Banana root and soil health project - Australia

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Abstract

The banana plant forms an adventitious root system that is dependent on soil physical, chemical and biological properties to function efficiently. A pot experiment demonstrated that increasing soil compaction was able to significantly reduce the weight of banana roots and shoots. However, in the presence of *Radopholus similis* the effects of soil compaction were obscured, due to the significant reduction in root weight caused by the nematode.

The use of a basic set of soil quality indicators that can be readily used by farmers, was linked to soil nematode indicators to determine relationships between soil properties. In a survey of banana fields in North Queensland, different diameter root classes were affected differently by changing soil properties. Banana roots greater than 5 mm diameter were positively correlated with aggregate stability and negatively correlated with soil bulk density. Banana roots less than 1 mm were positively correlated with electrical conductivity. Specific interactions between soil properties become apparent as crop production systems become more uniform. This allows farmers to prioritise management options to improve the most deficient soil health indicators.

The addition of organic amendments is one possible method of correcting degrading soils. The use of amendments with high carbon contents, such as grass hay, banana trash and alfalfa hay, were able to significantly suppress *R. similis* in the roots of banana plants relative to untreated soil. Due to banana production being located near environmentally sensitive areas there is an increasing need to monitor and modify soil management practices. However, this needs to be linked with a framework that allows the integration of all soil components with a system to allow continual improvement in soil management to allow banana production to have minimal impact on the surrounding environment.

Resumen - Proyecto sobre salud del suelo y raíces de banano - Australia

La planta de banano forma un sistema radical adventicio que depende de las propiedades físicas, químicas y biológicas del suelo para su buen funcionamiento. Un experimento en macetas demostró que el aumento de la compactación del suelo fue capaz de reducir significativamente el peso de las raíces del banano y de los rebrotes. Sin embargo, en presencia de *Radopholus similis* los efectos de la compactación fueron dudosos debido a la significante reducción en el peso radicular causada por los nematodos.

El uso de un grupo básico de indicadores de calidad del suelo, que puede ser fácilmente usado por los agricultores, fue correlacionado a indicadores de nematodos en el suelo para determinar las relaciones existentes entre las propiedades del suelo.

En un diagnóstico de suelos bananeros en el norte de Queensland, diferentes clases de diámetro de raíces fueron afectadas diferentemente al cambiar las propiedades del suelo. Raíces de banano con diámetros mayores a 5 mm fueron correlacionadas positivamente con la estabilidad de los agregados del suelo y negativamente correlacionadas con la densidad total. Raíces de banano menores de 1 mm

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fueron correlacionadas positivamente con la conductividad eléctrica. Interacciones específicas entre las propiedades del suelo se hicieron más aparentes a medida que los sistemas productivos de los cultivos fueron más uniformes. Esto permite a los agricultores priorizar las opciones de manejo, para mejorar los indicadores de salud del suelo más deficientes. La aplicación de enmiendas orgánicas es un posible método para corregir suelos degradados. El uso de enmiendas con alto contenido de carbono, tales como heno de pasto, residuos de banano y heno de alfalfa, fueron capaces de suprimir significativamente a *R. similis* en las raíces de las plantas de banano en comparación con suelos no tratados. Debido a que la producción de bananos está localizada cerca de áreas ambientalmente sensibles, existe una necesidad creciente de monitorear y modificar las prácticas de manejo de suelos. Sin embargo, esto necesita estar ligado a un marco de referencia que permita la integración de todos los componentes del suelos en un sistema que permita el continuo mejoramiento del manejo de suelos para asegurar que la producción bananera tenga un impacto mínimo en el ambiente que le rodea.

Introduction

The banana plant forms an adventitious root system that is wide spreading, unbranched, shallow and gives rise to a dense mat (Blake 1969, Price 1995). The function of banana roots is to provide anchorage, absorption of water and nutrients and synthesis of some plant hormones (Price 1995). The growth of roots is an important factor contributing to banana productivity and is dependent on soil physical, chemical and biological properties (Delvaux 1995). It is suggested that increased size and altered architecture may improve both resource acquisition and anchorage of banana plants, creating a more efficient root system (Price 1995). The condition of the soil has large impact on the development of the root system, with heavy or compacted soils restricting root growth (Araya and Blanco 2001, Price 1995). There are also biological constraints to the development and function of the banana root system such as *Radopholus similis* (Gowen and Queneherve 1990, Gowen 1995, Fogain 2001, Moens *et al*. 2001).

Delvaux (1995) suggested that soil fertility (health), was a poorly defined concept that not only relied on soil chemical, physical and biological properties, and their interaction with the plant community, but on management practices, farming skills and economics. Doran and Parkin (1996) defined soil health as “the capacity of a soil to function within an ecosystem and land use boundary, to sustain biological productivity, maintain environmental quality and promote plant and animal health”. Van Bruggen and Semenov (2000) suggested a healthy soil is a stable soil with resilience to stress, high biological diversity and internal cycling of high amounts of nutrients. Knowledge of the function of the soil ecosystem is a basic requirement for soil stewardship (Ferris *et al*. 2001).

Nematodes are a component of the soil ecosystem that interacts with biotic and abiotic soil factors (Yeates 1979). Because of this interaction, nematodes are excellent bio-indicators of soil health, because they form a dominant group of organisms in all soil types, have high abundance, high biodiversity and play an important role in recycling within the soil (Neher 2001, Schloter *et al*. 2003). Nematodes are heterotrophs, higher in the food chain than micro-organisms and so serve as integrators of soil properties related to their food source, predators and parasites (Ferris *et al*. 2001, Neher 2001). Nematode diversity tends to be greatest in ecosystems with the least disturbance (Yeates 1999). The disturbance to the soil by environmental or land management practices changes the composition of nematodes (Bongers 1990, Yeates and Bongers 1999, Ferris *et al*. 2001). There are a number of indices derived from nematode community analysis that can be used to determine the impact of management changes on the soil ecosystem (Bongers 1990, Yeates and Bongers 1999, Ferris *et al*. 2001).

However, the use of nematodes as indicators of soil ecosystem health and banana management is not a practical tool for farmers, as it requires specialised knowledge and equipment (Neher 2001). Doran (2002) suggested linking "science to practice" in assessing the sustainability of land management practices, by the use of simple indicators of soil quality and health that have meaning for farmers. To embrace changes in environmental management of their land, farmers need to understand why they need to change (Marsh 1998). The best way to achieve this is by the use of participatory research strategies using simple on-farm techniques (Freebairn and King 2003, Lobry de Bruyn and Abbey 2003). A basic set of soil quality indicators was developed by J.W. Doran (USDA-ARS, Lincoln, NE), and developed into an on farm test kit (http://soils.usda.gov/sqi/soil_quality/assessment/kit2.html). The basic set of soil parameters has been used to measure the effects of changes in soil management on agricultural crops (Sarrantonio et al. 1996, Stamatiadis et al. 1999) but not on bananas.

If advances are to be made in improving the efficiency of the banana root system there needs to be a link between indicators and more complex soil processes. Nematodes as integrators of soil properties, linked with chemical, physical and biological indicators may increase our understanding of soil management to improve the efficiency of the banana root system. The Banana Root And Soil Health (BRASH) project aims to highlight for farmers limits of the present banana soil management techniques, provide tools and indicators to measure soil health and potential solutions to overcome soil limitations to create a more efficient banana root system.

Materials and methods

Impact of soil compaction

A pot experiment was designed to determine the impact of soil compaction on the roots of banana plants (*Musa* AAA cv. 'Williams'). The density of soil in 10 L plastic pots was adjusted by adding perlite to field soil to achieve a bulk density of 1.00 and 1.25 g/cm^3 or compacted by compressing moist field soil in the pots around a banana plant to achieve a bulk density of 1.50 and 1.75 g/cm^3. Half of the plants were inoculated with 2390 motile *R. similis*, 7 days after planting. Each treatment was replicated 8 times in a completely randomized design. The plants were maintained in the glasshouse at 20-30^{o}C and were watered by misting twice daily for 15 minutes. The banana plants were fertilized by adding 5 g of Osmocote Plus Mini™ (16.0:3.5:9.1 + trace elements, Scotts Australia Pty Ltd) at planting.

The banana plants were harvested after 12 weeks. Plant growth parameters, including shoot dry weight, were measured by drying the shoots at 70^{o}C for three days at harvest. A transverse section through the soil next to the plant was made and the number of roots greater than 2 mm in diameter originating from the corm were counted. The roots were then washed free of soil and the fresh root weight determined for different root diameter classes, > 5 mm, 1-5 mm and < 1 mm diameter (Araya and Blanco 2001). Nematodes were extracted from the root system in a misting cabinet for seven days (Hooper 1986) and quantified under a compound microscope.

Banana soil health survey

Soil health measurements

A soil health survey method was developed using basic soil quality indicators (Sarrantonio *et al.* 1996, http://soils.usda.gov/sqi/soil_quality/assessment/kit2.html). On site evaluation of water infiltration was measured with aluminium infiltration rings (150 mm d x 125 mm) inserted 75 mm into the soil. The ring was placed 100 mm from the follower sucker of the banana plant, so that it was in line with the follower sucker and the mother plant. Soil respiration was measured from the head space of the covered infiltration rings for 30 min using CO_2 gas sampling tubes (0.01-2.6%, 126SA, Kitigawa, Japan) before determining water infiltration rates. The ring was then inserted level with the soil surface and excavated. All roots within the ring were washed free of soil and banana roots were divided into classes, > 5 mm, 1-5 mm and < 1 mm diameter (Araya and Blanco 2001) and expressed as the weight of root in one litre (dm^3) of soil.

A second aluminium ring (75 mm d x 125 mm) was inserted into the soil until level with the soil surface. The ring was excavated from the soil and the soil within the ring was used in the laboratory determination of soil bulk density, gravimetric water content and aggregate stability (Sarrantonio *et al*. 1996). Additionally, soil pH and electrical conductivity (EC), were determined in a 1:1 soil-water mixture. Soil nitrate-N was determined from the filtered extract of the soil water mixture using test strips (Aquacheck™, Hach company, Loveland, USA). A 200 g sub-sample was used for nematode community analyses by placing the sub-sample on a single ply of tissue in water for 1 day (Whitehead and Hemming 1965). The community structure was determined using the method described by Yeates (2001). The nematodes were further subdivided into functional guilds and nematode indices calculated (Yeates and Bongers 1999, Ferris *et al*. 2001).

Further observations made in the field included soil temperature (100 mm depth), presence or absence of earthworms, finger number per bunch (Turner *et al*. 1988), leaf emergence rate and height increase of the follower sucker and the amount of banana trash on the soil surface around the banana plant.

Paired site survey

A survey compared soil and plant measurements (described above) made around banana plants with undeveloped plant systems, such as rainforest and pasture. Four sites in north Queensland were compared, located at East Palmerston, Mission Beach, Tully and Kennedy. The sites represented the major banana growing regions and soil types used in banana production in north Queensland. An organic farm was also included in the survey at the Mission Beach site. At each site, five samples were taken from each plant system.

Banana farm survey

Twenty-one banana fields were surveyed using the methods described above, in the major banana production zone of north Queensland. At all sites sampled, banana farms were more than three years old and the cultivars were members of the Cavendish subgroup (*Musa* AAA). In each farm, five samples were collected.

Banana field survey

An eight year old banana field (*Musa* AAA cv. 'Williams') near Innisfail, north Queensland was surveyed nine times beginning in October 2002. The sampling occurred monthly and five banana plants were sampled on each occasion.

Soil amendments

A pot experiment was established in 10 L plastic containers using three soils from different banana growing areas of north Queensland. The soils were amended with the equivalent of 40 tonnes/ha of grass hay, alfalfa hay, banana trash, mill mud, mill ash (by-products of sugar cane processing), paunch (cattle rumen contents), bio-solid, or municipal waste compost (MW compost). Additional treatments of 120 t/ha of mill ash, 5 t/ha of wolastonite (calcium silicate) and 300 L/ha of molasses were compared with an untreated control. The chemical composition of the amendments was determined (Table 1).

A banana plant (*Musa* AAA cv. 'Williams') was grown in each pot. Half of the pots were inoculated with 860 motile *R. similis* 3 days after planting the bananas. All treatments were replicated four times in a randomized block design. The plants were maintained in the glasshouse at 20-30°C and were watered by misting twice daily for 15 minutes. Trays were placed at the base of the pots and water collected in the trays returned to the soil surface. The banana plants were fertilized by adding 5 g of Osmocote Plus Mini™ at planting.

The plants were harvested after 12 to 15 weeks from planting. The shoot dry weight was determined as described previously. The fresh root weight was determined by washing the soil from the roots and allowing the roots to drain on absorbent paper. Nematodes were then extracted from the root system in a misting cabinet for seven days (Hooper 1986) and quantified under a compound microscope.

Statistics

Nematode numbers from pot experiments were transformed, ln(x+1), before conducting analysis of variance. Means were separated using the least significant difference (LSD) method and presented as back transformed values. Linear correlations between soil properties were determined for the three surveys. Soil health properties that were significantly correlated ($P<0.05$) were linked using a concept map. All statistical analyses were performed using Genstat 6 (version 6.1.0.205)

Results

Impact of soil compaction

The weight of banana roots and shoots declined significantly as the soil bulk density increased (Figure 1). However, the addition of a disease-causing organism such as *R. similis* obscured the effects of soil compaction causing a significant ($P<0.05$) reduction in the weight of banana roots (Figure 1). The difference in root weight caused by *R. similis* was greater at lower than higher bulk densities (Figure 1). There was a significant decline in shoot weight of bananas with increasing soil bulk density in the absence of *R. similis*. However, when *R. similis* was present there was no significant relationship

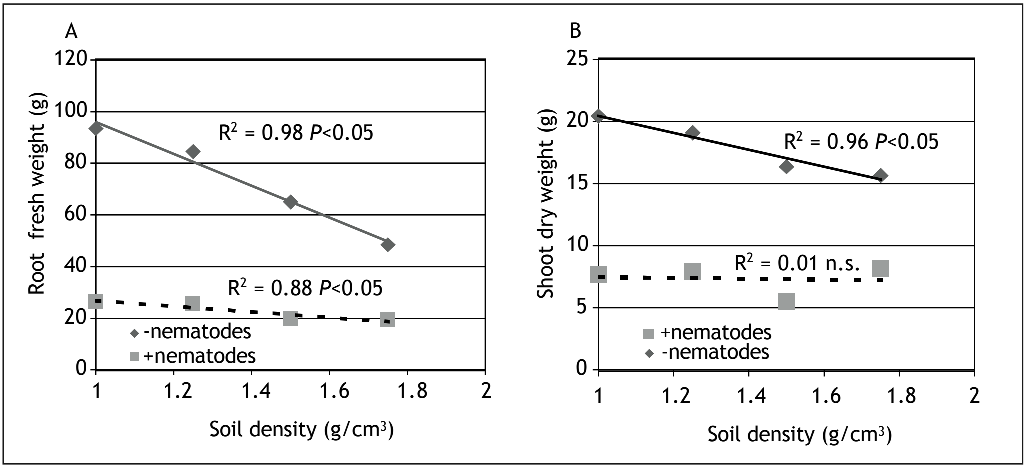

Figure 1. Effects of increasing soil density on banana root fresh weight (A) and shoot dry weight (B) in the presence and absence of *R. similis*.

between shoot weight and soil bulk density (Figure 1). The weight of roots less than 5 mm in diameter were reduced with increasing soil bulk density (Table 2). Similarly, the number of roots greater than 2 mm in diameter originating from the corm was reduced with increasing soil bulk density (Table 2).

Banana soil health

Paired site survey

Banana soils tended to be dominated by plant-parasitic nematodes relative to undeveloped plant systems (Table 3). This contributed to the lower nematode diversity (H′) in the soil (Figure 2). Aggregate stability tended to be lower on banana producing soils relative to soils in the undeveloped plant systems (Table 3). Aggregate stability was negatively correlated with the amount of nitrate-N in the soil (Figure 2), with banana farms tending to have high soil nitrate-N relative to undeveloped sites, except at the Mission Beach site (Table 3). Electrical conductivity (EC) appeared to be a central indicator of many soil properties (Figure 2). Higher EC was evident on banana farms relative to undeveloped sites, except at Mission Beach (Table 3). Lower EC favoured fungal domination in the soil with nutrients being decomposed by fungal pathways, determined by the channel index (determined by the nematode community analyses as a resource decomposition pathway, Ferris *et al*. 2001)(Figure 2).

Banana farm survey

The soil properties on the banana farms exhibited a greater number of significant relationships than comparing different plant systems (Figures 2 and 3). Again, the soil nematode community on banana farms was dominated by plant-parasitic nematodes and low nematode diversity (Table 4). The proportion of plant-parasitic nematodes in the soil was negatively correlated with other nematode feeding types, nematode diversity and increased the nematode dominance index (Figure 3).

Table 1. Chemical composition of amendments applied to soil before growing bananas in pots.

Soil amendment	Nutrient (%)								C:N ratio	Nutrient (mg/kg)					
	N	P	K	Ca	Mg	S	Na	C		Cu	Zn	Mn	Fe	Al	B	Si
Biosolid	0.81	0.39	1.50	0.97	0.77	0.64	2.24	7.1	8.7	14.9	95	180	330	90	54	1.38
MW compost	1.85	0.28	0.15	32.0	0.19	0.13	0.05	29.0	15.7	56.8	120	83	670	2200	11	15.86
Mill Mud	1.44	0.39	0.54	6.30	0.23	0.40	0.52	19.8	13.7	248.0	460	270	13000	11000	< 0.3	15.7
Mill Ash	0.30	0.27	0.28	0.70	0.16	0.05	0.01	19.4	64.7	32.4	76	930	13000	38000	< 0.3	25.35
Banana trash	1.82	0.35	2.00	1.50	0.72	0.10	0.40	46.8	25.7	59.3	110	1300	24000	55000	< 0.3	2.31
Grass hay	2.28	0.29	3.20	0.49	0.16	0.54	0.76	44.7	19.6	9.0	22	190	170	140	5.9	1.29
Alfalfa hay	3.16	0.25	1.70	1.70	0.52	0.35	0.30	45.8	14.5	6.1	15	61	880	700	45	0.63
Molasses	0.50	0.06	3.80	0.72	0.25	0.43	0.04	-	-	2	8.8	70	350	110	2.7	-

Table 2. Banana root measurements in soil at different soil bulk densities.

Soil bulk density (g/cm^3)	Fresh root weight (g/L)				Corm root number
	>2 mm	Total roots	>5 mm	1-5 mm	<1 mm
1.00	60.0 c	0.3 n.s.	30.2 b	29.4 b	5.1 bc
1.25	54.9 bc	0.9 n.s.	27.8 b	26.2 b	5.8 c
1.50	42.4 ab	0.1 n.s.	19.8 a	22.5 ab	4.0 b
1.75	33.9 a	0.3 n.s.	17.3 a	16.2 a	2.1 a

Means with the same subscript within a column are not significantly different at the 5% level. Values are the means of 16 plants with and without *R. similis*.

Table 3. Properties (mean ± standard error) of soil quality indicators and nematode communities comparing banana cultivation to undeveloped plant systems at four locations in north Queensland.

Location	East Palmerston		Mission Beach			Tully			Kennedy	
Vegetation	Banana	Pasture	Banana	Organic	Rainforest	Banana	Rainforest	Pasture	Banana	Rainforest
Indicators					*Chemical*					
NO3-N (kg/ha)	24±7	6±1	15±2	16±1	43±10	109±42	60±4	28±14	76±36	31±7
pH	6.5±0.2	5.4±0.1	5.2±0.1	5.5±0.3	4.6±0.1	5.5±0.3	4.3±0.2	4.1±0.1	4.3±0.3	5.2±0.1
EC soil (dS/m)	0.25±0.04	0.04±0.00	0.11±0.02	0.30±0.03	0.22±0.02	0.38±0.09	0.13±0.01	0.07±0.01	0.40±0.162	0.21±0.01
					Physical					
Temperature (C°)	24.6±0.1	26.1±0.1	20.9±0.2	20.9±0.1	20.4±0.1	18.9±0.1	18.5±0.3	20.2±0.1	19.4±0.2	19.6±0.0
Infiltration rate (s)	11±4	161±16	82±13	65±6	49±20	791±359	1195±320	1800±0	122±23	39±13
Soil water (g/g)	0.39±0.02	0.34±0.01	0.25±0.01	0.32±0.01	0.29±0.01	0.30±0.010	0.33±0.01	0.42±0.01	0.15±0.02	0.14±0.01
Bulk density (g/cm^3)	0.86±0.02	0.91±0.01	1.12±0.01	1.04±0.02	1.07±0.02	1.12±0.06	1.03±0.02	1.06±0.01	1.24±0.01	0.92±0.05
Aggregate stability (%)	62±1	66±3	62±2	76±1	78±2	20±4	71±4	74±3	41±5	80±5
					Biological					
Soil Respn (kg CO_2.ha^{-1}.d^{-1})	7.3±0.7	12.6±1.13	5.1±0.47	4.5±0.21	6.1±0.56	7.1±1.00	8.7±0.39	15.2±1.60	5.9±0.37	5.1±0.32
Root weight (g/L)	11.3±3.2	21.0±3.5	9.0±1.1	16.0±3.3	19.8±5.7	9.4±4.9	11.3±1.1	35.1±5.3	13.6±5.1	26.8±2.8
Soil surface trash (g/m^2)	40±16	79±8	1.3±1.0	83±27	47±15	159±37	21±2	--	135±29	154±14
					Nematode proportions					
Plant parasitic (%)	82±5	44±4	91±3	28±7	18±1	55±6	57±3	19±4	74±9	14±5
Bacterial feeding (%)	13±4	20±2	6±2	18±3	33±3	23±6	13±2	26±2	17±6	47±4
Fungal feeding (%)	2±1	11±2	1±0	15±4	9±1	3±1	7±1	8±2	4±1	11±2
Predatory (%)	0±0	2±1	1±0	23±4	7±1	5±1	9±1	5±1	1±1	6±1
Plant associated (%)	0±0	12±2	0±0	2±1	14±1	7±1	7±1	30±7	3±2	10±1
Omnivorous (%)	3±2	10±1	2±1	15±4	20±2	6±3	7±2	12±3	2±1	12±2
					Nematode indices					
Shannon-Weiner (H')	1.39±0.10	1.93±0.08	0.76±0.15	1.76±0.08	2.24±0.08	1.80±0.10	2.21±0.07	2.00±0.05	1.39±0.19	2.23±0.07
Dominance (λ)	0.33±0.03	0.23±0.03	0.10±0.08	0.17±0.01	0.13±0.01	0.20±0.03	0.09±0.02	0.18±0.02	0.35±0.04	0.15±0.02
Bacterial.(Bact+Fung)$^{-1}$	0.78±0.08	0.50±0.06	0.68±0.06	0.37±0.05	0.53±0.03	0.69±0.08	0.46±0.05	0.56±0.04	0.70±0.07	0.67±0.03
Structural index	50±10	62±5	73±9	84±5	85±1	62±15	79±4	77±6	43±13	68±3
Enrichment index	63±5	51±5	82±4	67±5	83±3	82±5	66±6	82±4	70±5	77±3
Channel index	9.1±2.6	38.3±4.2	6.3±3.1	28.8±7.6	9.4±1.5	8.1±4.0	30.1±9.1	10.9±2.3	15.6±4.5	10.4±1.5

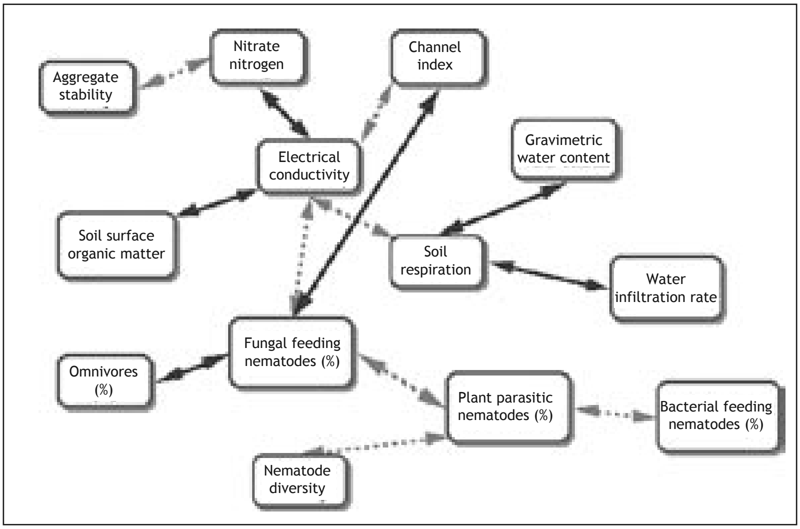

Figure 2. Significant (P<0.05) correlations between soil properties and nematode community analysis comparing banana cultivation with undeveloped plant systems in north Queensland. Dashed lines (---) depict a negative relationship, solid lines (____) depict a positive relationship.

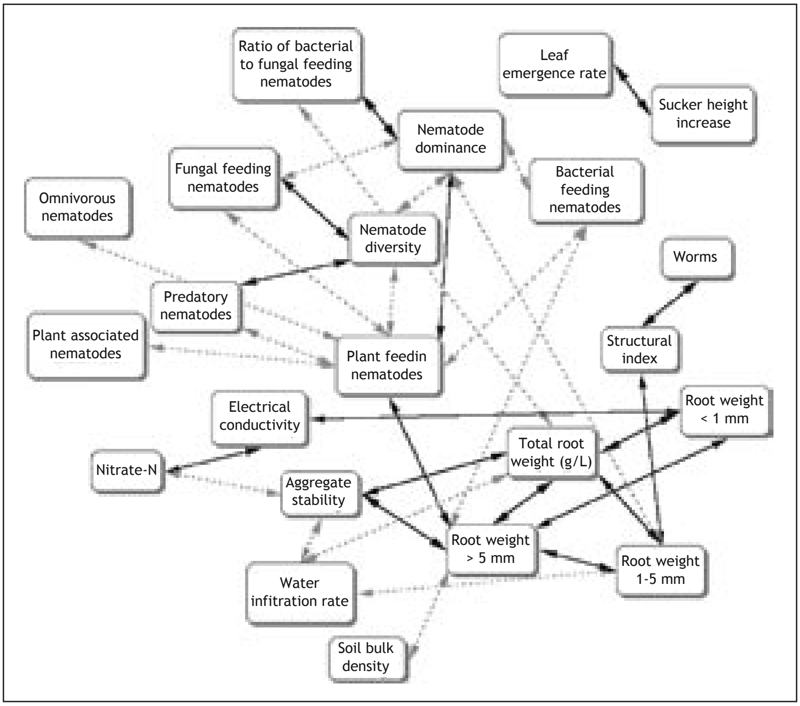

Figure 3. Significant (P<0.05) correlations between soil properties and nematode communities within 21 banana fields in north Queensland. Dashed lines (---) depict a negative relationship, solid lines (____) depict a positive relationship.

The total weight of banana roots was made up of the different root diameter classes (Figure 3). However, roots of different diameters were affected by different soil properties. Roots greater than 5 mm were negatively correlated with soil bulk density and the proportion of bacterial feeding nematodes, but were positively correlated with aggregate stability and the proportion of plant feeding nematodes in the soil (Figure 3). The weight of roots 1-5 mm was positively correlated with the structure index (determined by the nematode community analyses as a measure of the trophic layers and potential for opportunists, Ferris *et al*. 2001), but negatively correlated with nematode dominance and water infiltration rates (Figure 3). Roots less than 1 mm in diameter were positively correlated with electrical conductivity (Figure 4). Aggregate stability was again negatively correlated with nitrate-N amounts in the soil (Figure 4). There was

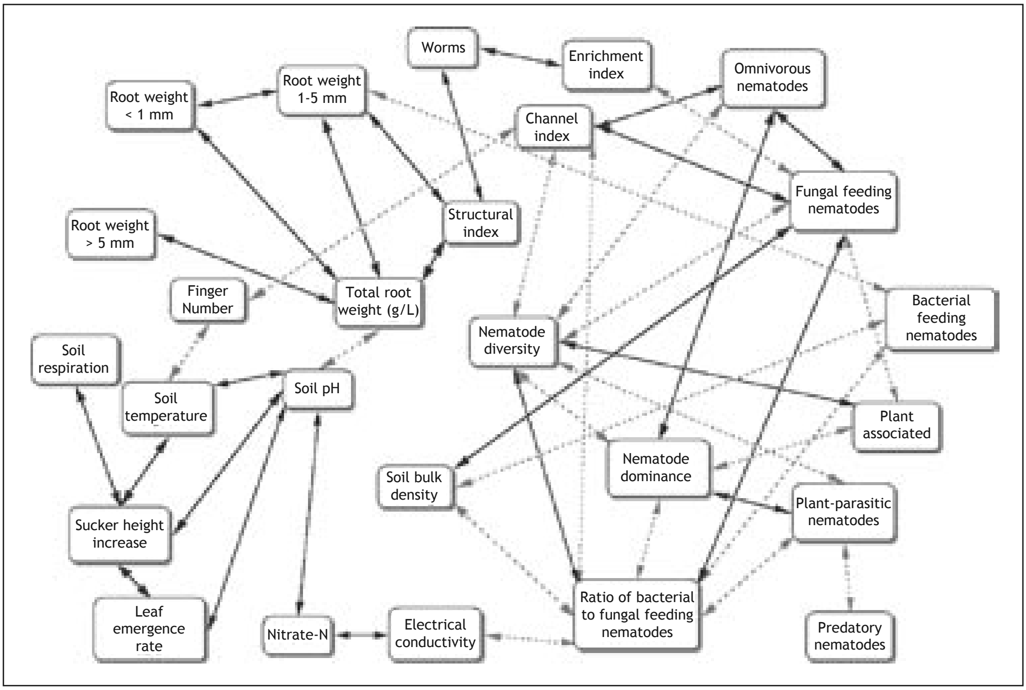

Figure 4. Significant (P<0.05) correlations between soil properties and nematode communities within a banana field in north Queensland sampled monthly 9 times since October 2002. Dashed lines (---) depict a negative relationship, solid lines (____) depict a positive relationship.

no correlation between soil factors and plant production parameters (Figure 4), which suggested that farmer management of the crops may be able to obscure poor soil and root characteristics.

Banana field survey

In a single banana field there was an increasing number of relationships between soil properties (Figure 4). Plant parasitic nematodes were not the dominant trophic nematode group at this site (Table 5). The structure index (Ferris *et al*. 2001) was positively correlated with the total weight of roots and the weight of roots between 1-5 mm (Figure 4). The channel index (33) was almost double the banana industry average (19), which suggested that fungi were more important in the recycling of nutrients even though bacterial feeding nematodes dominated the nematode community (Table 5). The site also had low soil nitrate-N (14 kg NO_3-N.ha^{-1}), approximately half of the north

Table 4. Properties (grand mean ± standard error) of soil quality indicators and nematode communities of 21 banana fields in north Queensland, n=105.

Soil property	Mean	±Standard error
Physical properties		
Soil temperature (°C)	24.2	0.5
Water infiltration rate (secs)	448	108
Gravimetric soil water (g/g)	0.25	0.02
Soil bulk density (g/cm^3)	1.11	0.03
Aggregate stability (%)	43.9	4.2
Chemical properties		
Electrical conductivity (dS/m)	0.25	0.04
pH	6.13	0.16
No_3-N (kg/ha)	32.9	6.6
Biological properties		
Soil respiration (kg CO_2-C ha^{-1} d^{-1})	6.53	0.30
Worms (0=absent, 1=present)	0.4	0.1
Banana measurements		
Finger number per bunch	133	9
Leaf emergence rate (leaves/week)	0.50	0.04
Sucker height increase (m/week)	0.06	0.01
Total root weight (g/L)	8.19	0.83
Root weight >5 mm (g/L)	3.19	0.40
Root weight 1-5 mm (g/L)	2.45	0.24
Root weight <1 mm (g/L)	2.56	0.41
Surface trash (t/ha)	8.1	1.1
Soil nematodes		
Plant parasitic nematodes (%)	61.7	4.8
Bacterial feeding nematodes (%)	21.5	2.5
Fungal feeding nematodes (%)	4.5	1.1
Predatory nematodes (%)	4.2	0.9
Plant associated nematodes (%)	2.0	0.9
Omnivorous nematodes (%)	6.1	1.1
Nematode indices		
Shannon-Weiner diversity index H′	1.11	0.09
Dominance λ	0.37	0.04
Bacterial.$(\text{Bacterial+Fungal})^{-1}$	0.82	0.03
Structural index	60.3	3.1
Enrichment index	68.3	2.6
Channel index	18.6	4.3

Queensland industry mean (33 kg NO_3-N.ha^{-1}), which meant that recycling of nutrients is more important to supply nitrogen for crop production at this site (Tables 4 and 5).

The site was measured over different environmental conditions and soil temperature was positively correlated with the increase in follower sucker height and soil pH and negatively correlated with bunch finger number (Figure 4). This suggested that seasonal fluctuations may impact more on crop production than on soil characteristics and obscure effects of soil health on crop production.

Table 5. Properties (grand mean ± standard error) of soil quality indicators and nematode communities within a banana field in north Queensland sampled 9 times at monthly intervals from October 2002.

Soil property	Mean	±Standard error
Physical properties		
Soil temperature (°C)	25.5	0.8
Water infiltration rate (secs)	350	129
Gravimetric soil water (g/g)	0.27	0.01
Soil bulk density (g/cm3)	1.13	0.01
Aggregate stability (%)	47.6	2.4
Chemical properties		
Electrical conductivity (dS/m)	0.18	0.02
pH	6.47	0.29
NO3-N (kg/ha)	13.6	1.9
Biological properties		
Soil respiration (CO_2-C ha^{-1} d^{-1})	5.6	0.4
Worms (0=absent, 1=present)	0.4	0.1
Banana measurements		
Finger number per bunch	101	6
Leaf emergence rate (leaves/week)	0.7	0.1
Sucker height increase (m/week)	0.07	0.02
Total root weight (g/L)	6.59	0.89
Root weight >5mm (g/L)	1.77	0.47
Root weight 1-5mm (g/L)	2.53	0.38
Root weight <1mm (g/L)	2.29	0.36
Surface trash (t/ha)	5.2	0.7
Soil nematodes		
Plant parasitic nematodes (%)	23.6	2.7
Bacterial feeding nematodes (%)	37.0	4.6
Fungal feeding nematodes (%)	19.2	3.6
Predatory nematodes (%)	7.0	1.8
Plant associated nematodes (%)	1.8	0.8
Omnivorous nematodes (%)	11.3	2.1
Nematode indices		
Shannon-Weiner diversity index H′	1.56	0.09
Dominance λ	0.24	0.02
Bacterial.(Bacterial+Fungal)$^{-1}$	0.65	0.07
Structural index	67.7	5.5
Enrichment index	61.8	4.3
Channel index	33.1	7.7

Means are calculated from 45 samples.

Soil amendments

The addition of mill mud (40 tonnes/ha) or mill ash (120 tonnes/ha) significantly increased the weight of banana roots relative to the untreated control (Table 6). However, only the addition of mill mud was able to significantly increase the shoot weight (Table 6). The addition of biosolids to the soil significantly reduced the weight of banana roots and shoots (Table 6).

R. similis numbers within the roots of bananas were significantly suppressed when grass hay, alfalfa hay, mill mud and banana trash were added to the soil (Table 6).

Table 6. Effects of applications of soil applied amendments on R. similis numbers in the roots of bananas and the weight of banana roots and shoots.

Amendment	Rate (t/ha)	Nematodes in 100 g root	Shoot dry weight (g)	Root fresh weight (g)
Untreated	-	10 046 d	17.8 bcd	53.8 bc
Bedminster	40	7 449 d	18.1 bcd	54.8 bcd
Biosolid	40	3 935 bcd	11.6 a	36.0 a
Grass	40	1 734 b	21.2 cde	61.4 bcde
High ash	120	3 931 bcd	22.0 de	71.4 de
Low ash	40	5 452 cd	21.1 cde	52.9 abc
Lucerne	40	569 a	15.7 ab	50.5 abc
Mill mud	40	2 121 bc	25.9 e	75.9 e
Molasses	300 L/ha	8 847 d	16.6 bc	46.1 ab
Paunch	40	4 354 bcd	17.5 bcd	45.6 ab
Trash	40	1 778 b	24.5 e	66.9 cde
Wolastonite	5	9 661 d	16.8 bc	56.4 bcd

Means with the same letter within a column are not significantly different at the 5% level.

There was no interaction between soil type and the amendments, which suggested that the effects of the amendments would be the same on banana growth and *R. similis* in banana producing soils of north Queensland.

Discussion

The health of the banana root system is linked to the conditions of the soil in which the plants grow. Complex interactions between soil physical, chemical and biological properties can be mapped to gain a greater understanding of the interactions of crop production and soil health under specific soil conditions. As the cropping systems and conditions in which the plants are grown become more uniform, the interactions within the soil become more distinct. This was seen in moving from a survey of different plant systems, to a survey of banana growing systems finally to a single banana field (Figures 2, 3 and 4).

Skilful farm management can mask the deterioration of the soil and obscure interactions of soil components to obtain profitable banana production. It is not until the plant is placed under stress that soil degradation becomes apparent within the banana production system. The time needed for the soil to respond and overcome an imposed stress may be one method of determining the health of the soil (van Bruggen and Semenov 2000). Damage to banana roots by *R. similis* can be interpreted as a stress on the soil ecosystem. The nematode is capable of significantly reducing the root system of banana plants even in favourable physical soil conditions (Figure 1). Therefore, improved biological and chemical management of the soil appear as important in suppressing nematode damage to banana roots as developing an extensive root system.

Tools and indicators are needed to measure changes in soil properties to prevent soil degradation. The basic soil quality indicators (Sarrantonio *et al.* 1996, http://soils.usda.gov/sqi/soil_quality/assessment/kit2.html) used in the BRASH project showed relationships with nematode indicators (Yeates and Bongers 1999, Ferris *et al*. 2001). This suggested that simple tools can indicate more complex soil processes. The tools can be used to depict how farmer's soil management decisions can have 'flow on' effects that are not easily recognisable. In the survey of banana farms in north Queensland the accumulation of soil nitrate was positively correlated with EC and negatively correlated with aggregate stability (Figures 2 and 3). Aggregate stability in turn was negatively correlated with water infiltration rates, which were negatively correlated with the total weight of banana roots (Figure 3). As EC increased so did the weight of roots less than 1 mm diameter. It could be proposed that as EC increased the banana plant produced more fine roots, possibly to absorb the readily available nitrate-N. Therefore, the use of nitrate-N fertilisers in the short term may produce higher yields, however, the long-term effects may lead to soil degradation as aggregates become less stable. Excessive soil nitrogen has also been linked with increased soil-borne diseases in crops due to the lack of microbial diversity (van Bruggen and Termorshuizen 2003). This requires further investigation in banana production.

Abawi and Widmer (2000) suggested that soil-borne diseases are most damaging when soil conditions are poor as a result of inadequate drainage, poor soil structure, low organic matter, low soil fertility and high soil compaction. However, effects of soil health on the suppression of soil-borne diseases need to be extrapolated to the banana field. Management of the soil microbial environment may be able to reduce the susceptibility of bananas to soil-borne diseases. Increasing the nematode diversity in the soil was negatively correlated with the proportion of plant-parasitic nematodes (Figures 2, 3 and 4). The addition of soil amendments high in carbon was found to suppress *R. similis* in a pot experiment (Tables 1 and 6). Similarly, Stirling *et al.* (2003) found that amendments with high C:N ratios are the most effective in enhancing biological control activity against plant-parasitic nematodes. One possible mechanism for the suppression of plant parasitic nematodes is that there are a variety of nematode parasitic fungi in the soil that use nematodes as a source of nitrogen (Stirling *et al*. 2003). Conditions in the field need to be manipulated to increase soil organisms that suppress plant-parasitic nematodes. This has been promoted as longer control than the use of chemicals (Widmer *et al*. 2002) and may promote a more efficient banana root system.

One important soil characteristic that is not easily measured is soil organic carbon. Widmer *et al.* (2002) suggested that maintenance of high concentrations of organic matter, especially the active fraction, greatly improves the physical, chemical and biological properties of soils leading to increased productivity. Tropical soils used in banana production tend to have high soil water contents and high soil temperatures, which are favourable for organic matter decomposition (Sikora and Stott 1996). Additionally, intensive cultivation of the soil in preparation for planting bananas in north Queensland may also be reducing soil carbon. A simple on farm test to determine soil organic carbon is needed to allow monitoring and linking in to other soil health indicators.

The commercial production of bananas in monoculture, using the same clone, makes commercial bananas susceptible to pests and diseases due to the lack of diversity. Yeates (1999) found that plant communities were responsible for dictating soil nematode communities. The use of ground-cover plants may be one method of increasing the diversity around the banana root system and improving soil physical, chemical and biological properties. The mechanized method of banana cultivation in north Queensland would allow mowing of ground-cover plants to return organic matter to the banana soil ecosystem. The choice of species is important and ideally would be deep rooted, allowing the capture of nutrients that escape the banana root system, shade tolerant and capable of withstanding waterlogging and traffic.

The use of soil health indicators needs to be linked with a framework of continual crop and environmental improvement, to support management decisions if farmers are to make advances in environmentally responsible soil management. However, soil management issues may be specific to individual farming systems. Heisswolf *et al.* (2003) designed a process that valued farmer's motives, knowledge and experience, was participative and encouraged farmers to identify their own environmental issues within an economic perspective. This process could be linked with the tools and indicators used in monitoring soil health and allow farmers to understand the effects their management is having on soil health. However, soil management must be seen as a holistic system, made up of physical, chemical and biological components that cannot be separated.

The health of the banana root system is strongly reliant on soil health determined by soil physical, chemical and biological properties. The soil properties are linked within the soil ecosystem, so that subtle management changes can have long-term effects leading to soil degradation and future problems with banana production. The BRASH project aims to involve farmers in changing soil management practices by demonstrating the impact that soil degradation, such as soil compaction, has in reducing banana root development. BRASH develops simple tools for farmers to monitor the trends in soil health and provides solutions to correct adverse trends, such as the use of soil amendments. However, due to complex interactions occurring in the soil and the long time frame needed to detect changes in soil indicators, a framework for integrating and managing all of the components is required if sustained changes in environmental management practices are to occur. Most banana production world-wide is in environmentally sensitive of areas. Therefore, responsible soil management is needed to ensure that banana production remains socially and economically viable with minimal impact on the surrounding environment.

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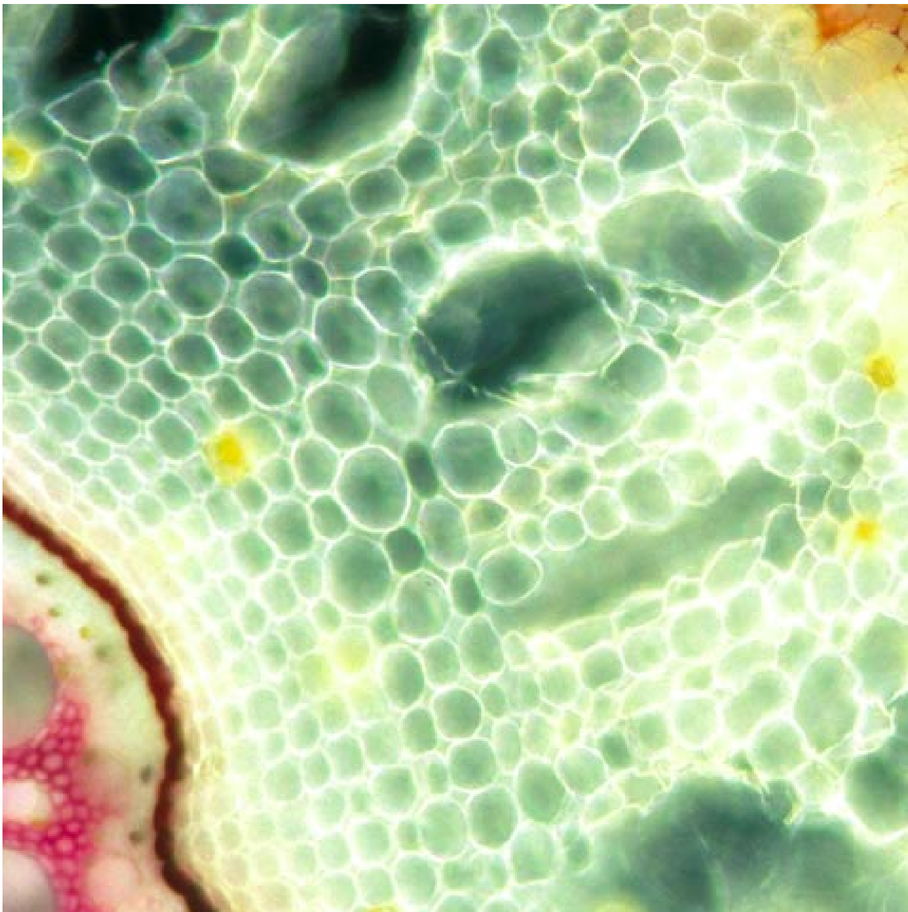
Banana Root System: towards a better understanding for its productive management

Proceedings of an international symposium held in San José, Costa Rica, 3-5 November 2003

Sistema Radical del Banano: hacia un mejor conocimiento para su manejo productivo

Memorias de un simposio internacional, San José, Costa Rica, 3-5 noviembre 2003

David W. Turner and Franklin E. Rosales, editors



INIBAP – International Network for the Improvement of Banana and Plantain

The mission of INIBAP is to sustainably increase the productivity of banana and plantain grown on smallholdings for domestic consumption and for local and export markets.

The Programme has four specific objectives:

- To organize and coordinate a global research effort on banana and plantain, aimed at the development, evaluation and dissemination of improved cultivars and at the conservation and use of *Musa* diversity
- To promote and strengthen collaboration and partnerships in banana-related research activities at the national, regional and global levels
- To strengthen the ability of NARS to conduct research and development activities on bananas and plantains
- To coordinate, facilitate and support the production, collection and exchange of information and documentation related to banana and plantain.

INIBAP is a network of the International Plant Genetic Resources Institute (IPGRI), a Future Harvest centre.

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*MUSA*LAC was created under the umbrella of FORAGRO on 6 June 2000 in Cartagena de Indias, Colombia, following the signing of a Constitution Agreement. *MUSA*LAC is composed of 15 national research and development institutions representing their respective country (Bolivia, Brazil, Colombia, Costa Rica, Cuba, Ecuador, Honduras, Jamaica, Mexico, Nicaragua, Panama, Peru, Puerto Rico, Dominican Republic and Venezuela) and 4 regional/international institutions (CATIE, CIRAD, IICA and INIBAP). The main objective of *MUSA*LAC is to increase the productivity and competitiveness of the plantain and banana commodity chain through scientific and technological development by strengthening national research and development programmes, facilitating exchanges between stakeholders and prioritizing and coordinating actions in Latin America and the Caribbean. *MUSA*LAC is led by a Steering Committee composed of one representative from each member country; one President and two Vice-presidents and an Executive Coordinator, which is INIBAP-LAC, headquartered at CATIE in Turrialba, Costa Rica.

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- To establish jointly with the Costa Rican Government, banana policies to help maintaining the industry on the long term.
- To centralize banana information to promote and facilitate the participation of the banana sector in research and technological development of the banana sector.

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Cover illustration: Transverse section of a mature root of 'Williams' (*Musa* AAA, Cavendish) showing aerenchyma development in the mid cortex. (Credit: Michael W. Shane).

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Reconocimientos

La Red Internacional para el Mejoramiento del Banano y el Plátano (INIBAP) y la Corporación Bananera Nacional (CORBANA, S.A.), organizadores del Symposium Internacional "Sistema radical del banano: hacia un mejor conocimiento para su manejo productivo", agradecen a los patrocinadores y colaboradores quienes, con su contribución, hicieron posible el desarrollo de este evento tan importante para el beneficio del sector bananero mundial.

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Contents

Preface

The fruit of bananas and plantains (*Musa* spp.) being delicious and the aerial parts of the plant spectacular, it is easy to overlook the root system that supports them. Many scientists have commented on our limited knowledge of banana and plantain roots. However, those who work on root systems, especially in plantations, are aware that a huge effort is needed to extract even a small piece of information.

This volume contains papers presented during the International symposium on the 'Banana Root System: towards a better understanding for its productive management' held in San José, Costa Rica, in November 2003. Although root health is a universal preoccupation, the idea to hold a symposium on the topic follows from concerns expressed by the banana producing/exporting sector, especially Romano Orlich, President of the National Banana Corporation from Costa Rica. CORBANA asked INIBAP to work with them in exploring solutions to the problems of the banana root system. This Symposium shows that the private and public sector can share a research agenda.

The objective of the symposium was to present the state of the art knowledge on the functioning of the *Musa* root system and its interrelationships with micro-organisms and pests, and to propose ways to improve root health. The demand for this kind of information is increasing because of the need to prevent deterioration of root health, which contributes to a steady decline in production in many commercial farms of Latin American and the rest of the world. The papers present work done on cells as well as whole plants, and short-term studies as well as ones that cover many years and multiple locations. An appreciation of these differences in scale is important because knowledge gained about root tissues in short-term experiments, for example, needs to be integrated with our knowledge at higher levels of plant organization and over longer time scales. Similarly, laboratory results on root structure and function, and on roots and microbes, need to be compared with results from field experiments. Only by facilitating interactions between people working at different scales, will we increase our understanding of banana and plantain root systems, in the laboratory as well as in the field. This is exciting in its own right, and provides the basis for sound management decisions needed to sustain our markets and our environment.

Work on banana and plantain root systems is usually done within the broader international framework of research on root systems in plants. This is a valuable approach. Good progress is being made on evaluating the impact of the pests that attack the root system. We are learning about the importance of having a soil that is amenable to management, such as drainage, irrigation and fertilization. We should not push this knowledge aside as we explore other aspects of root performance. On the other hand, we are making slow progress in understanding the role of genetics in the functioning and architecture of the banana root system. Indeed, we have yet to ask the question: what sort of root system do we want for banana plants? The answer may be somewhat different, according to the local situation, but there will be some general principles as the plants will always need water, nutrients and being able to stay upright! These answers may help us see clearly what is important and help us focus on how best to achieve our objectives. In the final session of the symposium, the participants produced an outline on the way ahead. These points reflect a consensus following the diversity of ideas and information presented during the symposium.

We would like to thank the contributing authors for their insights into the problem, and INIBAP and CORBANA for bringing us together and making this publication available worldwide. We hope that these proceedings will stimulate readers into exploring how this knowledge might be translated into improved management practices.

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Objective

Present and discuss actual knowledge about and new insights into the functioning of the *Musa* root system, the interrelation with micro-organisms and pests, and propose alternatives to improve root health.

Objetivo

Presentar y discutir el conocimiento actual y nuevos puntos de vista sobre el funcionamiento del sistema radical de *Musa*, la interrelación con microorganismos y plagas, y presentar alternativas para mejorar la sanidad del sistema radical.

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