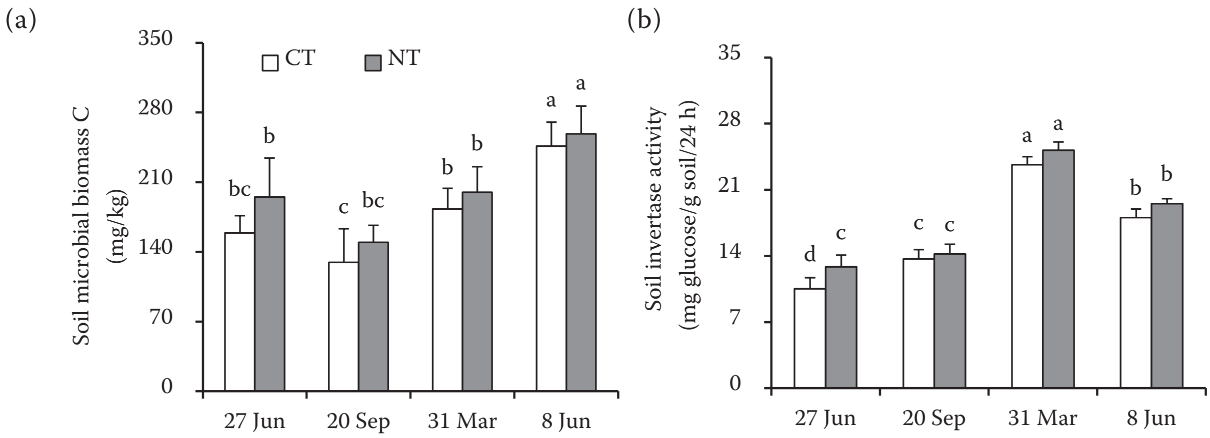


Figure 1. Soil microbial biomass C (a) and invertase activity (b) under conventional tillage (CT) and no tillage (NT) treatments at jointing and maturing stages of maize (27 June and 20 September) and wheat (31 March and 8 June). Vertical T bars indicate standard deviations. Bars not topped by the same letter indicate a significant difference in values ($P < 0.05$)

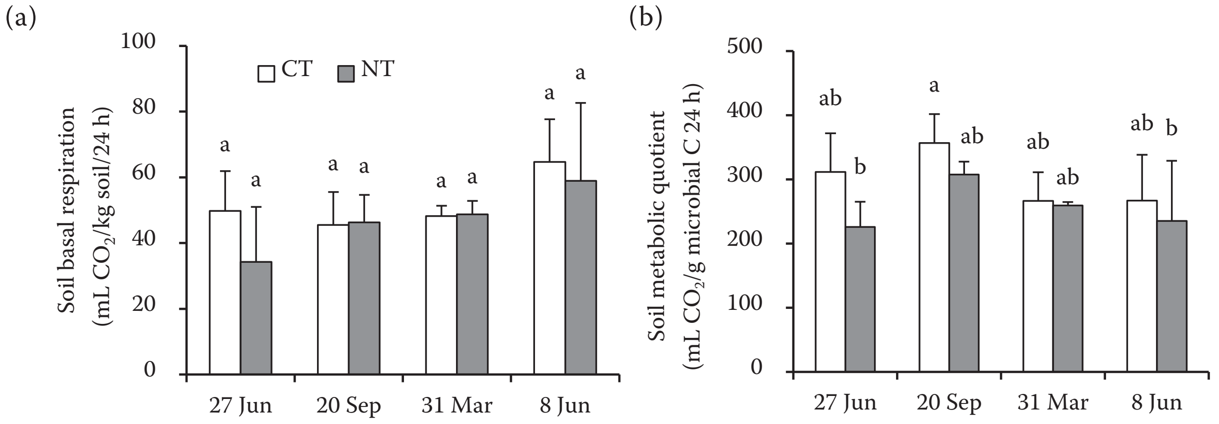


Figure 2. Soil basal respiration (a) and metabolic quotient (b) under conventional tillage (CT) and no tillage (NT) treatments at jointing and maturing stages of maize (27 June and 20 September) and wheat (31 March and 8 June). Vertical T bars indicate standard deviations. Bars not topped by the same letter indicate a significant difference in values ($P < 0.05$)

invertase activity significantly correlated ($P < 0.01$) to microbial biomass C and also negatively but closely correlated ($P < 0.05$) to metabolic quotient.

## DISCUSSION

There are seasonal variations of soil chemical and biochemical parameters, such as soil pH (Table 1) and invertase activity (Figure 1b), which increased from summer to spring and then decreased from spring to summer. With a delay of about 3 months, a trend towards lower microbial biomass C was observed from summer to autumn (Figure 1a), and then turned to increase till next summer. Seasonal variations of microbial biomass reflect the degree of immobilization-mineralization of soil C (Yang et al. 2010). A decrease in microbial biomass can result in mineralization of nutrients, whereas an increase may relate to the immobilization of nutrients (McGill et al. 1986). Microbial biomass may correlate with abiotic variables, i.e. moisture, temperature, etc. (Devi and Yadava 2006). It was higher in summer than in spring and autumn, being consistent with a previous forest study (Yang et al. 2010). However, the increase of microbial activity or biomass cycling may lead to an increase in soil respiration (Leita et al. 1999). A high respiration might indicate an ecological disorder (Islam and Weil 2000); thus, metabolic quotient was utilized as a microbial stress indicator and interpreted as 'microbial efficiency', due to the energy necessary to maintain metabolic activity in relation to the energy necessary for synthesizing biomass (Bardgett and Saggar 1994). Although soil basal respiration correlated to microbial biomass

Table 2. Pearson's correlation coefficients among measured parameters

| | Soil pH | Soil organic C | Microbial biomass C | Invertase activity | Basal respiration | Metabolic quotient |
|---|---|---|---|---|---|---|
| Soil organic C | –0.117 | – | – | – | – | – |
| Microbial biomass C | 0.161 | 0.556 | – | – | – | – |
| Invertase activity | 0.939** | 0.173 | 0.454 | – | – | – |
| Basal respiration | 0.213 | –0.067 | 0.622* | 0.323 | – | – |
| Metabolic quotient | –0.173 | –0.723* | –0.792** | –0.429 | –0.056 | – |
| Earlier invertase activity[a] | –0.290 | 0.469 | 0.878** | / | 0.550 | –0.658* |

[a]using the data from 8 June 2010 for 27 June 2009, and using the data from an earlier sampling time for the other three times, respectively; *$P = 0.05$; **$P = 0.01$

(Table 2), the seasonal dynamics of basal respiration were more moderate, which may involve soil moisture, temperature, and other environmental factors (Devi and Yadava 2006). As a result, a trend towards higher metabolic quotient (Figure 2b) was observed from summer to autumn, and then turned to decrease till next summer.

Different tillage trials also caused differential outcomes. For example, at maize jointing stage there was a remarkable increase in invertase activity upon NT (Figure 1b). Higher enzymatic activities are usually associated with higher organic matter content (Srinivasulu and Rangaswamy 2006). The higher invertase activity may be caused by a higher turnover of microbial biomass (Kandeler et al. 1999). The causing mechanisms seem to be due to the decrease in destruction by tillage on soil physico-chemical environment (Tabaglio et al. 2009). For instance, soil organic C were significantly lower under CT at all 4 sampling times, similar to the results from other studies (Alvear et al. 2005, Tabaglio et al. 2009). It appears obvious that a long-term period under NT may result in an increase in soil bulk density. Curaqueo et al. (2011) found that the mean weight diameter of soil aggregates was greater in NT compared with CT; thus, the aggregates fraction ≥ 4.75 mm was higher in CT, while the microaggregate fraction (≤ 0.25 mm) was predominant in NT. These processes may also generate a reduction in soil porosity, leading to a more limited $O_2$ supply for heterotrophic microbial decomposition (Álvaro-Fuentes et al. 2008), explaining also the accumulation of a high soil organic C (Table 1). The increase of soil organic C would also stimulate microbial activity (Emmerling et al. 2000) and biomass cycling, and soils under nutrient-deficient stress would present higher metabolic quotient than the non-stressed ones (Fernandes et al. 2005). Thus, microbial metabolic quotient significantly and negatively correlated to soil organic C (Table 2). It follows that NT could play an important role in the improvement of 'microbial efficiency', especially at maize seedling season.

In summary, soil invertase activity increased from summer to spring and then decreased from spring to summer. With a delay of about 3 months, soil microbial biomass C changed in a similar pattern, while microbial metabolic changed on the contrary. Compared with CT, NT increased soil organic C, and tended to result in higher soil microbial biomass C and invertase activity, as well as lower soil microbial metabolic quotient, especially at maize seedling season.

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*Corresponding author:*

Prof. Xiangui Lin, Chinese Academy of Sciences, Institute of Soil Science, State Key Laboratory of Soil and Sustainable Agriculture, Nanjing 210008, P.R. China
phone: + 86 25 8688 1589, fax: + 86 25 8688 1000, e-mail: xglin@issas.ac.cn