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Effects of banana and sweet potato intercropped on soil physical and chemical properties

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In order to study the effect of intercropped sweet potato in banana orchard on soil physical and chemical properties, the soil nutrients, temperature, humidity and enzyme activities of sweet potato intercropped and banana monocultured were compared by using Guijiao-1 and Pushu-32 as research materials. The soil temperature of sweet potato intercropped in the 5-20cm soil layer was 0.46-4.55℃ lower than that of banana monocultures in the hot summer, but in the 10 cm and 20 cm soil layers higher with 0.37-0.97℃ than that of monocultured in October and November. The water content in 5-20cm soil layer of sweet potato intercropped was 1.42-14.55% higher than that of banana monocultured. From May to September, the activities of soil sucrase, phosphatase, catalase and urease in sweet potato intercropped were significantly higher than those in banana monocultured. The contents of soil organic matter, total nitrogen, total potassium, available nitrogen, soil available phosphorus and potassium were 10.64-37.11%, 16.35-32.04%, 4.15-9.55%, 25.39-32.15%, 3.56-8.29%, 31.16-171.04% higher than those in banana monoculture. Thus, there had positively effects on improving the soil physical and chemical properties and the activity of important metabolic enzyme in banana field by sweet potato intercropped.
Keywords: Banana; Intercropping pattern; Soil enzyme activity; Soil nutrient content.

INTRODUCTION

Banana (Musa nana Lour.) is one of the largest fruits in fresh fruit production and trade of the world, and it is an important cash crop for major producing countries such as India, China and the Philippines in tropical and subtropical regions. The banana industry has become a pillar industry for rural economic prosperity and for farmers to shake off poverty and become rich in the main producing countries (Arvanitoyannis and Mavromatis, 2009; Dita *et al*., 2018; Chabi *et al*., 2018). However, the monoculture and multi-year continuous cropping of bananas in many growing areas has led to serious pest and disease problems such as Fusarium wilt. At the same time, banana plantations that have been cultivated for many years are suffering from bunchy top disease, which is spread by aphids. The incidence of Fusarium wilt in some growing areas is as high as 30-80% (Huang *et al*., 2012), and the bunch-top disease is as high as 20-40% (Das *et al*., 2018), which poses a serious threat to the sustainable and stable development of the banana industry. At present, the large area planted varieties are relatively poor disease resistance while varieties with high disease resistance have not been recognized by consumers in the market due to poor quality and appearance (Ploetz, 2015).

In addition to causing disease and insect damage, several years of continuous cropping can also cause the deterioration of soil texture and physical and chemical properties, the imbalance of nutrient consumption (Pang *et al*., 2021). The occurrence and harm of banana fusarium wilt are mainly related to soil acidification and a lack of organic matter (Deltour *et al*., 2017; Li *et al*., 2019). The soil microbial diversity was reduced and the growth of antagonistic bacteria was inhibited due to soil acidification and low organic matter content in banana field. Thus, the pathogen fusarium proliferated greatly (Fu *et al*., 2016; Dita *et al*., 2018). Therefore, the current cultivation methods of banana monocultures and continuous cropping for many years must be changed for improving the physical and chemical properties of soil and increasing the content of soil organic matter. Some studies indicated that the soil texture and its physical and chemical properties could be improved, and the soil nutrients are used in a balanced way and the harm of pests and diseases would not be increased year over year by employing a compound planting mode of intercropping and rotation planting of several crops (Chang *et al*., 2020; Li *et al*., 2018). The benefits of intercropped have been demonstrated that the efficiency of soil nutrient conversion and the nitrogen, phosphorus, potassium and other nutrients

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absorbed and utilized by crops were increased and the enzyme activity and soil structure were improved (Zhang *et al*., 2010; Tang *et al*., 2021; Tian *et al*., 2019; Khan *et al*., 2020). Research on different intercropped patterns, it has been reported that the contents of available nitrogen, phosphorus, potassium and organic matter and the activities of sucrase, urease and other enzymes in soil significantly increased with inter-cropping and weeds and insect population could be significantly reduced with inter-planting (Zhang *et al*., 2012; Dai *et al*., 2015; Wang *et al*., 2017). Compared with crops such as chives and peanuts, sweet potato has the advantages of fast stem and leaf growth, a high biological yield and creeping growth on the ground, which covers the ground, reducing soil water evaporation and slowing down the scouring intensity of heavy rainfall on the surface soil layer in summer and high temperature seasons. The return of all the sweet potato stems and leaves to the soil after withering may would help to increase the content of organic matter and main nutrients in the soil and then the diversity microorganisms could be increased. However, to date, whether interplanting sweet potatoes on banana plantations has negative effects on banana growth and yield, as well as the actual effects on soil temperature and humidity, microbial diversity and physical and chemical properties, has not been reported. In this paper, the effects of planting sweet potato between banana rows on soil physical and chemical properties were studied, so as to provide a theoretical basis and technical support for improving banana planting methods and reducing damage inflicted by pests and diseases.

MATERIALS AND METHODS

***Test site*:** The experiment was carried out in banana industry technology system test and demonstration base of the subtropical agricultural new town of Guangxi University, which is located in Quli Town, Fusui County, Chongzuo City, longitude 107°78 'east and latitude 22°51' north. The experimental site is located in the south subtropical monsoon climate region, with an annual average temperature of 21.3-22.8℃ and an annual precipitation of 1050-1300mm. Soil properties were as follows: organic matter 19.09 g kg^{-1}, available nitrogen 69.98 mg kg^{-1}, available phosphorus 118.13 mg kg^{-1}, available potassium 71.45 mg kg^{-1}, pH 4.50.

Testing methods: The experiment was conducted from March 2018 to December 2020. The banana and sweet potato variety was Guijiao-1 and Pushu-32, respectively. Two treatments were set up in the experiment, bananas intercropped with sweet potatoes (labeled as IC) and banana monocultured (labeled as MC). In the intercropped treatment, the row and plant spacing of bananas was 2.7× 2 m and two rows of sweet potatoes were planted between banana rows, in which the row and plant distance of sweet potato was 1× 0.5 m. The row spacing and plant spacing of banana in the monocultured treatment were the same as those in intercropped. The plot area of each treatment was $81m^2$, and the experiment was replicated three times. In banana field management, fertilization, irrigation and pest control was carried out according to conventional cultivation measures. From May to September, the sweet potato stems and vines within 30 cm of the banana plants were pulled out or cut once a month or two months to prevent the sweet potato stems and vines from covering the soil around the banana plants, which was conducive to fertilization management. The fertilization ratio of nitrogen, phosphorus and potassium in banana was 2:1:4, and applied 5-9 times in the whole growth period. Sweet potatoes were fertilized with base fertilizer when they were planted. Other management measures were the same as those used in field production management. The growth status of the banana plantation during the experiment is shown in figure 1. Three-channel soil temperature and humidity meter was installed between banana rows to measure the temperature and moisture content of the 5, 10 and 20 cm soil layers.

(MC, Banana monoculture）

(IC, Sweet potato intercropped on banana plantation)

Figure 1. The photos of banana plantation field treated in the experiment.

***Soil sampling*:** The soil samples were collected randomly from 5-6 sampling points of different treatments in banana orchard in May, July and September 2020 respectively. Weeds and debris in the surface layer of the soil were removed at 50 cm away from the stem bases of the banana plants. The soil samples were taken from the 0-20 cm soil layer with a soil sampler and mixed evenly, and the animal and plant residues, stones and nodules were removed. The excess samples were discarded by using the four-part method, and 1-kg soil samples were kept in sterilized polyethylene sealed pockets and placed in ice boxes. The samples were transported back to laboratory, dried naturally, sifted through an 18-mesh sieve and used to determine soil enzyme activity and fertility content.

Soil enzyme activity: Soil sucrase activity was determined by using the 3,5-dinitrosalicylic acid method and expressed as milligrams of glucose per gram of soil after reaction for 24 hours (Guan, 1986). Soil catalase was determined by using $KMnO_4$ titration and expressed as millilitres of 0.02 mol L^{-1} potassium permanganate per gram of soil after reaction for 20 min (Guan, 1986). Soil phosphatase was determined by applying the disodium benzene phosphate colorimetric method and expressed as milligrams of P_2O_5 per 100g soil after reaction for 2 hours (Guan, 1986). Soil urease was determined by using phenol sodium colorimetry and expressed as milligrams of NH_3-N per gram of soil after reaction for 24 hours (Guan, 1986).

Soil physical and chemical attributes: The physical and chemical properties of soil are determined as follows. The organic matter content was determined by using the potassium dichromate-sulfuric acid solution method (Bao, 2000). The contents of available phosphorus, potassium and nitrogen in soil were determined by using the 0.5 mol $L^{-1}$$NaHCO_3$ extraction-molybdenum-antimony resistance colorimetric method, ammonium acetate extraction–atomic absorption spectrophotometry and the alkali hydrolysis diffusion method (Bao, 2000), respectively. The contents of total potassium, phosphorus and nitrogen in soil were determined by applying NaOH melting atomic absorption spectrophotometry, NaOH melting molybdenum antimony resistance colorimetry and semi micro Kjeldahl method (Bao, 2000), respectively. The soil pH was determined by using a pH meter with a soil-to-water ratio of 2.5 (v/m) (Bao, 2000). Soil temperature and moisture were measured and recorded with a soil temperature and moisture recorder（Luge, Model-L99-TWS, China).

Data processing and statistical analysis: Microsoft Excel 2010 and Origin 2019 software was used to process the data, and IBM SPSS Statistics, version 26.0 (Armonk, NY; IBM Corp.) statistical software was used for variance analysis and correlation analysis.

RESULTS

***Effects of sweet potato intercropped in banana field on soil temperature*:** According to Table 1, from May to November, the month with the highest average soil temperature of different soil layers in banana orchard is July. From May to July, the soil temperature gradually increased, and it was 27.67-33.33℃ in different soil layers. After August, the soil temperature gradually decreased, and it was 30.39-19.19℃ in different soil layers. From May to September, the soil temperature with sweet potato cover in 5cm soil layer was lower than that without cover, with a decrease of 1.57-4.55℃. It was decreased by 0.46-3.63℃ in 10cm soil layer and dropped with 0.72-3.34℃ in 20cm soil layer, of which the soil covered with sweet potato has the highest temperature drops in July, reaching 3.34-4.55℃. During October and November the soil temperature in 5 cm soil layer covered by sweet potato decreased by 0.98-1.6℃ compared with that in the monocultured, but in the 10 cm and 20 cm soil layers it was higher than that in no cover, with increased by 0.37-0.97℃. The results showed that the soil temperature in the surface soil layer could be reduced in summer and increased in 10-20 cm layer below the topsoil layer in autumn and winter when the sweet potatoes were planted between banana rows.

***Effects of sweet potato intercropped in banana garden on soil moisture content*:** As can be seen from Table 2, from May to November, the soil moisture content of different soil layers of intercropped sweet potato was higher than that of the banana monoculture. The water content of the 10 cm soil layer was the highest, 19.73-32.34%, which was 5.17-14.55% higher than that of the monoculture (11.92-24.19%), and it was 17.19-25.23% in the 5 cm soil layer, which was 2.4-10.66% higher than that of the monoculture soil (11.41-18.28%). Except for in July, the water content in the 20 cm soil layer in the other months was 17.46-26.15%, and the average water content was higher with 1.42-3.49% than that of the monocultured. In addition, from May to October, the soil water content of the 5 cm soil layer of intercropped sweet potato was all higher than that in monoculture, and the highest water content reached 25.23% in June, while it was always less than 20% in the monoculture without any cover. The soil water content in 10 and 20 cm soil layers intercropped with

Table 1. Effects of sweet potato intercropped in banana plantation on soil temperature.

ST (℃)	IC (5cm)	MC (5cm)	TD	IC (10cm)	MC (10cm)	TD	IC (20cm)	MC (20cm)	TD
May	27.67	29.24	-1.57	27.84	29.15	-1.31	27.32	28.91	-1.59
Jun	28.40	31.05	-2.65	28.62	30.75	-2.13	28.15	30.26	-2.11
Jul	28.78	33.33	-4.55	29.24	32.87	-3.63	28.85	32.19	-3.34
Aug	26.83	30.39	-3.56	28.68	30.22	-1.54	28.28	29.93	-1.65
Sept	26.68	28.86	-2.19	28.39	28.86	-0.46	28.09	28.82	-0.72
Oct	20.98	22.59	-1.60	23.85	22.88	+0.97	23.78	23.30	+0.48
Nov	19.19	20.17	-0.98	21.34	20.45	+0.89	21.21	20.84	+0.37

ST, Soil temperature; IC, Intercropping; MC, Monoculture; TD, Temperature difference; Different depths of soil:5cm, 10cm, 20cm

Table 2. Effects of sweet potato intercropped in banana plantation on soil moisture.

SMC (%)	IC(5cm)	MC(5cm)	SMD	IC(10cm)	MC(10cm)	SMD	IC(20cm)	MC (20cm)	SMD
May	20.68	18.27	+2.40	24.63	18.21	+6.41	26.15	22.66	+3.49
Jun	25.23	18.28	+6.95	26.73	17.22	+9.51	25.42	22.64	+2.78
Jul	21.30	16.81	+4.49	19.73	11.92	+7.82	17.46	18.18	-0.72
Aug	24.89	14.87	+10.02	30.09	15.54	+14.55	24.44	21.51	+2.93
Sept	22.07	11.41	+10.66	30.51	17.40	+13.10	24.04	20.65	+3.39
Oct	22.24	16.18	+6.07	32.34	24.19	+8.15	24.64	22.40	+2.24
Nov	17.19	13.33	+3.86	24.79	19.62	+5.17	20.05	18.63	+1.42

SMC, Soil moisture content; SMD, Moisture content difference; IC, Intercropping; MC, Monoculture.; Different depths of soil: 5cm, 10cm, 20cm.

sweet potatoes was higher than 20% in all months other than July, whereas only in October it exceeded 20% in 10 cm soil layer of monocultured banana. Therefore, soil moisture content could be increased effectively by intercropped sweet potatoes in banana plantation.

***Effects of sweet potato intercropped in banana plantation on soil sucrase activity*:** As can be seen from Figure 2, the soil sucrase activity, where sweet potatoes were intercropped was higher than that in the banana monocultured, and the difference reached a significant level($p<0.01$). In May, July and September, the soil sucrase activity of intercropped sweet potato was 2.15 mg g^{-1} $24h^{-1}$, 2.24 mg g^{-1} $24h^{-1}$ and 2.61 mg g^{-1} $24h^{-1}$, respectively, and it was higher in September than that in July but the lowest in May. The sucrase activity in monocultured soil was 0.66 mg g^{-1} $24h^{-1}$, 0.64 mg g^{-1} $24h^{-1}$ and 0.87 mg g^{-1} $24h^{-1}$, respectively, and it was higher in September than that in May but the lowest in July. The highest sucrase activity with intercropped sweet potato and monocultured banana occurred in September, while the largest difference of sucrase activity between the two treatments occurred in July, and the sucrase activity with intercropped sweet potato increased by 250% compared with that of monocultured banana. The results showed that the activity of sucrase in soil could be increased significantly through intercropped sweet potato in banana plantation.

***Effects of sweet potato intercropped in banana plantation on soil catalase activity*:** During the May, July and September, the catalase activities in the soil of intercropped sweet potato with banana were 1.46 ml g^{-1} 20 min^{-1}, 2.31 ml g^{-1} $20min^{-1}$, 2.00 ml g^{-1} $20min^{-1}$, respectively, and it was higher in July than that in September but the lowest in May. Catalase activity in monocultured banana soil was 0.37 ml g^{-1} $20min^{-1}$, 0.76 ml g^{-1} $20min^{-1}$and 0.49 ml g^{-1} $20min^{-1}$, respectively (Fig.3). The soil catalase activity of intercropped sweet potato was significantly higher than that of banana monocultured in the three months. The catalase activity in the soil of banana field with both intercropping and monoculture reached a maximum in July, and the difference in catalase activity between two treatments was the largest in September, and it was increased with 308.16% by intercropping compared with monoculture. The results indicated that the activity of catalase in soil could be increased significantly by sweet potato planted between banana plants.

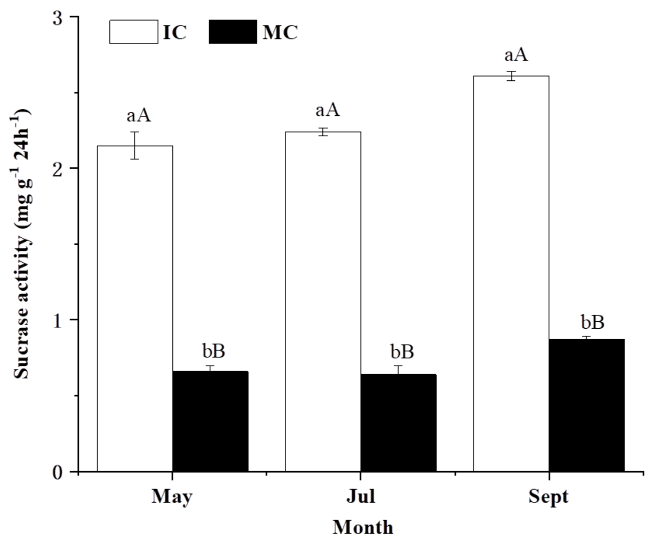

Figure 2. Effects of sweet potato intercropped in banana plantation on soil sucrase activity.

IC, Intercropping; MC, Monoculture; Different lowercase letters and uppercase letters indicate that there are significant differences between treatments in the same month at the levels of $P < 0.05$ and $P < 0.01$, the same below.

***Effects of intercropped sweet potato in banana plantation on soil phosphatase activity*:** During the May, July and September, the phosphatase activity in the soil of sweet potato intercropped with banana was 0.65 mg $100g^{-1}$ $2h^{-1}$, 0.69 mg $100g^{-1}$ $2h^{-1}$ and 0.72 mg $100g^{-1}$ $2h^{-1}$, respectively, and it was higher in September than that in July, while lowest in May. The phosphatase activity in monoculture soil was 0.56 mg $100g^{-1}$ $2h^{-1}$, 0.58 mg $100g^{-1}$ $2h^{-1}$ and 0.60 mg $100g^{-1}$ $2h^{-1}$, respectively, and the trend in enzyme activity over three months was the same as the increasing trend of intercropping from May to September.The soil phosphatase activity with intercropping and monoculture showed a gradual increasing trend, and it was significantly ($p<0.05$) or very significantly(p<0.01) higher with intercropping than that in monoculture. The difference in soil phosphatase activity between two treatments was the greatest in September, when, compared with that in monoculture, it increased with 20.00% in intercropping (Figure 4). The results showed that the soil phosphatase activity could be significantly increased by intercropped sweet potato in banana garden.

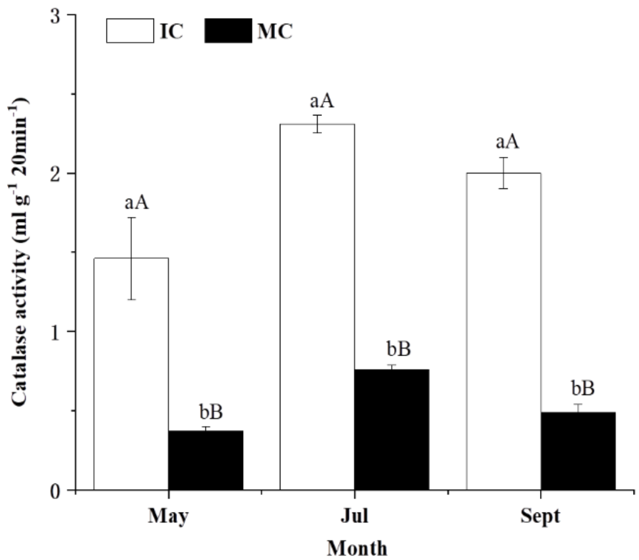

Figure 3. Effects of sweet potato intercropped in banana plantation on soil catalase activity.

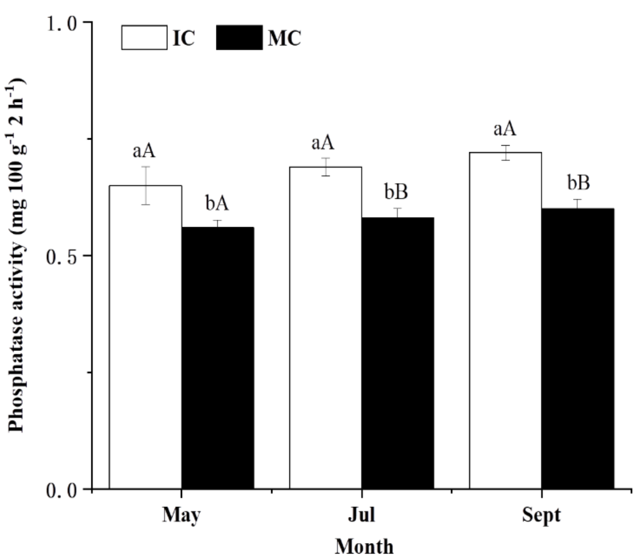

Figure 4. Effects of sweet potato intercropped in banana **plantation on soil phosphatase activity**

Effects of sweet potato intercropped in banana plantation on soil urease activity. During the May, July and September, the soil urease activity with intercropped decreased at first and then increased, while it decreased gradually in the monoculture. In banana intercropped with sweet potato, soil urease was 0.017 mg g^{-1} $24h^{-1}$, 0.013 mg g^{-1} $24h^{-1}$, 0.016 mg g^{-1} $24h^{-1}$, respectively, and it was higher in May than that in September but lowest in July. The urease activity in monoculture soil was 0.013 mg g^{-1} $24h^{-1}$, 0.011 mg g^{-1} $24h^{-1}$, 0.011 mg g^{-1} $24h^{-1}$, respectively, and it was higher in May than that in July, and in July it was equal to that in September. The soil urease activity with intercropping was significantly higher than that of the monoculture, with 45% increased, and its difference between two treatments was the largest in September (figure 5). The results showed that the soil urease activity could be enhanced significantly by intercropped sweet potato in banana garden.

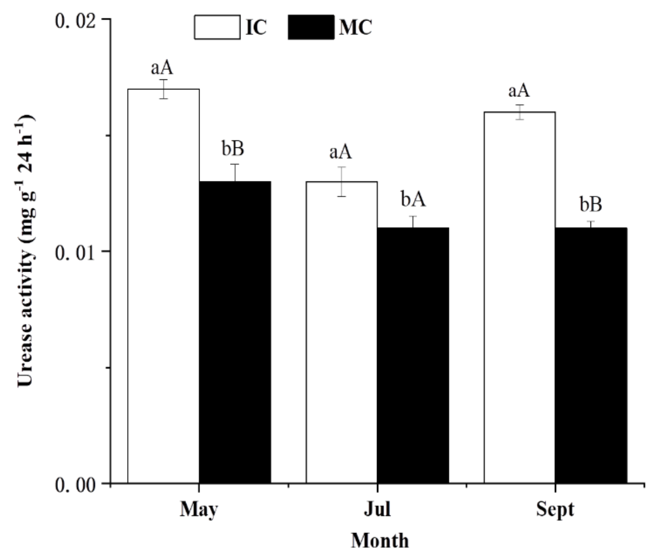

Figure 5. Effects of sweet potato intercropped in banana garden on soil urease activity.

***Effects of sweet potato intercropped in banana plantation on the total nitrogen, phosphorus, potassium and organic matter contents in soil*:** The content of soil organic matter, total nitrogen and potassium could be increased by sweet potato planted in banana field. The soil organic matter content of sweet potato intercropped was higher than that of banana monocultured during the May, July and September, respectively, with 10.64-37.11% increased, and the difference in three months all reached a significant level. In the July and September, the soil total nitrogen content measured in soil of sweet potato intercropped was higher than that of banana monocultured, with an increase of 32.04% and 16.35%, respectively, and the difference reached a significant level, but there was no significant difference in the May.Then in the May, the total potassium content of sweet potato intercropped measured in soil was significantly higher than that of banana monocultured , with an increase of 9.55%, but between two treatments there was no significant difference in July and September. The content of total potassium with intercropped sweet potato increased by 4.15% compared with that of monocultured banana in July (Table 3). The total phosphorus content in banana garden soil was less affected with sweet potato planted, and there was no significant difference between two treatments. The results showed that the contents of soil organic matter, total nitrogen and potassium could be significantly improved by sweet potato intercropped in banana plantation.

***Effects of sweet potato intercropped in banana plantation on the available nitrogen, phosphorus, potassium contents and pH in soil*:** The contents of soil available nitrogen, available phosphorus and potassium could be significantly enhanced by sweet potato intercropped in banana field. During the May, July and September, the available nitrogen content in soil of sweet potato intercropped was higher than that of banana monocultured, increased with 25.39%, 32.15% and 30.51%, respectively, and the differences reached significant or extremely significant levels. The content of available phosphorus was also higher than that of monoculture, increased with 3.56%, 6.46% and 8.29%, respectively. The difference between the two treatments in July and September reached a significant level, but there was no significant difference in May. The available potassium content in soil of sweet potato intercropped in May and July compared with that of banana monocultured increased with 171.04% and 31.16%, respectively, but it was lower than that of banana monocultured in September, decreased with 11.09%, and the difference between two treatments from May to September was extremely significant. In addition, the pH value of soil interplanted with sweet potato increased by 1.66-1.84 compared with that of banana monocultured, and the difference reached a very significant level (Table 4). The results showed that the pH value and the content of soil nutrients such as available nitrogen, available phosphorus and potassium could be significantly increased by sweet potato intercropped in banana field.

***Correlation analysis between soil enzyme activities and soil fertility indexes*:** Soil enzyme activity is closely related with soil physical and chemical properties, temperature and humidity. In this paper, a correlation analysis about enzyme activity, the physical and chemical property index and soil temperature and humidity was carried out. The results showed that the activities of sucrase and phosphatase were significantly positively correlated with organic matter, available phosphorus, available nitrogen, pH and soil moisture, and it was negatively correlated with soil temperature. Catalase activity was significantly positively correlated with organic matter, pH, available phosphorus and nitrogen, and it was significantly positively correlated with available potassium and soil moisture. The urease activity was extremely positively correlated with available nitrogen, pH and soil moisture, and it was significantly positively correlated with available phosphorus, but extremely negatively correlated with soil temperature. In addition, there was an extremely or significantly positive correlation among the activities of sucrase, catalase, phosphatase and urease (Table 5).

DISCUSSION

Suitable soil temperature and moisture conditions are required for crops to grow normally. The suitable soil temperature for root growth of most crops is 20-28℃ (Feng *et al*., 1995a,b), and the soil water content is 20-30%(Hou, 2007). If the soil

Table 3. Effects of sweet potato intercropped in banana plantation on the major nutrient contents in soil.

Month	Treatment	Soil organic matter ($g\ kg^{-1}$)	Total nitrogen ($g\ kg^{-1}$)	Total phosphorus ($g\ kg^{-1}$)	Total potassium ($g\ kg^{-1}$)
May	IC	22.90aA	1.26aA	0.84aA	5.85aA
	MC	19.85bA	1.34aA	0.74aA	5.34bA
Jul	IC	25.79aA	1.36aA	0.81aA	2.76aA
	MC	18.81bB	1.03bB	0.96aA	2.65aA
Sept	IC	22.15aA	1.21aA	1.08aA	2.47aA
	MC	20.02bA	1.04bA	0.92aA	2.51aA

IC, Intercropping; MC, Monoculture; Different lowercase letters and uppercase letters indicate that there are significant differences between treatments in the same month at the levels of $P < 0.05$ and $P < 0.01$, the same below.

Table 4. Effects of sweet potato intercropped in banana field on the contents of available nutrients and pH in soil.

Month	Treatment	Available nitrogen ($mg\ kg^{-1}$)	Available phosphorus ($mg\ kg^{-1}$)	Available potassium ($mg\ kg^{-1}$)	pH
May	IC	92.15aA	118.04aA	197.07aA	6.36aA
	MC	73.49bB	113.98aA	72.71bB	4.52bB
Jul	IC	86.33aA	120.57aA	385.07aA	6.46aA
	MC	65.33bB	113.25bA	293.6bB	4.80bB
Sept	IC	89.83aA	121.96aA	237.53bB	6.33aA
	MC	68.83bB	112.62bB	269.59aA	4.56bB

Table 5. Correlation *analysis* between enzyme activities and nutrient contents, temperature and humidity in soil.

Index	Iase	Case	Pase	Uase	SOM	AN	AP	AK	TN	TP	TK	pH	ST	SM
Iase	1													
Case	0.917**	1												
Pase	0.917**	0.904**	1											
Uase	0.759**	0.518*	0.582*	1										
SOM	0.792**	0.848**	0.700**	0.415	1									
AN	0.916**	0.784**	0.796**	0.863**	0.742**	1								
AP	0.846**	0.828**	0.863**	0.565*	0.673**	0.724**	1							
AK	0.323	0.561*	0.415	-0.254	0.467	0.060	0.264	1						
TN	0.438	0.447	0.323	0.410	0.656**	0.619**	0.425	-0.215	1					
TP	0.178	0.117	0.320	0.073	-0.145	0.037	0.307	0.197	-0.459	1				
TK	-0.056	-0.230	-0.251	0.456	0.001	0.287	-0.113	-.711**	0.495*	-0.410	1			
pH	0.960**	0.933**	0.852**	0.720**	0.836**	0.898**	0.817**	0.390	0.473*	0.148	0.017	1		
ST	-.567*	-0.374	-.552*	-.577*	-0.436	-.647**	-.490*	0.203	-0.423	0.177	-0.306	-0.426	1	
SM	0.717**	0.523*	0.624**	0.813**	0.398	0.773**	0.613**	-0.234	0.452	-0.068	0.300	0.614**	-.754**	1

* and ** denote significant correlation at P<0.05 and P<0.01 level, respectively. Iase, sucrase activity; Case, Catalase activity; Pase, Phosphatase activity; Uase, Urease activity; SOM, Soil organic matter; AN, Available nitrogen; AP, Available phosphorus; AK, Available potassium; TN, Total nitrogen; TP, Total phosphorus; TK, Total potassium; ST, soil temperature (Average value of three soil layers); SM, Soil moisture (Average value of three soil layers).

temperature is too low or too high, the growth of crop roots and their absorption efficiency to soil nutrients will be reduced. If the soil moisture content is too low, the red loam will become firm and hard, and the growth of banana roots would be inhibited. The results of this paper showed that the soil temperature condition was improved and moisture content increased during sweet potato intercropped in banana garden. The reason is that the stems and leaves of sweet potato grown fast, crawled on the ground and covered the soil, the evaporation and loss of soil moisture can be effectively decreased and the scouring effect of heavy rainfall on the topsoil can be reduced in hot summer. At the same time, the temperature of the topsoil was lower than that of banana monocultured in hot season such as July and August since with the stems and leaves of sweet potatoes covering, the soil was not directly exposed to the sun's radiation.

In tropical and subtropical regions, the available nitrogen, phosphorus and potassium contents decreased (Qiu *et al*., 2021; Baptista *et al*., 2015; Kun *et al*.,2002) and the pH value dropped below 5 in soil (Liu *et al*., 2021; Yu *et al*., 2014; Zhang *et al*.,2019) due to the uncovered soil scoured seriously for a lot of rainfall in summer, acidification of soil and increase of humidity was conducive to the proliferation of harmful bacteria such as Fusarium (Gregory *et al*., 2015; Bubici *et al*., 2019; Yao *et al*., 2015; Liu *et al*., 2012). On the other hand, the activities of beneficial microorganisms and the major metabolic enzymes such as urease, catalase, sucrase and phosphatase in banana field was suppressed (Carrino-Kyker *et al*., 2019; Bai *et al*., 2019), thus the degradation of soil organic matter was affected and the available nutrient content decreased (Xiong *et al*., 2015; Acosta-Martínez and Tabatabai, 2000). The results of this study showed that sweet potato interplanted in banana garden had positive effects on improving soil chemical properties such as the available nitrogen, phosphorus and potassium content greatly increased and the activities of main metabolic enzymes were significantly enhanced. The main reason was that the organic matter content in soil increased as the withered leaves and stems of sweet potato returned back to the soil, and the microbial proliferation accelerated and the microbial diversity were enhanced (Wu *et al*., 2021; Wang *et al*., 2016). The content of available potassium in intercropping soil increased in July but decreased significantly in September, which may be due to the higher temperature in July and the withered sweet potato leaves degraded faster. At the same time, the erosion of soil by heavy rainfall and the leaching loss of available potassium was decreased since the topsoil layer with sweet potatos covered. Within a certain temperature range, the temperature raised was conducive to the decomposition of organic matter (Xia and Lu, 2020; Yang *et al*., 2018) while the soil temperature in monoculture in September was higher, which was conducive to the transformation of soil available potassium, thus its content was higher than that of intercropping.

The results in this paper are similar on main enzyme activity, available nitrogen, phosphorus and potassium content in soil with that of sugarcane intercropped with peanut (Shen *et al.*, 2014), maize intercropped with peanut (Li *et al*., 2018) and chestnut intercropped with tea (Zhang *et al*., 2008), etc. But the differences from sweet potato intercropped with corn (Zhang *et al*., 2020) is that the soil phosphatase activity was enhanced greatly in banana intercropped with sweet potato. The reason is that the content of soil organic matter was increased obviously and the proliferation and activity of microorganism were accelerated for sweet potatoes intercropped in banana garden, and the activity of phosphatase directly be regulated by the number and activity of soil micro-organisms (Luo *et al*., 2016; Yu *et al*., 2015).

***Conclusions*:** It may be concluded from the results of this paper that there had positively effects on improving the soil physical and chemical properties and the activity of important metabolic enzyme in banana field by sweet potato intercropped.The soil temperature of sweet potato intercropped in the 5-20 cm soil layer was 0.46-4.55℃ lower than that of banana monocultured in the hot summer, but in the 10 cm and 20 cm soil layers higher with 0.37-0.97℃ than that of monocultured in October and November. The water content in 5-20cm soil layer of sweet potato intercropped was 1.42-14.55% higher than that of banana monocultured. From May to September, the activities of soil sucrase, phosphatase, catalase and urease in sweet potato intercropped were significantly higher than those in banana monocultured and the contents of soil organic matter, total nitrogen, potassium, available nitrogen, soil available phosphorus and potassium were also higher than those in banana monocultured.

***Conflict of Interest*:** The Authors declare that there is no conflict of interest.

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