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Fusarium Wilt Incidence, Growth, Yield and Post-Harvest Quality of Banana as Affected by Organic Farming in Taiwan

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Abstract

Organic banana farming is an alternative to conventional banana production in Taiwan. Results from a 10-year study on organic banana production at the organic farm of the Taiwan Banana Research Institute (TBRI) indicate that average incidence of Fusarium wilt for four Cavendish cultivars was 25.7% for the organic farming system, as compared to 66.9% for the conventional farming system. The lower incidence of Fusarium wilt in the organic system was considered to be associated with a positive change in the properties of the soil. Horticultural parameters at shooting did not show significant differences between organic and conventional banana, except for a lower number of healthy leaves in the organic banana. No differences in the post-harvest quality could be found between organic and conventional banana. A smaller bunch weight was recorded for the organic banana; however, more harvested bunches resulted in a higher overall yield in the organic farming system. Promotion of the organic farming system for adoption by more banana growers could enhance the sustainability of the Taiwan banana industry.

INTRODUCTION

Banana used to be one of the most important agricultural crops in Taiwan. In 1967, Taiwanese bananas accounted for 82% of the banana market in Japan. The same year, the first case of Fusarium wilt (Panama disease) was identified in southern Taiwan. It became widespread in nearly the entire banana-growing area in 10 years, causing huge yield decrease and economic loss to banana growers (Su et al., 1986). The quantity of Taiwanese bananas exported to Japan dropped from over 20 million cartons in the 1960s to less than 1 million cartons in 2008. A further shrinkage (and possibly eventual termination) of the Taiwanese banana export would severely impact the domestic banana market and in turn endanger the sustainability of the Taiwanese banana industry.

Fusarium wilt is a soil-borne disease, and the occurrence and infestation of the pathogen, *Fusarium oxysporum* f. sp. *cubense* (Foc), is closely related to the properties of the soil and improper cultivation practices. Many researchers have pointed out that high diversity in soil microbial conditions could reduce the severity of soil-borne disease incidence through suppressive mechanisms of deactivation, competition, parasitism and antagonism (Granastein, 1998; Ingham, 1998; Schneider, 1982; Sullivan, 2004). To effectively control the devastating Fusarium wilt, focus should be placed on the creation of soil conditions unfavourable to the pathogen and/or possibly favourable for the plants to resist or tolerate invasion of the pathogen; in other words, to improve soil quality and rebuild soil health of the plantation. This concept is true not only for bananas but also for other crops.

To understand how organic farming would affect banana production and alleviate Fusarium wilt incidence in banana plantations through the rebuilding of soil health, the Taiwan Banana Research Institute (TBRI) research team initiated in 1998 a 10-year project on the effect of organic banana farming on Foc incidence. This paper compares Fusarium wilt incidence, growth, yield and post-harvest quality of Cavendish bananas grown in organic and conventional cropping systems in the 9th cropping season in 2007.

MATERIALS AND METHODS

Planting Materials

In 1998, an experimental plot of 0.44 hectares from a 40-year old TBRI banana plantation was divided in two subplots, one for organic farming (ORG), the other for conventional farming (CON). In each of the farming systems, four major Cavendish cultivars (AAA) were planted: the susceptible 'Pei-Chiao', 'Tai-Chiao No 2' and 'Tai-Chiao No 6', and the partially resistant 'Formosana'. In February 2007, suckers of each cultivar were selected for a ratoon cropping.

Fertilisation

In the organic plot, liquid fertiliser fermented from soybean powder, rice bran and rock phosphate was applied once a month. Incinerated ash (K_2O, 26-28%) from oil palm was used biennually at a rate of 3.0 kg per plant as supplementary potassium. Annual supplies of N, P_2O_5 and K_2O for 2007 cropping were 145.5 g, 97.8 g, and 1014 g, respectively. Recycling of the residuum of banana plants of the previous cropping served as sources of organic matter and mineral nutrients.

In the conventional plot, compound fertiliser (11-5.5-22) was applied at a rate of 1.5 kg per plant per annum for the whole growing period. Six split dosages with increasing rate were designed to satisfy the progressive growth of the plants. The total supply of N, P_2O_5 and K_2O was 165.0 g, 82.5 g and 330 g, respectively.

Disease and Pest Control

In the organic plot, a solution made from rice vinegar with hot chili powder and freshly crushed garlic was sprayed for disease and pest control. Deleafing was the major practice to slow down the spread of leaf freckle disease. Both a weed-inhibiting net covering the space between the rows and weed eater were used for weed control.

In the conventional plot, Mancozeb (80% WP) was sprayed to protect leaves from freckle disease. Deleafing was also practiced to avoid the spread of the disease. Carbofuran (3% G) was applied for pest control on the bunch. Glyphosate (41% SL) and Glufosinate-Ammonium (13% SL) were applied alternatively for weed control.

Fruit Protection

Field practices including bagging, irrigation, deleafing, desuckering and propping were done in the same way in two plots. A non-pesticide-impregnated kraft paper bag was put on the bunch as a physical barrier for bunch protection to prevent physical injuries and damage from freckle disease infection, sunburn, scratching and pest attack. Underground water was pumped for irrigation.

Soil and Leaf Sampling

A composite leaf sample was collected for each cultivar at the appearance of the first male flowers for the analysis of leaf nutrient contents (Martin-Prével, 1977). After harvest, a composite soil sample was also taken at depth of 0-20 cm for analysis of physico-chemical and microbiological properties.

Data Analysis

The Statistical Analysis System (SAS Institute, 2003) was used to determine the differences in the growth, yield and post-harvest quality of bananas grown in organic and conventional cropping systems.

RESULTS AND DISCUSSION

Incidence of Fusarium Wilt

For all four cultivars, the incidence of Fusarium wilt was lower in the organic plot than in the conventional plot (Fig. 1). In the organic plot, 'Formosana' had the lowest incidence (2.7%), 'Tai-Chiao No 6' the highest (61.29%), and 'Tai-Chiao No 2' and 'Pei-Chiao' were in between (31.20 and 30.97%, respectively). A similar trend was found in the conventional plot, except for 'Pei-Chiao' which had the highest incidence (95.5%) of all four cultivars. A lower and fairly constant incidence of Fusarium wilt of 24.06%, 25.5% and 25.65% was observed in the organic plot during the cropping years of 2006, 2007 and 2008, respectively, as compared to 52.6%, 63.1% and 66.9% in the conventional plot (Fig. 2). The results revealed that long-term organic farming in banana plantations reduces the Fusarium wilt incidence on Cavendish bananas, and the degree of reduction depends on the cultivar. The reduction was highest for 'Tai-Chiao No 2' and 'Pei-Chiao'.

Shooting Status

Time from planting until 50% of the plants had started shooting was 55, 85 and 35 days earlier in the organic plot for 'Pei-Chiao', 'Tai-Chiao No 2' and 'Tai-Chiao No 6', respectively, as compared with the conventional plot. However, almost no difference was found for 'Formosana'. This indicated that in the conventional plot, Fusarium wilt resulted not only in a loss in yield but also in a delay in the harvesting time.

Leaf Nutrient Contents

No mineral nutrient deficiency symptoms were observed in either the organic or conventional banana plants. Results of the leaf analysis showed sufficient levels of macronutrients and micronutrients for all four cultivars in both the organic and conventional plot.

Horticultural Traits

There were no significant differences at shooting stage between organic and conventional plants of 'Pei-Chiao', 'Tai-Chiao No 2', and 'Tai-Chiao No 6' in terms of plant height and plant girth (Table 1). Number of healthy leaves of organic bananas at shooting stage was significantly lower (by 1.4-2.3 leaves) for all cultivars, indicating that leaf protection for freckle disease using solution of garlic-hot pepper-vinegar in banana plantation was less effective than using chemicals. However, a leaf number greater than ten was sufficient to support nine hands during the bunch development. Hands per bunch

and fingers per hand were significantly lower in the organic 'Formosana' in comparison with the conventional 'Formosana', while the plant girth of organic 'Formosana' was greater than that of the conventional one.

Post-Harvest Quality Attributes

The shelf life of organic 'Formosana' was significantly shorter (by 0.5 days) as compared with conventional 'Formosana'. However, total soluble solids (TSS) of organic 'Formosana' were 0.8 ºBrix higher than that of conventional 'Formosana'. Shelf life and TSS of 'Pei-Chiao' and 'Tai-Chiao No 2' were not affected by the cropping system. Data of 'Tai-Chiao No 6' were missing due to Fusarium wilt.

Bunch Weight and Yield

As indicated in Table 2, the bunch weight of 'Formosana' in the organic plot was significantly lower than that in the conventional plot, while the cropping system did not affect the bunch weight of 'Pei-Chiao', 'Tai-Chiao No 2' and 'Tai-Chiao No 6'. Assuming that the incidence of Fusarium wilt was the only factor causing yield loss, the ratios of estimated yield and production value for organic and conventional 'Pei-Chiao' were far greater than for 'Tai-Chiao No 2', 'Tai-Chiao No 6' and 'Formosana'. This is an indication that in a Fusarium wilt-infected 'Pei-Chiao' plantation, organic production may give higher profit than conventional production. More than double of the profit for the conventional plot was also obtained for 'Tai-Chiao No 2' and 'Tai-Chiao No 6'. Economically, in a conventional plantation, 'Formosana' could be the most profitable substitute for cultivars 'Pei-Chiao', 'Tai-Chiao No 2' and 'Tai-Chiao No 6'. In addition, growing 'Formosana' in organic plantation had the greatest potential for creating the best profit.

Soil Properties

There was a similar trend in the variability over time of soil organic matter, pH and EC for both the organic and conventional plots (Fig. 3). An increase of soil organic matter with time indicated the accumulation of soil organic matter from growing banana, and the rate of increase was higher in the organic plot (Fig. 3a). Likewise, a slight increase in electrical conductivity with time was found in the organic and conventional plots (Fig. 3b). Despite the small difference in initial soil pH of the two plots (Fig. 3c), the conventional plot tended to drop from 6.7 to 5.5, while the organic plot remained relatively stable at a level of 7.5, resulting in a large difference of nearly two units after 10 consecutive years of cultivation.

Soil mineral nutrients – especially micronutrients – were higher in the organic plot than in the conventional plot, except for iron. Soil bulk density of the organic plot was lower than that of the conventional plot (Table 3). Aggregate stability and microbial biomass nitrogen were higher in the organic plot; however, microbial biomass carbon was lower in the organic plot. On average, the population density of soil microorganisms, including *Streptomycetes*, bacteria, free nitrogen-fixing bacteria, and phosphate- and calcium-solubilising bacteria were higher in the organic plot than in the conventional plot, except for soil fungi, indicating the effects of organic farming on the activation of soil microbial ecology and the amount of beneficial soil microorganisms (Table 4).

CONCLUSION

Fusarium wilt of banana has caused serious damage to the Taiwan banana industry during the last 40 years. Our results indicate that banana cultivation management in an organic way could produce organic bananas comparable to conventional bananas in terms of horticultural traits, yield and post-harvest quality. Organic banana production could give higher profit than conventional banana production. Results from soil analysis suggested that organic farming practices posed positive integrated effects on soil properties, presenting evidence that maintaining soil biological diversity and good soil health help reduce the incidence of Fusarium wilt (Akehurst, 2008).

Among the tested cultivars, 'Formosana' exhibited the highest resistance to Fusarium wilt. To achieve the highest profit, it is recommended that 'Formosana' be planted and managed by organic farming practices in a Fusarium wilt-infected plantation. More importantly, it is proven that adopting organic farming practices for banana production would be a good strategy against degeneration of plantation soils, which offers the potential to improve the sustainability of the Taiwan banana industry by lowering the damage from Fusarium wilt. This research also implicated that organic banana production in Taiwan is technically feasible, economically profitable and environmentally healthy.

ACKNOWLEDGEMENTS

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Figures

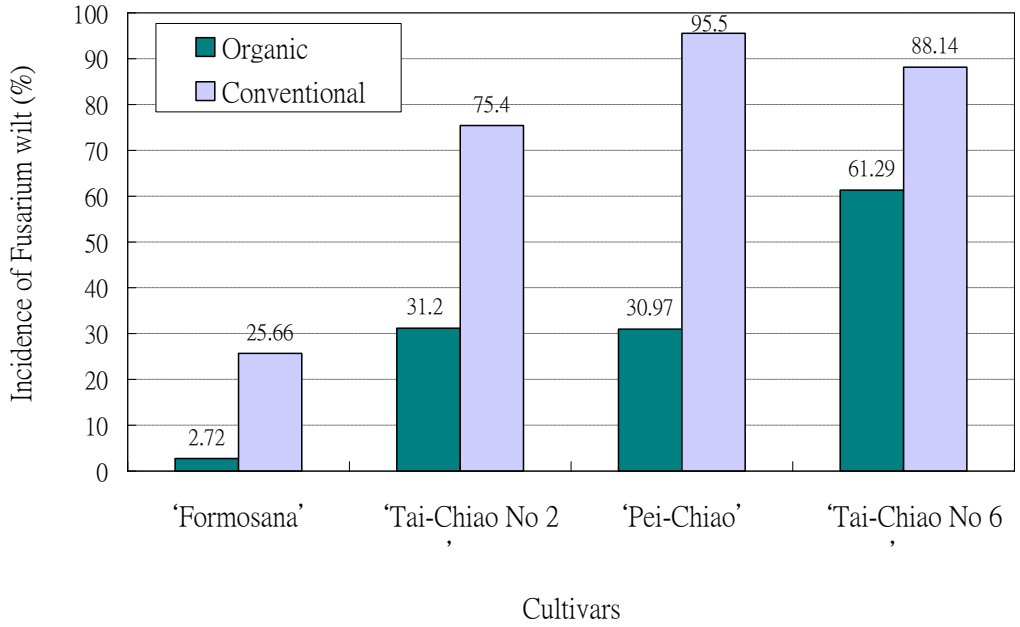


Fig. 1. Fusarium wilt incidence of four banana cultivars in organic and conventional cropping systems.

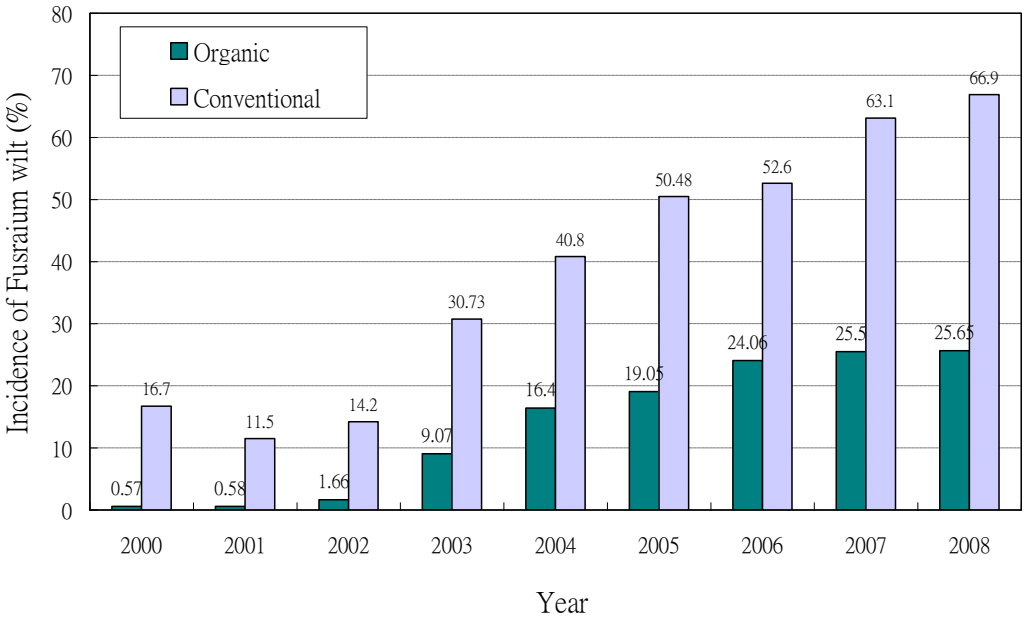
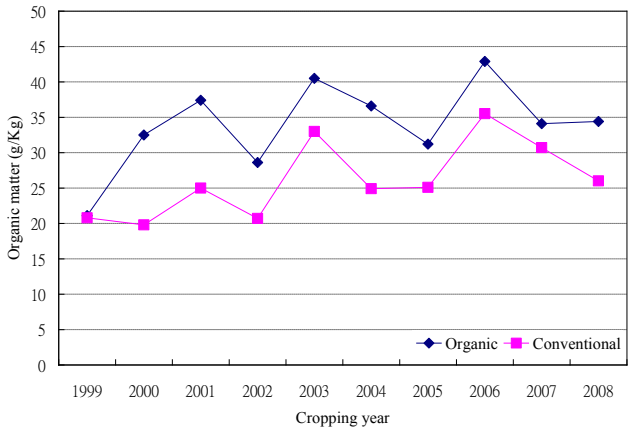
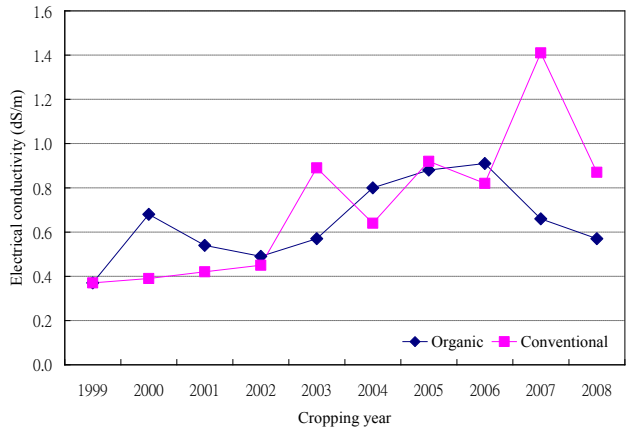


Fig. 2. Fusarium wilt incidence of organic and conventional ratoon banana plantations.





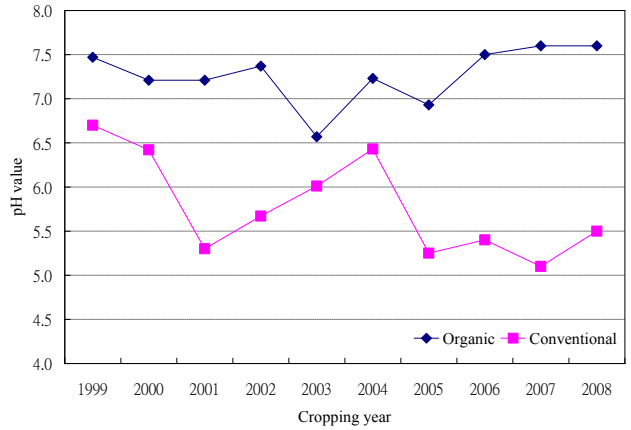


Fig. 3. Temporal variability in a) soil organic matter; b) EC and c) pH of organic and conventional plots.

Tables

Table 1. Horticultural traits of banana at shooting stage in organic (ORG) and conventional (CON) cropping systems.

Cultivar	Plant height (cm)		Plant girth[1] (cm)		No. of healthy leaves		Hands per bunch		Fingers per hand	
	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON
Pei-Chiao	319.4a	305.5a	77.4a	75.0a	11.1b	12.5a	8.6a	8.7a	152.9a	153.8a
Tai-Chiao No 2	281.8a	282.5a	80.2a	75.7a	10.7b	13.0a	9.3a	8.7a	176.2a	174.2a
Tai-Chiao No 6	299.8a	304.0a	85.4a	85.6a	11.6b	13.3a	10.6a	10.7a	208.2a	244.7a
Formosana	318.9a	320.2a	92.8a	87.1b	11.4b	13.0a	9.7b	10.9a	166.1b	204.9a

[1] Pseudostem circumference at 50 cm high.

The same letter under same parameter for each cultivar indicates insignificant difference in t-test analysis (α=0.05).

Table 2. Estimated yield and production value of banana in organic (ORG) and conventional (CON) plots.

Cultivar	Incidence of Fusarium wilt (%)		Bunch weight (kg)		Estimated yield[1] (t/ha)		Estimated production value[2] (NT$[3]/ha)		Index (ORG/CON)	
	ORG	CON	ORG	CON	ORG	CON	ORG	CON	Yield	Production value
Pei-Chiao	30.97	95.54	24.7a	22.3a	30,69	1,79	859,341	22,736	17.1	37.8
Tai-Chiao No 2	31.15	75.40	24.3a	26.2a	30,11	11,60	843,220	147,337	2.6	5.7
Tai-Chiao No 6	61.30	88.10	30.2a	33.6a	21,04	7,17	589,197	91,096	2.9	6.5
Formosana	2.72	25.66	28.7b	31.5a	50,25	42,15	1,407,136	535,315	1.2	2.6

[1] Planting density at 1,800 plants/ha.

[2] Calculated at 28 and 12.7 (on average) New Taiwan dollars (NT$) per kilogram of organic and conventional bananas, respectively.

[3] New Taiwan Dollars, one US$ is approximately equivalent to 33 NT$.

Table 3. Selected soil physical and biological properties of organic (ORG) and conventional (CON) plots[1].

Cropping system	Aggregate stability	Bulk density	Microbial biomass carbon	Microbial biomass nitrogen
	(%)	(Mg/m^3)	(g/kg)	(mg/kg)
ORG	0.2	0.92	1.78	2.63
CON	0.17	1.20	1.82	1.35

[1] Soil sampled on 1 July 2008 after harvest.

Table 4. Population density of soil microorganisms in organic (ORG) and conventional (CON) plots[1].

Cultivar	Streptomycetes		Bacteria		Free nitrogen-fixing bacteria		Fungi		Phosphate- and calcium-solubilising bacteria	
	10^5 CFU g^{-1} soil									
	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON
Pei-Chiao	170	80	270	120	270	90	130	69	26	12
Tai-Chiao No 2	150	160	260	140	210	120	90	150	14	14
Tai-Chiao No 6	200	160	300	220	110	130	64	150	36	25
Formosana	150	39	190	160	80	54	80	90	15	26
mean	168	110	255	160	168	99	91	115	23	19

[1] Soil sampled on 1 July 2008 after harvest.