

# Long-term interactions of reduced tillage and different amounts of residue retaining improved soil environment in a semi-arid tropical climate

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## ABSTRACT

Soil quality degradation caused by intensification is threatening the sustainability of banana (*Musa acuminata* Colla) production in South China. Hence comprehensive information about the benefits of conservation management on soil quality is urgently needed. This study aimed to assess the effects of tillage and residue on soil biological properties in a banana plantation for 25 yr. Treatments consisted of three tillage methods (conventional tillage, CT; reduced tillage, RT; no tillage, NT) combined with three residue levels (0, NR; 50%, HR; 100%, TR). Soil samples were taken in 2018-2019 from 0-40 cm depth. Soil moisture, pH, total organic C and total N in NT were 28.8%, 22.4%, 39.9% and 34.3% higher than in CT. However, NT decreased available P by 16.7% compared with CT. HR had higher NH<sub>4</sub>-N and available K and lower bulk density compared with NR. Microbial biomass C and N were on average 39.2% higher in TR than those in NR. Urease, dehydrogenase and β-glucosidase obtained a mean increase of 34.3% in RT compared to CT. Invertase and catalase were on average 32.9% greater when residue was applied than no residue input plots. CO<sub>2</sub> and N<sub>2</sub>O emissions decreased around 37.6% in different tillage treatments, but increased from 39.9% to 62.6% in all residue input plots. In general, soil biological properties are sensitive characters to changes caused by tillage and residue, and consequently they are well-established as soil physicochemical indicators for soil quality evaluation in conservation tillage systems.

**Key words:** Biochemical property, gas emission, microbial biomass, residue, tillage.

## INTRODUCTION

The giant, perennial, herbaceous bananas (*Musa acuminata* Colla) were grown in 51.3 million ha in 2019 with an average production of 69.6 t ha<sup>-1</sup> (FAO, IFAD, UNICEF, WFP, and WHO, 2019). The optimum temperature for production is 25 °C. The annual average water requirement is 3500 mm. The period of growth is 280-300 d, usually planted in July of the first year and harvested in May of the second year. Currently, many banana plantations in China have been cropped intensively to satisfy the increased demands for food and fruits. Intensification causes a reduction in soil macroaggregates and microbial abundance which leads to low nutrient availability and accelerated mineralization of soil organic matter. Combining no-tillage with cover crops shows minimal soil disturbance, decreases soil erosion, buffers soil temperature fluctuation and increases microbial activity and community diversity (Melman et al., 2019; Bilgili et al., 2019). The average banana yield in China is 385 t ha<sup>-1</sup> at present, which has increased over 260% in the last decade (Zhang et al., 2018). The main reason is that more than 75% of the area is devoted to conservation tillage management.

Soil microbiota composition and biochemical parameters are more sensitive than those of physicochemical ones when they are used to analyze changes due to tillage or covering crops. Studies conducted at different climatic regions have

shown that microflora composition, microbial biomass and enzymes as integrative indicators of soil quality respond to even the slightest modifications in management practices. For instance, reduced tillage greatly increases soil beneficial bacteria abundance and biomass (Saikia et al., 2019). Phosphatases are negatively correlated with P stress and disturbance (Mganga et al., 2016). Soil C and N sequestration respond positively to green manure addition as evidenced by high amount of greenhouse gas emissions (Pareja-Sánchez et al., 2019).

Despite some disadvantages, as represented by the increase of pesticide requirement, conservation tillage has been introduced in arid areas (Sayed et al., 2019) with great success. Conservation tillage is a more sustainable system compared to intensive cropping to solve agro-environmental problems such as soil biodiversity reduction and microbial function decline (Soares et al., 2019). However, most of the previous studies have focused on evaluating the single effects of tillage or crop residue incorporation on soil properties in mono cropping systems at temperate climate with a single timepoint (Yin et al., 2018; Pratibha et al., 2019). Furthermore, the effects of conservation tillage on indicators of soil quality are highly site-specific and therefore cannot be generalized for all agroecological regions with large variability in soil and climatic conditions (Jat et al., 2019). Therefore, the aim of this study was to undertake comprehensive multi-factor studies over 25 growing seasons on the interactive effects of tillage intensity and residue amounts management on soil biological indicators in banana-based rotation systems at semi-arid tropics in silt loam soils. We hypothesized that over a long-term (25 yr) conservation tillage application of reduced tillage combined with the crop residues incorporation in a banana-peanut (*Arachis hypogaea* L.) rotation has beneficial effects on soil physicochemical and biological properties, compared to conventional tillage (mouldboard plough and residue removal) due to favorable changes in soil environment (such as less disturbance through the reduced tillage and increased soil fertility through the addition of residues).

## MATERIALS AND METHODS

### Site description

The experiment has been conducted at the Ledong Experimental Station (18°37'48.3" N, 108°47'18.5" E), Chinese Academy of Tropical Agricultural Sciences, since 1994. Climate of the region is tropical monsoon. Average annual temperature is 25.8 °C and average annual precipitation is 2065 mm. The test soils are Aquic Hapluddepts (13.3% clay, 23.5% silt, and 63.2% sand) according to the USDA texture classification. The soil has 7.22 g kg<sup>-1</sup> total organic C, 0.73 g kg<sup>-1</sup> total N, 0.61 g kg<sup>-1</sup> total P, 1.23 g kg<sup>-1</sup>, total K and pH 6.59. The rotation of banana (*Musa acuminata* Colla) and peanut (*Arachis hypogaea* L.) was initiated in 1994 for the study (Figure 1).

**Figure 1. Study area of a long-term conservation tillage experiment at the Wanzhong Farm in Hainan Island, China.**



The experiment was a split-plot design with four replicates. Tillage management was the main plot and residue system was the split-plot factor. The text field was divided into nine plots and the size of each plot was 8 m × 7 m. Tillage systems were conventional tillage (CT), reduced tillage (RT) and no-tillage (NT). RT plots were stubble cultivated to 15 cm depth. CT plots were mouldboard ploughed to 30 cm depth. Both RT and CT plots were plowed in each May. Banana or peanut residue was incorporated into soil in CT and covered soil surface in RT and NT after harvest. Residue treatments were NR (0, no residues incorporation or coverage), HR (50%, 7.5 t ha<sup>-1</sup> residues incorporation or coverage) and TR (100%, 15 t ha<sup>-1</sup> residues incorporation or coverage). Each year, cow compost biochar (14.4 t ha<sup>-1</sup>), with 53.3% water content, 145 g C kg<sup>-1</sup>, 3.2 g N kg<sup>-1</sup>, 2.5 g P<sub>2</sub>O<sub>5</sub> kg<sup>-1</sup>, 1.6 g K<sub>2</sub>O kg<sup>-1</sup>, was applied as basal fertilizer. Urea, superphosphate and sulfate were applied as additional fertilizer with the rates of 129 kg N ha<sup>-1</sup>, 68 kg P ha<sup>-1</sup> and 292 kg K ha<sup>-1</sup>.

### Soil sampling

Soil samples were taken from 0–40 cm depth below the soil surface at the seedling stage (16 September 2018), jointing stage (15 December 2018), booting stage (17 March 2019) and ripening stage (19 May 2019) within the rows of plants. Each sample was a composite comprising five random cores (2.5 cm diameter). The fresh samples were sieved through a 2 mm mesh and stored at 4 °C before subsequent analysis. Results were based on oven-dried weight of the soil.

Soil physicochemical properties were measured according to Hulugalle et al. (2007). Soil microbial biomass was measured by the chloroform fumigation-extraction method (Vance et al., 1987). Urease, acid phosphatase, and dehydrogenase were determined based on the method of Tabatabai (1994). Invertase, β-glucosidase and catalase were estimated according to the method of Parthasarathi and Ranganathan (2000). For urease, 5 g soil with 10 mL of 10% urea solution were incubated for 24 h at pH 7.0 at 37 °C; for invertase 5 g soil with 15 mL of 8% sucrose solution were incubated for 24 h at pH 5.5 at 37 °C; for catalase 2 g soil with 5 mL of 0.3% H<sub>2</sub>O<sub>2</sub> were incubated for 30 min at pH 7.0 at 30 °C; for dehydrogenase 6 g soil with 5 mL of 3% triphenyltetrazolium chloride were incubated for 24 h at pH 7.5 at 37 °C; for acid phosphatase 1 g soil with the *p*-nitrophenyl phosphate substrate were incubated for 1 h at pH 6.5 at 37 °C; for β-glucosidase 1 g soil with the *p*-nitrophenyl-β-D-glucoside substrate were incubated for 1 h at pH 6.0 at 37 °C. Enzymes were determined in fresh soil and based on the oven-dried soil weight. Greenhouse gas emissions were measured every 40 d after crops transplanting, using non-steady state flow-through chambers (Zhang et al., 2014).

### Statistical analysis

Repeated measures ANOVA was used to test the effect of tillage and residue at each sampling stage on soil qualities. Overall effect of tillage, residue and sampling stage on measured variables were analyzed using the linear mixed-effect model procedure for split-plot designs. Differences at  $P < 0.05$  level were considered significant. When their interactions were significant, individual comparisons were based on an independent-samples T test. Linear correlation was used to characterize the relationship between physicochemical and biological properties. All statistical analyses were performed by SPSS version 16.0 (IBM, Armonk, New York, USA).

## RESULTS

### Soil physicochemical properties

Significant tillage (T), residue (R) and growth stage (S) effects were observed on the values of bulk density, pH, NO<sub>3</sub>-N, and available K ( $P < 0.05$ , Table 1). Interaction effect of T×R and T×R×S was observed in total organic C and NH<sub>4</sub>-N ( $P < 0.01$ ). Bulk density and pH were greatly higher at seedling and jointing stages than at booting stage ( $P < 0.05$ , Figures 2 and 3). This was true among all treatments.

Soil moisture and electrical conductivity (EC) were significantly higher in no-tillage (NT) than in conventional tillage (CT) ( $P < 0.01$ ), while available P showed the highest values in conventional tillage ( $P < 0.05$ ). The lowest total organic C and total N were found in CTNR, followed by CTHR and RTNR. Exchangeable Ca and Mg showed the highest values in 100% residue input plots and the lowest values in residue removal plots. Total K increased but bulk density decreased after the residue application (50% and 100% residue,  $P < 0.01$ ).

**Table 1. ANOVA for the effects of tillage and residue practices on soil physicochemical and biological properties in a long-term conservation experiment.**

ANOVA	Tillage (T)	Residue (R)	Stage (S)	T×R	T×S	R×S	T×R×S
	<i>P</i> value						
SM	< 0.01	< 0.01	ns	< 0.01	0.037	ns	ns
BD	< 0.01	0.031	< 0.01	0.012	ns	ns	ns
pH	< 0.01	ns	< 0.01	< 0.01	ns	< 0.01	ns
EC	< 0.01	< 0.01	ns	< 0.01	ns	ns	0.015
SOC	< 0.01	< 0.01	ns	< 0.01	< 0.01	< 0.01	< 0.01
TN	ns	0.034	< 0.01	< 0.01	0.046	0.012	< 0.01
NH <sub>4</sub> -N	< 0.01	ns	0.047	< 0.01	ns	< 0.01	ns
NO <sub>3</sub> -N	< 0.01	< 0.01	0.041	< 0.01	< 0.01	0.015	ns
AP	< 0.01	< 0.01	0.013	0.022	< 0.01	ns	< 0.01
AK	< 0.01	0.011	< 0.01	ns	ns	< 0.01	< 0.01
ECa	< 0.01	0.039	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
EMg	0.038	< 0.01	ns	0.026	ns	ns	ns
MBC	< 0.01	0.014	< 0.01	ns	ns	ns	ns
MBN	0.021	< 0.01	< 0.01	ns	0.046	ns	ns
UA	< 0.01	< 0.01	0.044	ns	ns	ns	0.024
IA	< 0.01	< 0.01	< 0.01	0.023	ns	ns	ns
DHA	< 0.01	< 0.01	< 0.01	ns	ns	< 0.01	ns
APA	0.043	0.022	ns	ns	ns	ns	< 0.01
GA	< 0.01	< 0.01	< 0.01	0.033	< 0.01	ns	ns
CA	< 0.01	0.019	< 0.01	ns	ns	0.035	ns
NE	0.019	< 0.01	ns	0.031	ns	ns	< 0.01
CE	< 0.01	< 0.01	< 0.01	< 0.01	ns	ns	ns
ME	< 0.01	0.020	< 0.01	ns	ns	< 0.01	ns

SM: Soil moisture; BD: bulk density; EC: electrical conductivity; SOC: soil total organic C; TN: total N; AP: available P; AK: available K; ECa: exchangeable Ca; EMg: exchangeable Mg; MBC: microbial biomass C; MBN: microbial biomass N; UA: urease activity; IA: invertase activity; DHA: dehydrogenase activity; APA: acid phosphatase activity; GA:  $\beta$ -glucosidase activity; CA: catalase activity; NE: N<sub>2</sub>O emission; CE: CO<sub>2</sub> emission; ME: CH<sub>4</sub> emission.

### Soil microbial biomass and enzymatic activities

Microbial biomass C, urease, invertase and dehydrogenase were significantly affected by tillage treatments at all sampling stages (Table 1). Microbial biomass N, catalase and  $\beta$ -glucosidase were significantly affected by residue treatments at three sampling stages (except seedling stage). Interaction of tillage and residue significantly affected microbial biomass C and dehydrogenase.

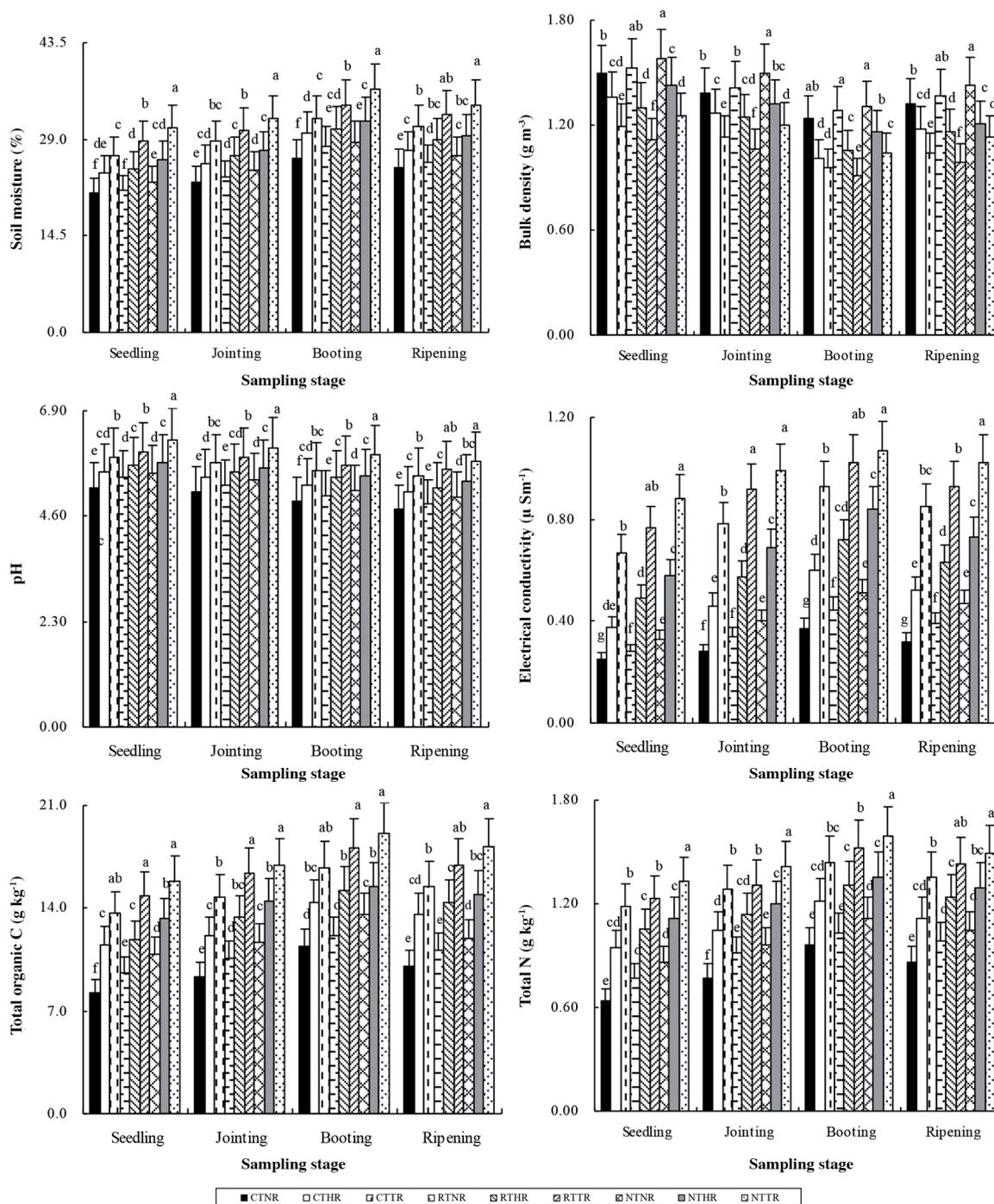
Microbial biomass N, urease and acid phosphatase increased by an average of 32.5% in RT and 44.6% in NT compared with CT ( $P < 0.01$ , Table 2 and Figure 4). Microbial biomass C, dehydrogenase and  $\beta$ -glucosidase were significantly higher in residue input plots than in the plots without residue ( $P < 0.05$ ). Almost all of the soil enzymes and microbial biomass exhibited temporal fluctuations. A significant increase ( $P < 0.05$ ) appeared during seedling to booting and smoothly decreased afterward.

### Soil gaseous emissions

Tillage effect at all sampling stages, and residue and their interaction at the fifth, sixth and seventh 40-d on CO<sub>2</sub> emission was significant ( $P < 0.01$ , Table 1). Residue effect on CH<sub>4</sub> emission was significant during the growing season. Except the first two 40-d, N<sub>2</sub>O and CO<sub>2</sub> emissions were on average 46.5% lower in less-tilled plots than in conventional tillage (Figure 5). CO<sub>2</sub> and CH<sub>4</sub> emissions were higher in 100% residue plots than in 0% and 50% residue plots. The average emissions of CO<sub>2</sub> and N<sub>2</sub>O were 36.8% and 40.3% higher in the booting than in other stages.

Microbial biomass C was positively correlated with total organic C ( $P < 0.01$ , Table 3) and negatively with soil moisture ( $P < 0.05$ ). Urease was positively correlated with NH<sub>4</sub>-N and EC ( $P < 0.01$ ). Acid phosphatase activity was positively correlated with available P and negatively with pH ( $P < 0.05$ ). CO<sub>2</sub> emissions were positively correlated with exchangeable Ca, and negatively with bulk density ( $P < 0.01$ ).

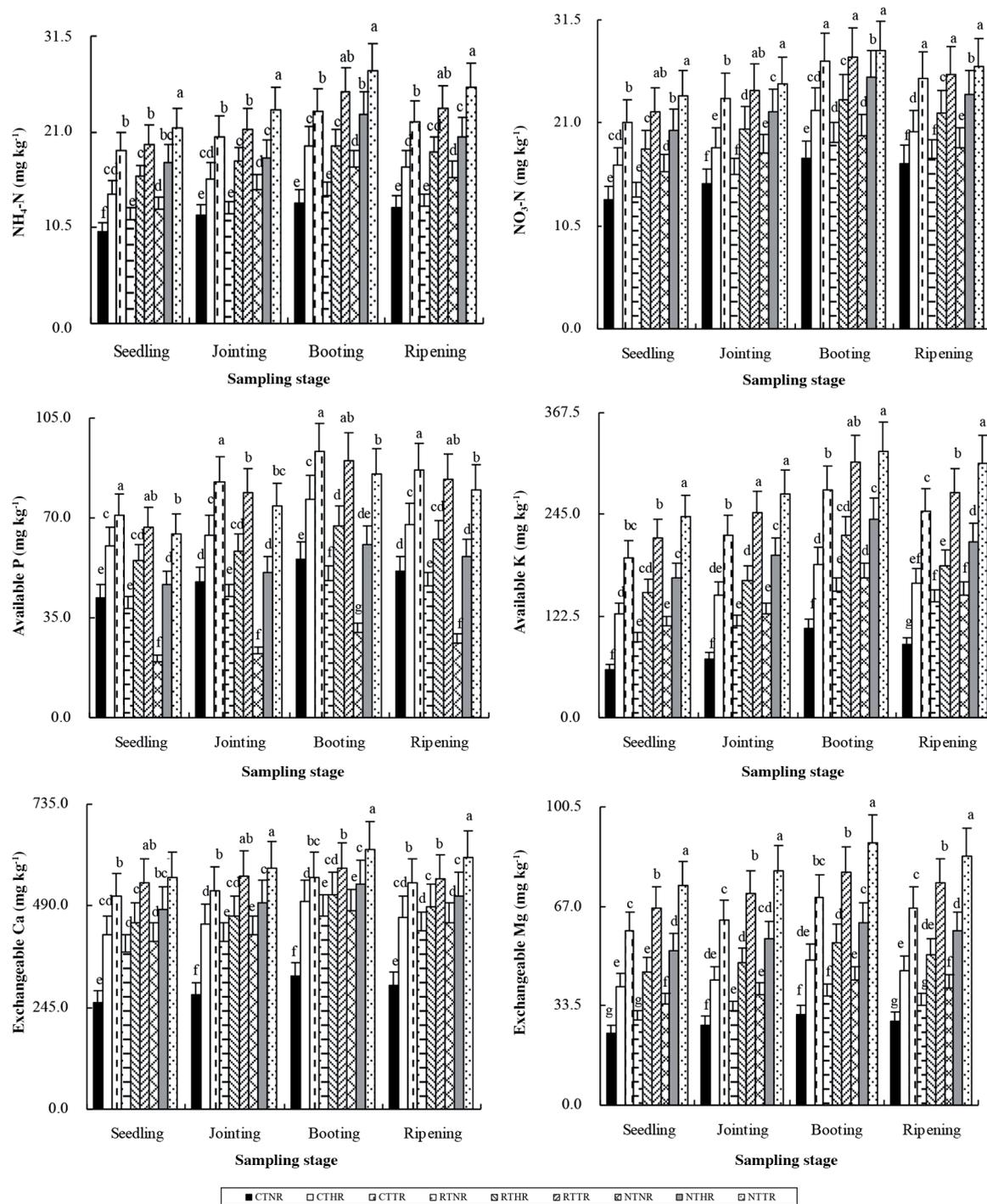
**Figure 2. Physicochemical properties in tillage and residue treatments at four sampling stages in a long-term conservation experiment.**



Error bars indicate standard error. Different lower-case letters in the figure mean significant difference according to Duncan's multiple range test ( $P < 0.05$ ).

CT: Conventional tillage; RT: reduced tillage; NT: no-tillage; NR: no residues incorporation; HR: 50% residues incorporation, 7.5 t ha<sup>-1</sup>; TR: 100% residues incorporation, 15 t ha<sup>-1</sup>.

**Figure 3. Available nutrients in tillage and residue treatments at four sampling stages in a long-term conservation experiment.**



Error bars indicate standard error. Different lower-case letters in the figure mean significant difference according to Duncan's multiple range test ( $P < 0.05$ ).

CT: Conventional tillage; RT: reduced tillage; NT: no-tillage; NR: no residues incorporation; HR: 50% residues incorporation, 7.5 t ha<sup>-1</sup>; TR: 100% residues incorporation, 15 t ha<sup>-1</sup>.

**Table 2. Soil microbial biomass in tillage and residue treatments at four sampling stages in a long-term conservation experiment.**

Indicators	Sampling	CT			RT			NT		
		NR	HR	TR	NR	HR	TR	NR	HR	TR
Microbial biomass C, mg kg <sup>-1</sup>	Seedling	10.7(1.2)e	13.6(1.4)cd	15.1(1.6)c	11.8(1.3)d	14.5(1.5)c	17.6(1.9)b	16.4(1.8)b	19.1(2.1)a	20.0(2.2)a
	Jointing	11.9(1.3)e	14.1(1.5)d	16.2(1.7)c	13.4(1.4)d	15.8(1.6)c	18.9(2.1)b	18.3(2.0)b	21.2(2.3)a	22.3(2.4)a
	Booting	14.2(1.5)f	16.8(1.8)de	18.6(2.0)d	15.5(1.7)e	18.8(2.1)d	22.7(2.4)bc	21.9(2.4)c	24.0(2.5)b	25.7(2.7)a
	Ripening	13.1(1.4)e	15.5(1.6)d	17.8(1.9)c	14.3(1.5)d	16.9(1.8)c	20.8(2.3)ab	19.5(2.2)b	22.6(2.4)a	24.1(2.5)a
Microbial biomass N, mg kg <sup>-1</sup>	Seedling	5.15(0.55)f	6.96(0.75)e	8.03(0.86)d	6.26(0.67)e	8.43(0.92)d	9.62(1.03)c	8.36(0.90)d	10.5(1.1)b	12.1(1.3)a
	Jointing	6.41(0.69)e	7.99(0.86)d	9.14(0.98)c	7.42(0.80)d	9.83(1.06)bc	10.9(1.2) b	9.58(1.02)c	12.0(1.3)ab	13.2(1.4)a
	Booting	8.67(0.93)e	9.64(1.04)d	11.3(1.2)c	9.24(0.99)d	11.9(1.3)c	13.4(1.4)ab	12.7(1.4)b	14.5(1.6)a	15.8(1.7)a
	Ripening	7.15(0.77)e	8.21(0.88)d	10.2(1.1)cd	8.38(0.91)d	10.7(1.1)c	12.1(1.3)b	11.2(1.2)c	13.4(1.4)ab	14.6(1.6)a

Values represented in the table as means across replicates of each site. Standard errors are in parentheses.

CT: Conventional tillage; RT: reduced tillage; NT: no-tillage; NR: no residues incorporation; HR: 50% residues incorporation, 7.5 t ha<sup>-1</sup>; TR: 100% residues incorporation, 15 t ha<sup>-1</sup>.

## DISCUSSION

### Effects of tillage on soil quality

Higher bulk density in NT compared to CT was consistent with Maharjan et al. (2017), and this was attributed to lack of mechanical operations in NT that led to progressive densification. pH increased greatly in RT compared with CT. Kiboi et al. (2019) obtained similar results. They attributed these to basal organic manure addition before transplanting. Total organic C and NH<sub>4</sub>-N showed the lowest values in CT and the highest in NT. The results indicate that CT in these lowly fertile soils allows for a faster turnover of soil C and N due to disturbed condition (de Cárcer et al., 2019). Reduced tillage greatly increased available K. Similar results were reported by previous researchers (Giagnoni et al., 2019). This is because less-tillage accelerates the accumulation of K-adsorbed particles.

Microbial biomass C increased by 38.2% in RT and microbial biomass N increased by 31.7% in NT relative to CT, which were consistent with those reported by Vazquez et al. (2019). The positive responses of less tillage to microbial biomass were attributed to larger amount of C and N substrates available for microorganisms (Kinoshita et al., 2017), as well as higher soil moisture, total organic C and total N compared to CT. In our study, CO<sub>2</sub> and N<sub>2</sub>O emissions in RT were on average 29.7% and 40.1% lower than in CT, which were attributed to improved soil structures and decreased disturbance in NT. Campanha et al. (2019) found similar negative effects.

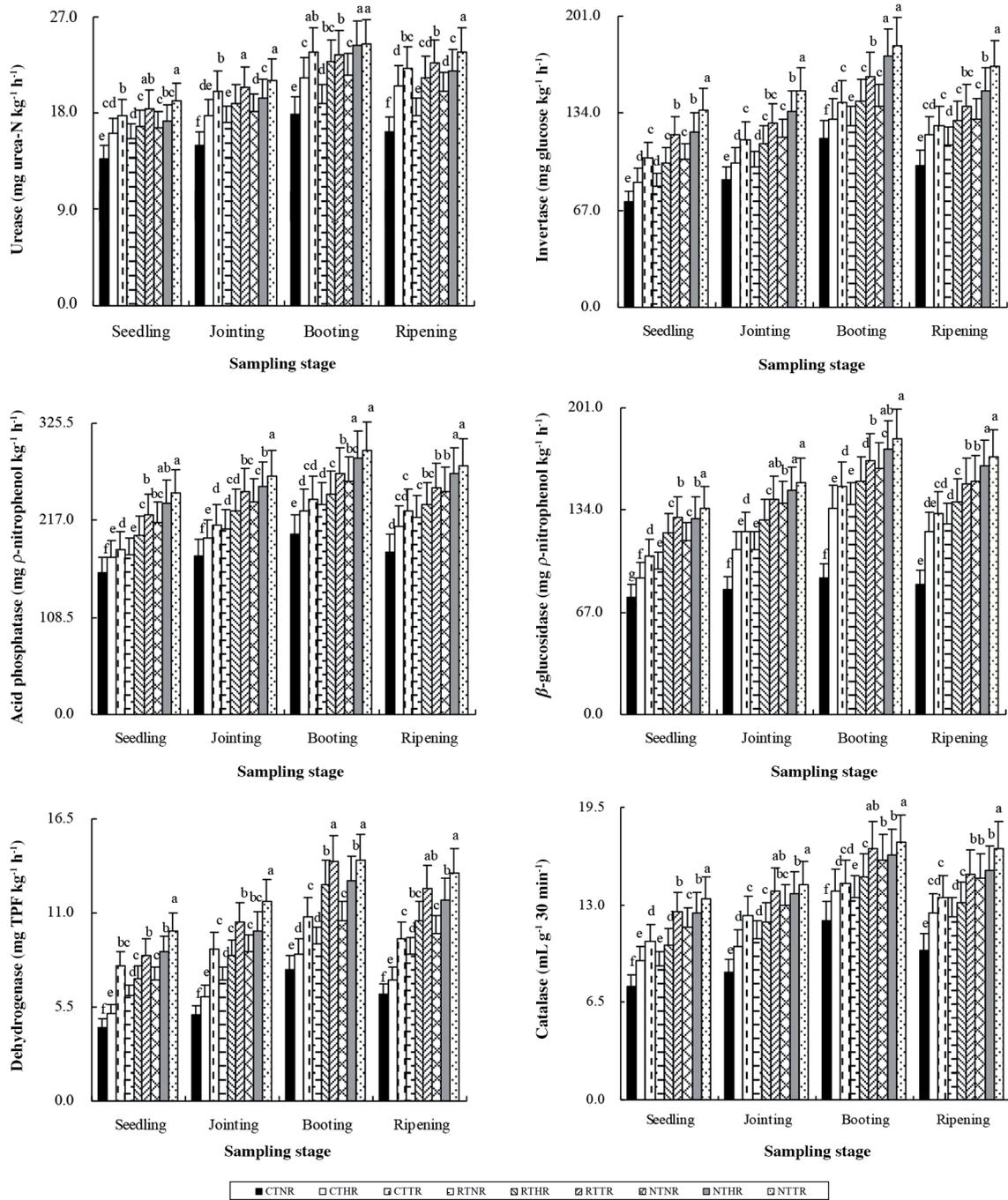
Except for catalase, other enzymes generally showed the highest activities in the treatments containing NT. No-tillage brings about two main modifications. Both of them greatly increase soil enzymes. Firstly, residues left on the soil surface help to increase organic C, N and P availability and microbial biomass (Moghimian et al., 2017). Secondly, reduced disturbance caused by NT prevents disruption in microbial community composition (Naujokiene et al., 2019).

### Effects of residue on soil quality

Soil moisture was 32.5% higher in 50% residue plots than in plots without residue. The result was in agreement with our previous findings (Zhong and Zeng, 2019) because of the retention on soil surface reducing temperature fluctuation and evaporation. Electrical conductivity increased by 47.8% for 100% residue input compared with no residue input. Similar results were reported by Liu et al. (2019). They suggested that accumulation of K, Ca and Mg increased soil salinity. Available P was unaffected by residue treatments, which showed that P decomposition of the returned remains would last several years (Nandan et al., 2019). Similar phenomenon had been found by Fang et al. (2018).

Microbial biomass C and N were in average 22.6% higher in 50% residue input and 38.5% higher in 100% residue input than in zero residue input. The reasons may be due to higher nutrient levels and slower C and N mineralization in residue input plots compared to residue removal plots (Mangalassery et al., 2019). Urease, invertase and acid phosphatase were strongly increased with the increase of residue returning. This is because 100% residue input increases microbial biomass and C storage to the maximum compared with zero C and N inputs. Residue treatments increased CH<sub>4</sub> emission during July to October, which was consistent with the results of Mei et al. (2018). The possible reasons were that moderate rainfall and large amount of crop stalk coverage provided a better soil environment for methanogens (Huang et al., 2018).

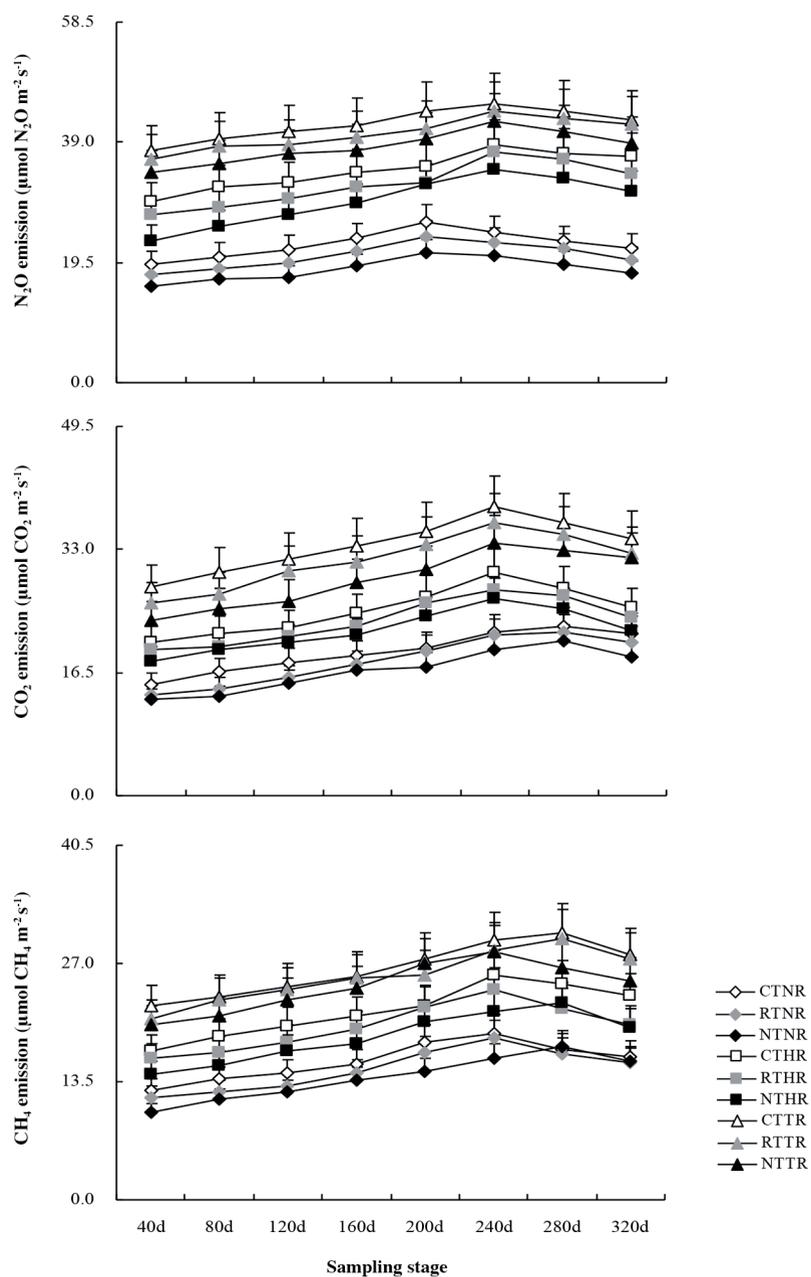
**Figure 4. Soil enzymatic activities in tillage and residue treatments at four sampling stages in a long-term conservation experiment.**



Error bars indicate standard error. Different lower-case letters in the figure mean significant difference according to Duncan's multiple range test ( $P < 0.05$ ).

CT: Conventional tillage; RT: reduced tillage; NT: no-tillage; NR: no residues incorporation; HR: 50% residues incorporation, 7.5 t ha<sup>-1</sup>; TR: 100% residues incorporation, 15 t ha<sup>-1</sup>; TPF: triphenylformazan.

Figure 5. Soil gaseous emissions in tillage and residue treatments at four sampling stages in a long-term conservation experiment.



Error bars indicate standard error. Different lower-case letters in the figure mean significant difference according to Duncan's multiple range test ( $P < 0.05$ ).

CT: Conventional tillage; RT: reduced tillage; NT: no-tillage; NR: no residues incorporation; HR: 50% residues incorporation, 7.5 t ha<sup>-1</sup>; TR: 100% residues incorporation, 15 t ha<sup>-1</sup>.

**Table 3. Pearson correlation coefficients between soil physicochemical and biological properties across tillage and residue treatments.**

Indicators	MBC	MBN	UA	IA	GA	APA	DA	CA	CE	NE	ME
SM	-0.456*	-0.244	-0.146	0.296	0.198	-0.204	0.056	0.107	0.219	0.127	0.097
BD	-0.123	-0.056	-0.215	0.141	0.171	0.119	-0.527*	-0.301	-0.588**	-0.298	0.155
pH	0.295	0.225	0.330	-0.078	0.023	-0.508*	0.115	0.074	-0.273	-0.128	0.186
EC	0.250	0.421	0.781**	-0.316	-0.368	0.695**	0.436	0.452*	0.104	0.180	0.339
SOC	0.578**	0.359	0.521*	0.375	0.221	0.217	0.545*	0.305	0.509*	-0.009	0.177
TN	0.289	0.611**	0.512*	0.473*	0.347	-0.111	0.261	0.152	0.271	0.443*	-0.072
NH <sub>4</sub> -N	0.477*	0.392	0.567**	0.324	0.103	0.225	0.609**	-0.158	0.399	0.301	0.265
NO <sub>3</sub> -N	0.314	0.408	0.482*	0.431	0.211	0.389	0.266	-0.288	0.260	0.219	-0.175
AP	0.334	0.318	0.114	0.348	0.422	0.529*	0.426	-0.045	0.384	-0.274	0.193
AK	0.224	0.205	0.194	0.587**	0.452*	-0.102	0.343	0.469*	0.416	-0.153	0.156
ECa	0.454	0.378	0.128	0.517*	0.416	-0.268	0.459*	0.473*	0.668**	0.138	-0.186
EMg	0.533*	0.679**	0.287	0.415	0.588*	-0.407	0.346	0.314	0.446	0.243	-0.050

\*, \*\*Significant at the 0.05 and 0.01 probability levels, respectively.

SM: Soil moisture; BD: bulk density; EC: electrical conductivity; SOC: soil organic C; TN: total N; AP: available P; AK: available K; ECa: exchangeable Ca; EMg: exchangeable Mg; MBC: microbial biomass C; MBN: microbial biomass N; UA: urease activity; IA: invertase activity; GA:  $\beta$ -glucosidase activity; APA: acid phosphatase activity; DA: dehydrogenase activity; CA: catalase activity; CE: CO<sub>2</sub> emission; NE: N<sub>2</sub>O emission; ME: CH<sub>4</sub> emission.

Seasonal fluctuations of microbial biomass N, urease and greenhouse gas emission were found among residue systems, being the minimum at seedling, reaching peak at booting then decreasing afterwards. These changes are likely due to crop root growth and soil environment. Over the growing stages, crop roots are vigorous at booting stage (Carlesso et al., 2019), so root exudation rate peaked at the same time. Therefore, preferred substrates are provided for rhizospheric bacteria and fungi. A declined soil temperature and moisture at ripening stage were expected to decrease the emission of CO<sub>2</sub> and N<sub>2</sub>O (Volpi et al., 2018).

## CONCLUSIONS

Our results demonstrated that no-tillage combined with maximum amount of residues retaining after 25 yr banana-based rotation significantly increased soil microbial biomass, enzymatic activities and soil C mineralization. Reduced tillage combined with sufficient residue addition of both crops (banana and peanut) decreased greenhouse gas emissions and increased soil physicochemical properties (soil moisture, pH and available nutrients). Overall, integration of crop residue application into reduced tillage systems in a semi-arid tropical climate was very effective in reducing soil degradation and maintaining soil fertility. Accordingly, soil biological properties combined with physicochemical parameters should be considered as useful indicators to assess soil quality in conservation tillage practices in sandy loam soils of South China.

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