

Effect of Continuous Cropping on Soil Chemical Properties and Crop Yield in Banana Plantation

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ABSTRACT

The effects of banana continuous cropping on soil quality and chemical properties and crop yield were investigated under continuous cropping for 1, 3, 5, 7, 10, and 15 years in Hainan province, China. The results indicated that the contents of total N, total K, available K, NH₄-N, exchangeable Ca, and available Cu tended to increase, while total organic C (TOC), available S, and available Zn tended to decrease with the increase of continuous cropping years at the four sampling stages. The contents of exchangeable Mg and available Fe and Mn were higher in the 3, 5, 7, and 10 years than in the 1 and 15 years at the four sampling stages. The values of pH, the contents of total P and available P decreased from 1 to 5 years and increased from 7 to 15 years at most of the sampling stages. Overall, average banana yield increased from 1 to 3 years and decreased afterwards. In conclusion, banana continuous cropping deteriorated soil quality as evidenced by increase of soil acidity, decrease of total organic C, accumulation of N, P, K, Ca and Cu, deficiency of Mg, S, Fe, Mn, and Zn and accompanying decline in banana yield. In order to improve the soil environment and sustain higher productivity under continuous-banana cropping system, application of balanced rate of fertilizers is of considerable importance.

Keywords: Balanced fertilization, Continuous cropping, Latosols, Nutrients accumulation, Soil acidity, Soil quality, Sustainability.

INTRODUCTION

Banana (*Musa* spp. L.) is a tropical plant and constitutes the 4th largest fruit crop of the world. Banana is also one of the major fruits produced in China, especially in Hainan Island, which has the biggest banana growth area in the country. The estimated area under banana cultivation in Hainan Island was 60,533.3 ha in 2010, with an average yield of 47.0 t ha⁻¹ in 2011 (Li *et al.*, 2011). Due to the limit of growers' skills, influence of market demand, and increasing land-use pressure, continuous banana-cropping has been a common practice in the humid tropical region of China.

In most of the current continuous cropping systems, all the crop residues are left as surface mulch after harvest before mouldboard plowing. These methods are generally believed to produce favorable seedbeds, conserve water, increase root growth and development, and maintain crop yields (He *et al.*, 2011). However, in the long term, continuous cropping significantly affects soil physical and chemical properties by increasing soil bulk density and reducing both macroporosity and macro-aggregates, resulting in less water and nutrient availability (Qin *et al.*, 2007). Consequently, crop yields become unstable and decline, especially in dry years (Sainju *et al.*, 2009).

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For example, after 7 years of continuous maize-cropping, the available P and S, total organic C, total N, and pH in Southern Pampas decreased significantly, whereas the bulk density, hydraulic conductivity, and sand content increased (Wyngaard *et al.*, 2012). Similarly, a significant reduction of the exchangeable Ca, Mg and Na, available K and Fe and crop yield has been observed in continuous cropping of maize and cotton (Hulugalle *et al.*, 2007; Singh *et al.*, 2010). However, the effect of continuous cropping years on soil nutrient levels and fertility losses under banana plantation has not been extensively studied.

The main types of soil where banana is grown are the Latosols and Andisols. The chemical properties of these soils are modified by cropping frequency, unbalance nutrients application, and return of residues to the soil (Rasiah *et al.*, 2009; van Asten *et al.*, 2010). In China, one ton of banana stalks extracts on average about 1.47 kg of N, 0.29 kg of P and 6.68 kg of K (El Tahir *et al.*, 2009). Harvest remnants (roots, stalks, and leaves) represent around 37% of the total banana aerial biomass (van Asten *et al.*, 2011). Currently, cultural practices and harvesting methods used for banana production cause the loss of soil nutrients by the transfer of stalks to the mill and the burning of residues in the field (Naranjo *et al.*, 2006). The common practice of burning residues or taking them away prevents their re-incorporation to the soil as green manure, thus producing losses of about 16 kg ha⁻¹ of N which affects yield. For example, a yield reduction of up to 21% has been observed by Dorel *et al.* (2010) in Guadeloupe. Chemical degradation, caused by long-term adoption of banana continuous cropping, can be evaluated using some indicators of soil quality. Some of the indicators proposed by Emami *et al.* (2012) are pH, total organic C, exchangeable Ca and Mg, and texture as major soil properties. A periodic evaluation of these indicators allows the quantification of soil changes caused by continuous cropping and helps in maintaining the ecological balance between soil-climate-

vegetation and the agricultural intensification desired. In practice, it allows planning of strategies to achieve sustainable management of the soil resources used in this case for banana production. The objective of this study was to determine the effect of continuous cropping on soil chemical properties and banana yield of a typical Latosols in the Hainan Island.

MATERIALS AND METHODS

Site Descriptions

This study was conducted at ChengMai long-term continuous banana-cropping experimental site (19° 53'-19° 54' N, 109° 52'-109° 53' E), Chinese Academy of Tropical Agricultural Sciences, Hainan, China. The region has a tropical monsoon climate with a mean annual temperature of 24.9°C (no frost period all year) and a mean annual precipitation of 2,160 mm. The test soil was classified as clay-sandy loam according to the USDA texture classification system with 13.84 g total organic C (TOC) kg⁻¹ soil, 1.37 g total N kg⁻¹, 0.73 g total P kg⁻¹, 1.89 g total K kg⁻¹, and pH 5.26. The total content of clay, silt, and sand were 47.89, 21.47, and 30.64%, respectively. Eighteen experimental plots (166 m² each) were planted by the staff of the experimental site with banana plants of cvs. Baxijiao (AAA) in a conventional tillage system. Banana plant was fertilized by organic manure and chemical fertilizers. The chemical N fertilizer (urea), P fertilizer (superphosphate) and K fertilizer (sulphate) were applied at the rates of 960.0 kg N ha⁻¹, 576 kg P ha⁻¹ and 2,880 kg K ha⁻¹, with 20% on the 60th, 30% on the 120th, 30% on the 180th, and 20% on the 240th day to a depth of 0-20 cm after transplanting every year. The manure used was cow manure compost (14.4 t ha⁻¹), with 83.3% water content, containing 145 g C kg⁻¹, 3.2 g N kg⁻¹, 2.5 g P₂O₅ kg⁻¹, 1.6 g K₂O kg⁻¹, 27 mg S kg⁻¹, 22 mg Cu kg⁻¹ and 64 mg Zn kg⁻¹ on a dry weight basis, which was basally applied before

transplanting (June 26th) to a depth of 0-20 cm every year. Lime was used (125 kg ha⁻¹ per year) together with cow manure compost for increasing soil pH. The plots were irrigated once a week. Bananas were removed at the beginning of May, soil was mouldboard ploughed (30 cm deep) at the end of May and bananas were re-planted at the end of June every year from 1996 to 2011. Six treatments, i.e., 1 y (banana was grown from 2010 to 2011), 3 y (2008-11), 5 y (2006-11), 7 y (2004-11), 10 y (2001-11) and 15 y (1996-11) were arranged in a completely random design with three replicates.

Soil Sampling

All soil samples were collected together in the last growing season. After the removal of above-ground plant debris, soil samples were extracted using a soil corer (3.0 cm diameter) at depth of 0-30 cm below the soil surface on seedling stage (September 2, 2010), jointing stage (December 3, 2010), booting stage (March 1, 2011) and ripening stage (May 4, 2011) within the plant rows, 50 cm from the base of the banana plants. For each sample, five random cores were combined to form one composite sample. Visible roots and residues were removed from the samples. The fresh soil samples were sieved through 2 mm meshes and subdivided into two subsamples. One was stored in individual plastic bags and kept at 4°C before analyzing NO₃-N and NH₄-N; while the other was air-dried and ground for other chemical analysis. Results were based on the oven-dried weight of the soil.

Soil Chemical Properties

Soil pH was determined by using a glass electrode (1:2.5, soil:water ratio). Total organic C was analyzed by dry combustion, using a Shimadzu TOC 5000 Total C analyzer. Total N was determined by semi-microkjeldahl method. Total P was digested

by H₂SO₄-HClO₄ and determined by Molybdenum-blue complex method (Page *et al.*, 1982). Total K was determined by flame atomic absorption spectrometry (Perkin Elmer 306, Shelton, CT, USA) after the soil samples were decomposed by fusion with NaOH (Agricultural Chemistry Committee of China, 1983). Soil NO₃-N and NH₄-N were determined by extraction with 2 M KCl, steam distillation and titration (Keeney and Nelson, 1982). Available P, K, and S were determined as described by Rayment and Higginson (1992). Exchangeable Ca and Mg were extracted by 1M NH₄OAc and determined with atomic absorption spectrophotometer (CSTPA, 1980). Available Fe, Mn, Cu, and Zn in soil were extracted with 0.005 M diethylenetriaminepentaacetic acid (DTPA), 0.1M CaCl₂, and 0.1M triethanolamine (TEA) with pH of 7.3, and determined with flame atomic absorption spectrometry (Perkin-Elmer AAnalyst 100, Norwalk, USA).

Banana Yield

Banana yield (kg ha⁻¹) was estimated based on bunch weights, mat spacing, and average crop cycle duration (i.e. time between two subsequent harvests from the same mat) as used by Wairegi *et al.* (2010) in the same regions.

Statistical Analysis

Results were statistically analyzed using SPSS window version 10.0 (SPSS Inc., Chicago, USA) packages with the ANOVA procedure. Means were compared between treatments and sampling stages by LSD (least significant difference) using Fisher's *F*-test. Two-way ANOVA was applied to test the effects of continuous cropping years and sampling stages as main effects and their two-way interaction on soil chemical properties. One-way ANOVA was applied to test the effects of continuous cropping



years as the main effect on banana yield. Difference at $P < 0.05$ and $P < 0.01$ level was considered as statistically significant.

RESULTS

Soil pH, Carbon, and Nitrogen

Treatments and sampling time effects were significant on the values of pH, the contents of TOC and $\text{NH}_4\text{-N}$ (Table 1). At the seedling, jointing, and booting stages, the values of pH gradually decreased from 1 y to 5 y and increased again afterwards, with the highest value (5.97) in the 10 y at seedling stage and the lowest (4.56) in the 5 y at jointing stage. At the ripening stage, the value of pH was higher in the 10 y (10 y > 1 y > 3 y > 5 y > 15 y > 7 y) than in the other treatments (Figure 1). At the jointing and ripening stages, the contents of TOC gradually increased from 1 y to 5 y and from 1 y to 7 y, respectively, then decreased again afterwards, with the highest value (16.79 $\text{g}\cdot\text{kg}^{-1}$) in the 7 y at ripening stage, and the lowest (11.34 $\text{g}\cdot\text{kg}^{-1}$) in the 15 y at booting stage (Figure 1). The contents of TOC at the seedling and booting stages, $\text{NH}_4\text{-N}$ at the seedling stage, and $\text{NO}_3\text{-N}$ at the jointing stage decreased sharply with the increase of continuous cropping years, while the contents of total N at booting and ripening stages and the contents of $\text{NH}_4\text{-N}$ at the jointing, booting, and ripening stages exhibited a reversed condition (Figure 1).

Soil Phosphorus, Potassium, Calcium, and Magnesium

The effects of different treatments, sampling times, and the interaction of treatments and sampling times were significant on the contents of total P, available P, available K, and exchangeable Ca (Table 1). The contents of total P at the seedling and booting stages and available P at the seedling and jointing stages gradually decreased from 1 y to 5 y and increased

Table 1. Two-way ANOVA table of P -values on the effects of treatment and sampling time on soil chemical properties .

ANOVA	P -values															
	pH	TOC ^a	TN ^b	$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$	TP ^c	AP ^d	TK ^e	AK ^f	E-Ca ^g	E-Mg ^h	AS ⁱ	AF ^k	AM ^l	AC ^m	AZ ⁿ
Treatment	< 0.01	< 0.01	<	< 0.01	ns	0.032	< 0.01	ns	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Time	< 0.01	< 0.01	ns	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Treatment × Time	0.030	ns	ns	< 0.01	ns	< 0.01	< 0.01	ns	< 0.01	< 0.01	ns	< 0.01	< 0.01	ns	ns	ns

^a Total Organic C; ^b Total N; ^c Total P; ^d Available P; ^e Total K; ^f Available K; ^g Exchangeable Ca; ^h Available Mg; ⁱ Available S; ^k Available Fe; ^l Available Mn; ^m Available Cu; ⁿ Available Zn.

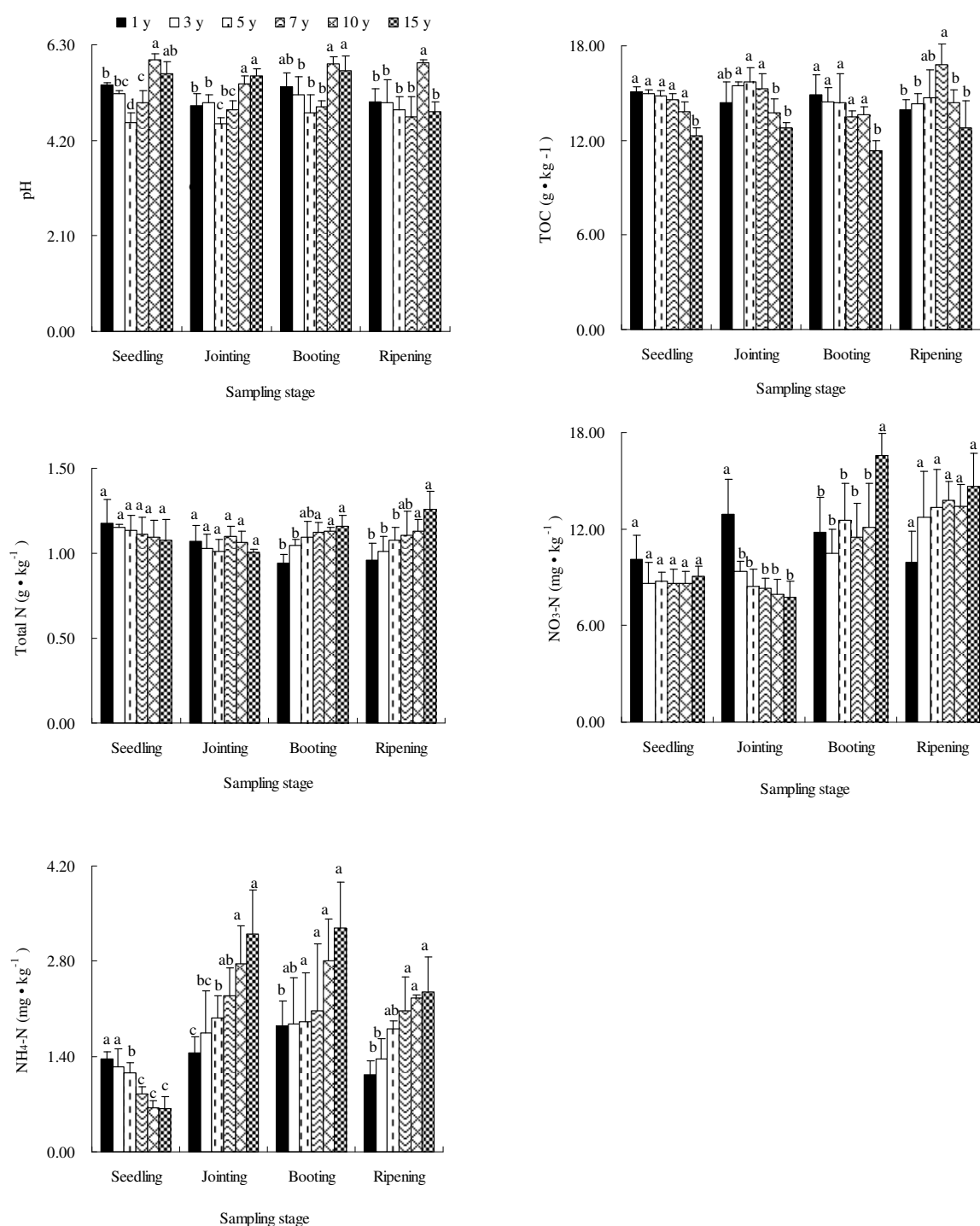


Figure 1. Soil pH, total organic C, total N, NH₄-N, and NO₃-N of banana gardens with different continuous cropping years (Error bars indicate standard error). Different lower case letters in the figure mean significant difference according to Duncan's multiple range test ($P < 0.05$). Note: 1 y= Banana was grown from 2010-11; 3 y= 2008-11; 5 y= 2006-11; 7 y= 2004-11; 10 y= 2001-11, 15 y= 1996 to 2011.



from 7 y to 15 y. The contents of total P and available P at the ripening stage showed the same tendency, but the turning points appeared at 7 y. The contents of total K at the ripening stage gradually increased from 1 y to 10 y and decreased at 15 y (Figure 2). The contents of total K and available K at the seedling, jointing, and booting stages and the contents of exchangeable Ca at the four sampling stages tended to increase with the increase of continuous cropping years (Figure 2). The contents of exchangeable Mg were higher in the 5 y, 7 y and 10 y treatments than in the other treatments at the four sampling stages (Figure 2).

Soil Sulphur, Iron, Manganese, Copper, and Zinc

Treatments and sampling time effects were significant on the contents of available S, Fe, Mn, Cu, and Zn (Table 1). The contents of available Cu increased sharply with the increase of continuous cropping years at the seedling, jointing, and ripening stages, while the contents of available S at the jointing and booting stages and the contents of available Zn at the seedling, jointing, and ripening stages exhibited a reverse condition (Figure 3). The contents of available S were higher in the 3, 5 and 7 y than in the other treatments at the seedling and ripening stages (Figure 3). The contents of available Fe were higher in the 3, 5, 7 and 10 y than in the other treatments at the seedling, jointing, and ripening stages. The contents of available Mn were higher in the 5 and 7 y, and lower in the 1, 3, and 15 y at the booting and ripening stages (Figure 3).

Banana Yield

Treatment effects were significant on banana yields. The overall average banana yields under 5, 7, 10, and 15 y were, respectively, 1.7, 8.1, 12.8, and 18.9% lower than under 1 y, while 8.9% increase was observed from year 1 to year 3 (Table 2).

Table 2. One-way ANOVA table of *P*-values on the effects of continuous cropping on the overall average banana yield ^a.

Cropping year	<i>P</i> -value						
	1 y ^b	3 y	5 y	7 y	10 y	15 y	<i>P</i> -value
Banana yield (kg ha ⁻¹)	41400±4080 a	45120±5160 a	40680±4440 ab	38040±4560 b	36120±3960 b	33560±3480 b	0.044

^a Mean values and standard errors of three replicates are presented. Significant differences of variable means among different treatments are indicated by different letter ($P < 0.05$). ^b years of banana continuous cropping.

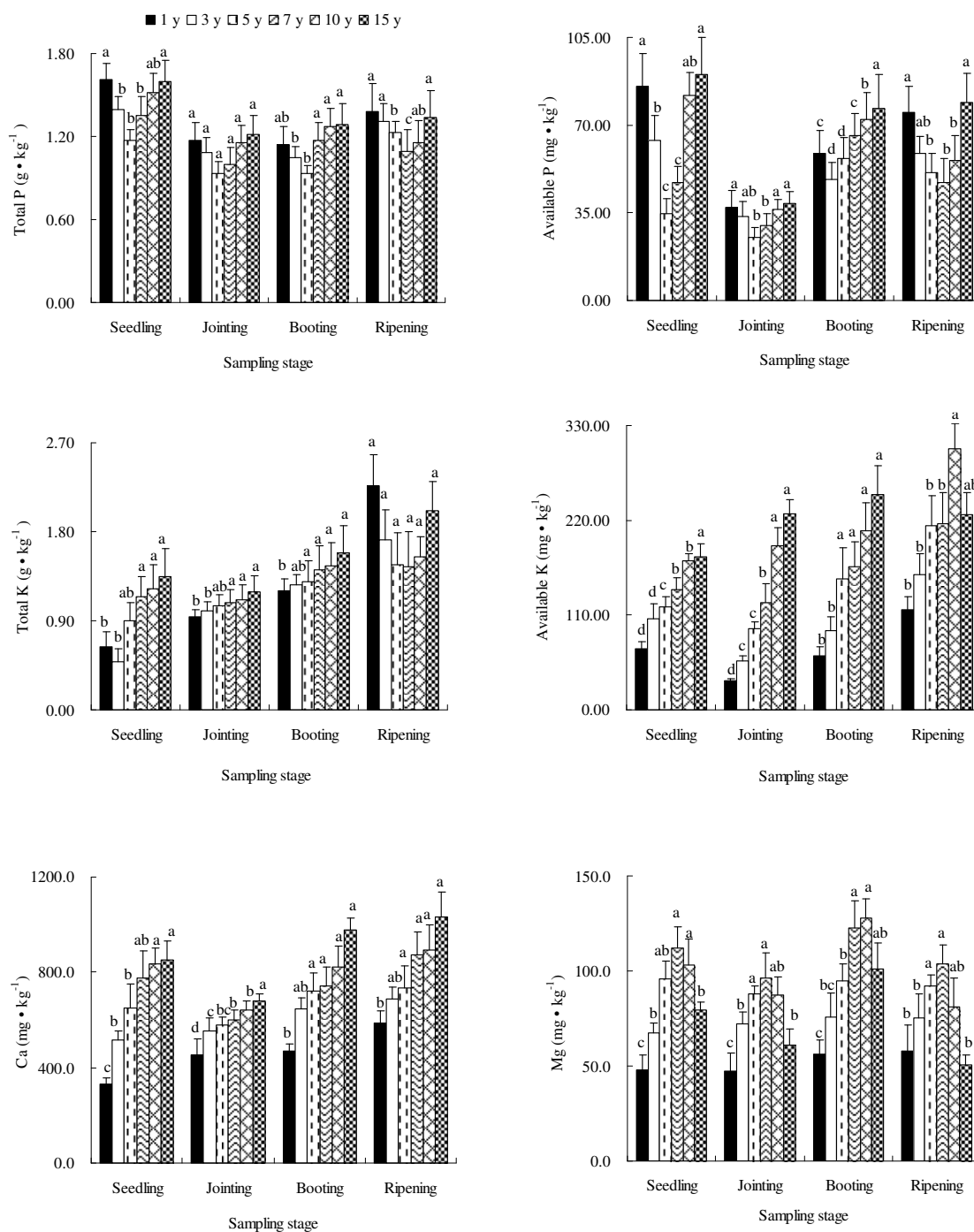


Figure 2. Soil total P and K, available P and K and exchangeable Ca, Mg of banana gardens with different continuous cropping years (Error bars indicate standard error). Different lower case letters in the figure mean significant difference according to Duncan's multiple range test ($P < 0.05$).

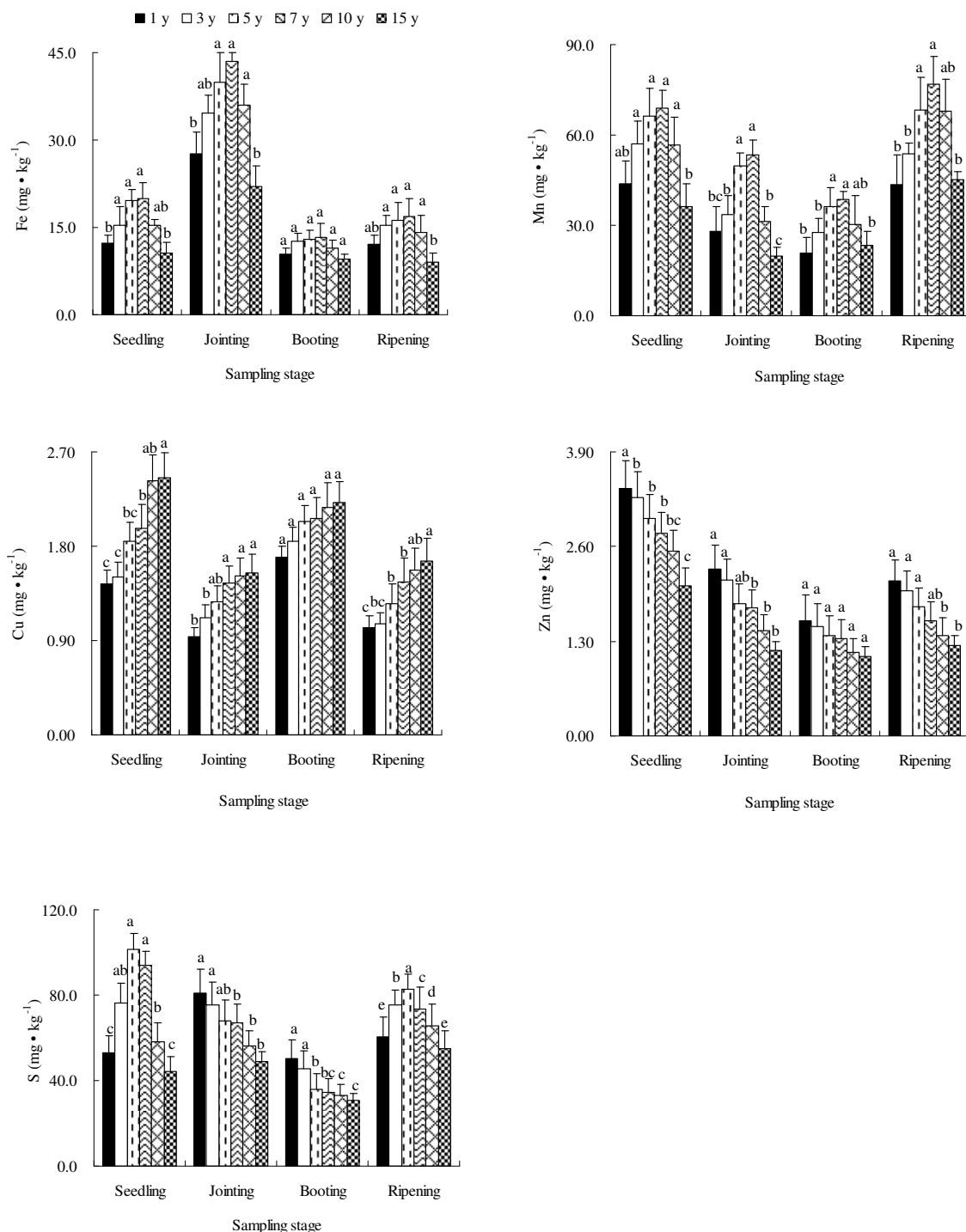


Figure 3. Soil available S, Fe, Mn, Cu and Zn of banana gardens with different continuous cropping years (Error bars indicate standard error). Different lower case letters in the figure mean significant difference according to Ducan’s multiple range test ($P < 0.05$).

The overall average banana yields were significantly higher in the 1, 3 and 5 y than in the other treatments with the highest value ($45,120 \text{ kg}\cdot\text{ha}^{-1}$) in the 3 y, and the lowest ($34,560 \text{ kg}\cdot\text{ha}^{-1}$) in the 15 y (Table 2).

DISCUSSION

Changes of Soil pH and Total Organic C

In our study, although there was an increase in pH after 7 years of continuous banana cropping, an initial decrease from 1 to 5 years was observed, which was in agreement with Naranjo *et al.* (2006) in a continuous sugarcane-cropping field. The decrease might have been due to the increased use of chemical fertilizers, primarily with large K and N rates undergoing degradation, however, the increase by 0.9 units from 7 to 15 years might have been due to the addition of banana stalk residues at the end of the harvest (Yusuf *et al.*, 2009). Continuous cropping tended to decrease the contents of TOC, although an increase from 1 to 5 years at the jointing stage and from 1 to 7 years at the ripening stage was observed, which was in agreement with Malhi and Lemke (2007) in an 8-year continuous wheat cropping field in Saskatchewan, Canada. The decrease was not only according to the deficit of organic C input but also an accelerated decomposition of organic manure and banana residues due to hot weather (Martin-Rueda *et al.*, 2007).

Changes of Soil Nutrients

The contents of total N, $\text{NH}_4\text{-N}$, and $\text{NO}_3\text{-N}$ showed an increased tendency from 1 to 15 years at the four sampling stages, except that $\text{NH}_4\text{-N}$ at seedling stage and $\text{NO}_3\text{-N}$ at the jointing stage showed a reverse condition. The result was in agreement with Fortuna *et al.* (2008) who observed an increase of organic N and available N in continuous soybean-cropping field in Lexington, which may be attributed to the addition of high level of inorganic N fertilizer to the soybean system. The contents of total P and available P decreased from 1 to 5 years and increased from 7 to 15 years at most of the

sampling stages, which differed from the increasing trend for total P and available P in southern China after 30 years of continuous rice-cropping on a clay soil (Zhang and He, 2004). The accumulation could partly be attributed to less export of P and partly to increased recycling within plant-soil systems (Colomb *et al.*, 2007), however, the deficiency could be attributed to high plant uptake and higher sequestrations of P in banana biomass (Assis *et al.*, 2010).

The contents of total K, available K, and exchangeable Ca showed an increased tendency from 1 to 15 years at the four sampling stages, which was consistent with Wright *et al.* (2007) in a 14 years continuous cotton-cropping field in Texas and Zougmore *et al.* (2002) in a 15 years continuous sorghum-cropping field in Faso. The increase in total K and available K could be explained by unbalanced fertilization strategy in the area, which was commonly practiced by the farmers. According to their opinion, the more K fertilizers were used, the higher banana yield could be, therefore, K fertilizers were overused and strong K accumulation in the banana soils was very common (Niu *et al.*, 2011). Lime and organic manure usually contain considerable Ca, which, in part, contribute to the increase of exchangeable Ca. Continuous cropping changed the contents of exchangeable Mg and available S from accumulation to deficit at most of the sampling stages, which was consistent with Hulugalle *et al.* (2007) in a Queensland cotton field after continuous cropping for 15 years. Exchangeable Mg and available S under all treatments were above 45 and 30 mg kg^{-1} , the generally accepted critical level of, respectively, Mg and S deficiency (Masto *et al.*, 2007), which suggested that soil Mg and S maintained a significantly high level under all treatments because of using superphosphate and cow manure compost.

During the growth season, available Cu increased as a result of continuous cropping, in agreement with the results of Behera and Singh (2009), who reported accumulation of soils available Cu in New Delhi as a result of continuous wheat-cropping for 31 years. According to them, this increase was probably due to continuous addition of Cu nutrient through fertilizers. The contents of available Fe, Mn, and Zn tended to decrease as the impact of continuous cropping, although available Fe and



Mn increased from 1 to 7 years, consistent with the findings of Rahman *et al.* (2008) in a Japanese wheat field after continuous cropping for 15 years. The decrease may be ascribed to the continuous uptake by the crops over the years in addition to their non-replenishment in the form of fertilizers, however, the increase might have been related to the decrease of soil pH from 1 to 7 years, which could have resulted in the release of previously non-available Fe and Mn from soil minerals (Singh *et al.*, 2010).

Changes of Banana Yield

Overall, the average banana yield tended to decrease with the increase of continuous cropping years, although an 8.2% increase from 1 to 3 years was observed, which was consistent with the results of van Asten *et al.* (2011) in a continuous coffee-cropping field in Uganda. The decrease of banana yield could have been caused by unbalanced nutrient application such as high N, P, K, Ca, and Cu and low Mg, S, Fe, Mn, and Zn. Similar results were observed by some other researchers (Kywe *et al.*, 2008; Alvarez and Steinbach, 2009).

CONCLUSION

Continuous cropping has resulted in significant changes in soil chemical properties and banana yield. Soil pH and the contents of total P and available P decreased from 1 to 5 years, and increased again afterwards at most of the sampling stages. The exchangeable Mg and available Fe and Mn increased from 1 to 7 years and decreased afterward at the four sampling stages. The contents of total N, total K (except ripening stage), available K, NH₄-N (except seedling stage), exchangeable Ca, and available Cu increased and total organic C (seedling and booting stages), available S (jointing and booting stages), and available Zn decreased with the increase of continuous cropping years. Overall, soil N, P, K, Ca, and Cu were maintained or increased under continuous banana cropping system. Other nutrients such as Mg, S, Fe, Mn, and Zn were

gradually depleted where no chemical fertilizer or organic manure was supplied, which decreased banana yield by 18.9% after continuous cropping for 15 years. Thus, soil nutrients deficiency or accumulation after continuous banana cropping for 5-7 years had negative effects on sustainability of banana production. Balanced application of fertilizers could have been an important tool to maintain the desired agricultural intensification level while improving soil fertility.

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اثر کشت مداوم موز روی ویژگی های شیمیایی خاک و عملکرد محصول

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چکیده

اثر کشت مداوم موز روی کیفیت و ویژگی های شیمیایی خاک و عملکرد محصول در دوره های ۱۰، ۱۵، ۲۰، ۲۵، ۳۰ و ۳۵ ساله در استان هینان چین بررسی شد. نتایج حاکی از آن بود که در چهار مرحله نمونه برداری، با افزایش سال های کاشت مداوم، مقدار نیتروژن کل، پتاسیم کل، پتاسیم قابل استفاده، نیتروژن آمونیاکی، کلسیم قابل تبادل و مس قابل استفاده افزایش یافت در حالی که میزان کل کربن آلی، گوگرد قابل استفاده و روی قابل استفاده رو به کاهش داشت. همچنین، در همان چهار مرحله نمونه برداری، مقدار منیزیم قابل تبادل و آهن و منگنز قابل استفاده در دوره های ۱۰، ۱۵، ۲۰ و ۳۰ ساله بیشتر از دوره ۱۵ ساله بود. نیز، مقدار اسیدیته (pH) و مقدار فسفر کل و فسفر قابل جذب از دوره ۱ تا ۵ ساله کاهش نشان داد و سپس از دوره ۷ تا ۱۵ ساله در بیشتر مراحل نمونه برداری افزایش یافت. به طور کلی، میانگین عملکرد موز از دوره ۱ تا ۳ ساله زیاد شد و پس از آن کاهش یافت. نتیجه گیری اینکه کشت مداوم موز موجب تخریب کیفیت خاک شد و شاهد این پدیده افزایش اسیدیته، کاهش مقدار کل کربن آلی، تجمع N, P, K و Ca و Cu و کمبود Mg, Zn, S, Fe و در نتیجه کاهش عملکرد بود. نکته دیگر این که به منظور بهبود محیط خاک و حفظ بهره وری بیشتر در سامانه کشت مداوم موز کاربرد کود به صورت متعادل اهمیت بسیار دارد.