7 Integrated Pest Management of Banana

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7.1 INTRODUCTION

Bananas (*Musa* spp.) are plagued by a variety of nonmicrobial pests. Most attention has focused on the banana weevil *Cosmopolites sordidus* Germar and a complex of plant-parasitic nematodes, of which the burrowing nematode *Radopholus similis* Cobb Thorne has received the most attention. However, banana is grown widely across tropical and subtropical regions, attracting a wide range of associated pests. These can vary greatly according to geography and clone, while changes in cropping practices and the introduction of new or unfamiliar cultivars can introduce new pest species. In addition, banana serves varying purposes, ranging from the genetically diverse production systems of subsistence foods to commercially managed plantations of genetically uniform dessert bananas for export markets. For example, flower and fruit pests that cause cosmetic damage are of limited importance to subsistence cooking bananas but can result in refusal of export shipments when detected in even low numbers. Often, the management of pests is discussed in the context of integrated pest management (IPM). IPM, however, is often misused, referring instead to a plethora of ill-linked management options that can at times still be at the research stage. Within this chapter, therefore, the full spectrum of banana production systems will be taken into account when discussing the vast diversity of banana pests, while providing an important assessment on how IPM principles can be applied to manage them.

7.2 PLANT-PARASITIC NEMATODES

7.2.1 An Overview of Nematode Species and Their Distribution

Plant-parasitic nematodes are the most detrimental soil-borne pests of banana (Gowen et al., 2005). On a global basis, the key pest species are *Helicotylenchus multicinctus* (Cobb) Golden, root knot nematodes *Meloidogyne* spp. (Figure 7.1), the root-lesion nematode *Pratylenchus coffeae* Sher and Allen, *Pratylenchus goodeyi* Sher and Allen, and *R. similis* (Coyne, 2009). Other species not generally viewed as key pests may, however, be of local significance such as the reniform nematode *Rotylenchulus reniformis* Linford and Oliveira or *Hoplolaimus pararobustus* Schuurmans Stekhoven and Teunissen Sher. Virtually without exception, species occur in mixed communities.

Radopholus similis has been considered as the most damaging nematode affecting bananas worldwide, especially in lowland tropical areas (Sarah, 2000). However, this perception has essentially stemmed from the nuisance *R. similis* poses to commercial dessert banana plantations, where it has wreaked havoc and resulted in the substantial application of carbamate- and organophosphate-based pesticides (Cianco and Mukerji, 2009). Consequently, *R. similis* has traditionally been the main focus in breeding programs. In subsistence farming systems, though, the situation is less clearly defined. The nematode is thermophobic and in the tropics does not occur at high, cool altitudes, above 1400 m in the East African highlands (Price, 2006) where a substantial proportion of Africa's banana production is concentrated, nor does it occur at high latitudes, such as Taiwan and the Canary Islands (Jones, 2009). *R. similis* was previously the key nematode pest species in West Africa (Speijer and Fogain, 1999), but recent surveys show *P. coffeae* is often the most damaging species (Coyne, 2009). Since *P. coffeae* is also prevalent across the Pacific and Southeast Asia, it is

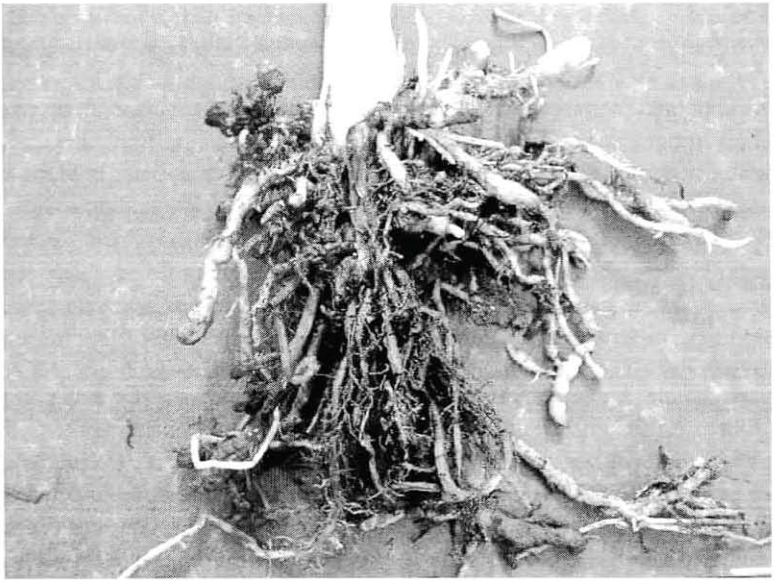

FIGURE 7.1 Root knot nematodes in banana (Courtesy of D. Coyne.)

of concern for banana and requires a greater attention in respect to pest management and resistance breeding.

Pratylenchus goodeyi, on the other hand, is viewed as thermophilic, and in the East African highlands, for example, replaces *R. similis* as the dominant species above 1400 m altitude (Speijer and Fogain, 1999). Its status as a pest of banana, however, is unclear. It can occur in extremely high densities, such as on banana in Tanzania (Speijer and Bosch, 1996) and enset in Ethiopia (Peregrine and Bridge, 1992), where it undoubtedly causes some damage. In Rwanda and Uganda, however, no correlation could be established between *P. goodeyi* and cooking banana losses (Gaidoshova et al., 2009; D. Coyne, unpublished). It is also interesting that *P. goodeyi* represents a major pest in commercial banana plantations in the Canary Islands (De Guiran and Vilardebo, 1962) and in Australia (Pattison et al., 2002) where prevailing temperatures tend to be higher than is optimal for this species. Recently, *P. goodeyi* was identified from bananas in Kenya. Further examination of *P. goodeyi* from toppled bananas on the Kenyan coast and the Canary Islands using molecular techniques demonstrated distinct molecular differences of these nematodes compared with *P. goodeyi* from the highlands of Uganda (Coyne and Waeyenberge, 2008). Results indicated that the "tropical" (Kenyan) *P. goodeyi* were more closely linked to *P. crenatus* Loof, *P. penetrans* Cobb, and *P. neglectus* Rensch than *P. goodeyi*, even though they physically resembled *P. goodeyi*. Within-species variability is a well-known phenomenon, which can explain differences in virulence and host range of some species (Starr et al., 2002). There are good reasons to separate certain strains into separate species, such as for the *P. coffeae* complex, which hitherto was a single species based on morphology (Duncan et al., 1999). For *R. similis*, studies have demonstrated that a series of different strains exist, with the Sri Lanka strain responsible for the severe damage to Ugandan bananas, amongst the most aggressive (Price, 2006), and able to overcome the resistance present in cv 'Yangambi Km5' (Plowright, 2000; Dochez, 2004). Such variability and diagnostic difficulties have significant implications to the development of management programs, especially for the use of resistance through breeding programs. Knowledge of the key pests and access to sources of resistance against these species and their variable strains are essential to make progress in managing these pests.

Helicotylenchus multicinctus is regularly associated with losses to banana, but almost exclusively in combination with other nematode species, especially *R. similis* and *Meloidogyne* spp. (Gowen et al., 2005). Its status has been subject to speculation, as determining the contribution of the individual nematode species to damage and losses is often difficult. Accumulating evidence, however, demonstrates that *H. multicinctus* is indeed responsible for large proportions of damage to banana production, even when other species are present (Ssango et al., 2004).

Meloidogyne spp. are amongst the most abundant nematode pests across all crops, with a global distribution. Their importance on bananas has been underestimated as they also regularly occur in combination with other damaging species (Gowen et al., 2005). However, in some instances they dominate the nematode populations and contribute significantly to production losses.

7.2.2 Nematode Damage

Nematodes generally cause damage through the destruction of root and rhizome tissue. Damaged tissue becomes necrotic and dies, reducing nutrient and water uptake, reducing bunch weights, and retarding harvest. Severe damage underscores plant anchorage, which can result in plant toppling (Sarah, 2000; Jones, 2009), while reduced plant turgidity can result in snapping of plant stems during periods of low water availability (D. Coyne, unpublished). Fruit on fallen plants generally have no value, resulting in extreme yield losses where infection levels and plant losses are high (Gowen et al., 2005). Common symptoms of severe nematode infection include stunting, poor plant growth, narrow and weak stems, foliar chlorosis, root rotting and galling, and plant toppling. Determining infestation levels can be difficult, especially to the untrained, as nematodes exist below ground and remain out of sight, until severe damage symptoms are observed. Nematodes almost always occur as species combinations that may be complex. Establishing the specific species contributions to damage is difficult, resulting in complications for developing management options that may be species specific.

7.2.3 Nematode Management

The discrepancy between management options for smallholders and commercial growers is vast. Nevertheless, nematodes remain a difficult group to manage effectively. However, because new infestations are primarily perpetuated through infected planting material, the use of clean, healthy, nematode-free planting material cannot be overemphasized for either system. Hot water treatment of suckers after removal of infected roots is a simple and effective technique for sanitizing material. For smallholder systems, this technique has been further adapted using a short 30 s exposure period in boiling water, which is less time and energy consuming, and more appealing to resource-poor farmers (Viaenne et al., 2006). For commercial systems, such as in Australia and Hawaii, hot water treatment is used to provide nematode-free material (Colbran, 1967). However, sterile plants produced using tissue culture and certified pest- and disease-free are ideal. Such material is now routinely used in commercial banana production but has yet to gain wider use by smallholder farmers (Dubois, Coyne, et al., 2006). The lack of virus indexing, suboptimal weaning procedures, accidental cultivar mixing during production, inappropriate farmer handling, and subsidization by governmental and nongovernmental organizations remain some of the major hurdles to overcome before tissue-culture technology can be widely rolled out among smallholder farmers.

In commercial plantations, postplanting nematicide applications continue to provide the most universal method of nematode management, primarily against *R. similis*, administered through granular applications or drip irrigation (Sarah, 2000; Jones, 2009). Soil sanitation can be achieved through a cleansing system based on glyphosate injection into banana plants before uprooting (Risède et al., 2009). However, many nematicides are being progressively removed from the market (Zum Felde et al., 2009). In the French West Indies, management of *R. similis* is based primarily upon the repeated application of carbamate or organophosphate nematicides; however, with increasing restrictions on their use, the search for alternative and environmentally responsible options has intensified. An environmentally sound scheme supported by three key pillars is being devised: use of tissue culture, fallow, and intercropping with nonhosts (Risède et al., 2009). In Hawaii's IPM scheme, incorporation of crop residue and fallowing fields for 6–8 months is common. Emphasis is also being increasingly placed on efforts to identify suitable biologically based solutions, such as mycorrhizae, endophytes, and biopesticides (Meyer and Roberts, 2002; Viaene et al., 2006; Sikora et al., 2008).

The use of healthy planting material is not only critical, but for smallholder farmers it also often is their only realistic option for nematode management. However, the use of locally grown, nematode-resistant cultivars, in combination with healthy planting material, is highly desirable (Coyne, 2009). Establishing nematode resistance is also a key target in banana breeding programs (Tenkouano and Swennen, 2004; Pillay and Tripathi, 2007; Lorenzen et al., 2009). Commercial dessert bananas are characterized by few landraces with an extremely narrow genetic base (Ortiz et al., 1995), while sources of resistance to nematode species are limited (De Waele and Elsen, 2002). To date no widely grown clone of export banana is known to be resistant to the important nematode species (Gowen et al., 2005). There are confirmed sources of resistance against *R. similis* but not necessarily against *Pratylenchus* spp. (De Waele and Elsen, 2002). Resistance to *R. similis* from cv 'Pisang Jari Buaya' has been incorporated into the widely used diploid parent cv SH-3142 of the Fundación Hondureña de Investigación Agrícola (FHIA) (Pinochet and Rowe, 1979). Recent successes have also been achieved in the breeding programs at the International Institute of Tropical Agriculture (IITA) (Pillay and Tripathi, 2007; Lorenzen et al., 2009) and the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD). At IITA, the diploid banana hybrids TMB2×5105-1 and TMB2×9128-3 have good combining ability and are resistant to *R. similis* (Tenkouano et al., 2003). At CIRAD, partial resistance to both *R. similis* and *P. coffeae* is reported within synthetic hybrids of *M. acuminata* (Quénéhervé et al., 2009). Meanwhile, the genetic modification of existing cultivars is also becoming a realistic option for nematode management (Roderick et al., 2009; Tripathi, 2009). Research efforts for biologically based solutions are equally being sought for smallholder farmers in Africa and India to compensate for the unsuitability and removal from use of nematicides.

7.3 INSECT AND MITE PESTS

Bananas can be attacked by a wide range of insect and mite pests. Rather than a taxonomic overview, it is best to group these into functional groups, as members from widely different taxa often pose similar problems and require similar management options.

7.3.1 Plant-Boring Pests

7.3.1.1 The Banana Weevil

The biology, distribution, and damage caused by *Cosmopolites sordidus* is comprehensively reviewed by Gold et al. (2001). Banana weevils feed only on bananas. Adults are most commonly found between leaf sheaths, in the soil at the base of the mat, or associated with crop residues. The banana weevil is nocturnally active and particularly susceptible to desiccation. As adults tend to have limited movement between mats and rarely fly, dissemination is primarily through infested planting material. The banana weevil is a typical k-selected insect with long life span and low fecundity. Adults normally survive for longer than 1 year, and oviposition has been estimated at 1 egg/week. Oviposition occurs in the leaf sheaths and rhizome surface, especially in flowered plants and in crop residues. Crop damage is inflicted by the larvae. The emerging larvae preferentially feed in the rhizome but will also attack the true stem and occasionally the pseudostem. Larval developmental rates are temperature dependent. Under tropical conditions, egg to adult development takes 5–7 weeks. Egg development does not occur below 12°C, restricting its distribution to lower altitudes. Adult banana weevils are attracted by volatiles emanating from host plants, explaining why cut rhizomes of fresh suckers for planting material are especially susceptible to attack (Gold et al., 2001).

The banana weevil has a cosmopolitan distribution, occurring in smallholder banana systems to commercial plantations. It is present in all banana and plantain production regions in the tropics and subtropics, and is generally considered the most important insect pest of banana (Jones, 2009). Beer, roasting, and cooking bananas are most susceptible, and therefore banana weevil problems appear to be most severe in smallholder systems and less in commercial cv Cavendish plantations (Gold and Messiaen, 2000).

Banana weevil attack has been reported to interfere with root initiation, kill existing roots, limit nutrient uptake, reduce plant vigor, delay flowering, and increase susceptibility to other pests and diseases. Yield reductions stem from both plant loss (plant death, rhizome snapping) and reduced bunch weights. Losses of more than 40% have been recorded (Gold and Messiaen, 2000; Gold et al., 2001). Young banana plants are most at risk because tunneling by the banana weevil can be fatal at this stage (Constantinides and McHugh, 2003).

As with nematodes, banana weevils are dispersed through contaminated planting material, emphasizing the importance of clean planting material as an essential prophylactic management measure. Rigorous field sanitation measures also take advantage of the adult's dependency on residues, lack of movement, and need for moisture. Despite numerous surveys, no known effective parasitoids of the banana weevil have been identified. In commercial systems, insecticides are applied. For resource-poor farmers, cultural management is the only means currently available to reduce banana weevil populations (Gold and Messiaen, 2000).

7.3.1.2 Stem Borers

Stem borers, such as the giant banana stem borer *Castniomera humboldti* Boisduval and the banana stem weevil *Odoiporus longicollis* Olivier, tunnel through the banana pseudostem (Jones, 2009). *Castniomera humboldti* occurs in Central and South America where it is a relatively minor pest, whereas *O. longicollis* can be a serious pest in Asia. The latter is among the main insect pests of quarantine importance for Australia (Pinese, 1999) and considered the most important insect pest in India. Eggs are laid inside air chambers through incisions made on the leaf sheath. In the advanced stage of infestation, severely affected plants break. Banana stem weevils often inflict total crop failures in susceptible cultivars (Jayanthi and Verghese, 1999). The pest survives in pseudostem stumps, which often remain as trash in the field after harvest. In India, the distribution of *O. longicollis* is aggravated when farmers cut the pseudostems at up to 1 m high from the ground level and allow them to decompose slowly until the establishment of the succeeding ratoon crop, which they believe transfers nutrition to subsequent ratoons (Padmanaban and Kandasamy, 2003).

7.3.2 Fruit and Flower Pests

Fruit and flower pests are especially important on exported banana. For example, in Hawaii, presence of the banana moth *Opogona sacchari* Bojer on fruit for export will result in their rejection (Constantinides, 2003). A small number of larvae of the banana scab moth *Nacoleia octasema* Meyrick may lead to the destruction of an entire bunch otherwise destined for export. The mere presence of *Bactrocera* spp. fruit flies, an insignificant pest of bananas, on shipments from Australia to New Zealand requires destruction of the fruit (Pinese, 1999; Ministry of Agriculture and Forestry, 2006). Most often, fruit and flower pests are managed using insecticide-treated bags that enclose the flower. Chlorpyrifos-treated bags are especially effective and used abundantly in commercial plantations, but environmentally safer alternatives, such as bifethrin, are increasingly sought (Chiquita Brands International, 2001).

7.3.2.1 Banana Moths

Opogona sacchari is endemic to Africa, where it is an insignificant pest. The pest has a wide host range and has been considered a serious pest of banana in the Canary Islands since the 1920s. In the 1970s, it was introduced into Brazil, where it has since become an important banana pest. The insect has also started to appear in a number of European countries on various tropical and subtropical glasshouse crops, and is now considered a serious quarantine pest (Smith et al., 1996; OEPP/EPPO, 2006). The banana moth oviposits on senescing flowers, decaying leaves, pseudostems, and fruits on which the larvae feed, although they will also feed on healthy adjacent tissue. Preventive management measures, such as the removal of plant debris and flowers, in addition to the application of insecticides to bunches prior to bagging, greatly reduces damage (Peña et al., 2002). Recently, a pheromone was discovered that attracts this pest, which may additionally aid the development of more efficient monitoring schemes (Wageningen University, 2009).

The banana fruit-piercing moth *Eudocima fullonia* Clercq attacks many fruits and vegetable crops, and can pose a serious banana risk. Unlike most moth and butterfly pests, the caterpillar stage is not the damaging stage. Instead, the adult moth punctures and feeds on ripening fruit, not only administering direct damage but also indirectly facilitating fungal and bacterial infections. High moth populations can result in premature ripening and fruit drop (CAPS online). Interestingly, in some endemic areas, such as Papua New Guinea, the pest is effectively managed below threshold levels by egg parasitoids (Sands and Liebregts, 2005).

The banana scab moth *Nacoleia octasema* Meyrick is one of the most serious pests in Malaysia, the southwest Pacific, and Queensland, Australia. Females lay eggs on flower bracts as the inflorescence emerges. Larvae feed on the surface of young fingers. They enter the flower and feed on the developing fruits within, gradually progressing down the maturing bunch. This causes brown scars, scabs, and severe cracking on the developing fruits. Cultural and biological control methods are not particularly effective due to the cryptic nature of the feeding larvae, and their management is based largely on injection of insecticides (Paine, 1964; Morton, 1987; Stover and Simmonds, 1987; Botha et al., 2000; Nelson et al., 2006).

7.3.2.2 Thrips

Numerous species of thrips of the family *Thripidae* feed on banana (CABI, 2005). Most thrips prefer sunny and dry areas, have a broad host range, and feed on flowers, fruits, or other young tissues, with both larvae and adults causing damage (Parker et al., 1995). Thrips cause superficial skin blemishes on immature banana fruits. Although severe infestations can cause peel splitting, the damage they cause is primarily cosmetic, and therefore only commercial banana systems require prophylactic management measures to meet stringent export requirements (Peña et al., 2002).

Banana is affected by several members of *Chaetanaphothrips*: the orchid thrips *Chaetanaphothrips orchidii* Moulton, the banana rust thrips *Chaetanaphothrips signipennis* Bagnall, and *Chaetanaphothrips leeuweni* Karny. These species are cosmopolitan pests, with most damage resulting from larval feeding. *Chaetanaphothrips signipennis* is a problem in Australia, while *C. orchidii* induces similar damage in Central and South America (Peña et al., 2002). Feeding on leaf sheaths results in damage on the outer surface of leaf petioles and is characterized by dark, V-shaped marks, while damage to the fruit initially presents a water-soaked appearance that later turns bronze- or rust-colored. The pest can split the fruit peel, exposing the flesh. It also feeds on the area where adjacent fingers touch, resulting in a reddish discoloration (Williams et al., 1990; CABI, 2005; Jones, 2009). The life cycle can be completed in 28 days. The insect is managed by spraying banana fruits with insecticide at bunch emergence and covering them with polyethylene bags prior to harvest (Morton, 1987; Hara et al., 2002; CABI, 2005).

The Hawaiian flower thrips, *Thrips hawaiiensis* Morgan and *T. florum* Schmutz, are similar, often confused with each other, and as a cosmopolitan species complex, feed on a wide variety of tropical flowers (Hollingsworth, 2003). The insect enters the developing fruit while the bracts remain present and oviposits on the young fruit. Feeding results in corky scabbing of the peel, flecked, spotted, or deformed flowers, and sometimes cracked fruits, especially during hot and dry weather. Infestations are lessened by removal of the terminal male bud, which tends to harbor the pest (Morton, 1987; CABI, 2005; Jones, 2009; Peña et al., 2002). Unlike most flower thrips, this species complex prefers wet and shady areas (Sakimura and Krauss, 1944).

The banded greenhouse thrips *Hercinothrips femoralis* Reuter is a cosmopolitan thrips species with a wide host range and has been recorded on bananas in various parts of the world. The closely related rind thrips *H. bicinctus* Bagnall, which is equally cosmopolitan, is considered a more important banana pest (Roditakis et al., 2006). Feeding by this insect causes unsightly silver and bronze fruit scars, reducing their marketability (Hawaiian Banana Industry, 2010a). The silvering usually occurs with small infestations. With larger infestations, especially in combination with the two-spotted spider mite *Tetranychus urticae* Koch, the fruits turn smoky-red in color, occasionally leading to skin cracks, further reducing the market value of the fruit (Lewis, 1997). *Hercinothrips* spp. are closely related to the rind thrips *Elixothrips brevisetis* Bagnall. *Elixothrips brevitis* is also a polyphagous foliage feeder and a common pest in commercial banana stands, and feeds on leaves, flowers, or stems. In Martinique, *E. brevisetis* has replaced *H. femoralis* as the predominant thrips pest (Rey, 2002). Flowers, buds, and the undersides of leaves become spotted with small black fecal specks. Injured tissue develops a silvery appearance and eventually turns dark brown, affecting banana marketing (Rey, 2002). *Elixothrips brevitis* also feeds on leaf tips, resulting in wilting and curling. When affected, buds may fail to open (Constantinides and McHugh, 2003; Hawaiian Banana Industry, 2010a).

Banana is also damaged by *Frankliniella* spp. The banana flower thrips *Frankliniella parvula* Hood pupates in the soil and only emerges during daylight hours to oviposit in the epidermis of young banana fruits. The host range of this thrips species seems restricted to banana plants (Harrison, 1963; Peña et al., 2002). The blossom thrips *Frankliniella insularis* Franklin mainly occurs in Central America (Mound and Marullo, 1996).

7.3.2.3 Peel-Scarring Beetles

Several species of *Colaspis* spp. are reported as banana pests, especially in Central and South America (Ostmark, 1975; Jones, 2009). *Colaspis hypochlora* Lefèvre in particular appears a troublesome pest in Venezuela, Guyana, and Mexico, where it invades young fruit on developing bunches, although this species is often confounded with other members of the genus. Severe outbreaks of this pest have been documented in Panama and Colombia (Ostmark, 1975; Morton, 1987). In the Philippines, several peel-scarring beetles belonging to *Philicoptus* spp. have also been reported as pests (Stephens, 1984).

7.3.2.4 Fruit Flies

Fruit flies only attack ripe banana fruits. Although minor pests, fruit flies, particularly of the genus *Batrocera* spp., can be highly significant quarantine pests (Nelson et al., 2006), disrupting international banana shipments. In October 2009, Mexico, for instance, halted all imports of fresh banana from regions where the banana fruit fly *Bactrocera musae* Tryon or the oriental fruit fly *B. dorsalis* Hendel occur (USDA, 2009). *Bactrocera musae* is considered among the most serious banana pests of Papua New Guinea (Kambuou, 2003). In Sri Lanka, severe outbreaks occurred of several *Bactrocera* spp. in the late 1990s (Ekanayake et al., 2002).

7.3.2.5 The Sugarcane Bud Moth Caterpillar

The sugarcane bud moth caterpillar *Decadarchis flavistriata* Walsingham is a localized pest in the Pacific, especially Hawaii. Caterpillars feed on decaying flowers, which can cause fruit scarring. Removing flowers prior to bagging reduces damage from this pest (Nelson et al., 2006).

7.3.3 Sucking Insects and Associated Arthropoda

7.3.3.1 The Banana Aphid

Colonies of the banana aphid *Pentalonia nigronervosa* Coquerel can occur anywhere on the plant but are most often found at the base (Robson et al., 2007). Young suckers are typically most heavily infested. The banana aphid is a phloem feeder, which causes plants to become deformed; the leaves

Planococcus spp., *Pseudococcus* spp., and *Ferrisia* spp. Although not a significant pest of banana in most locations, mealybugs have also been associated with transfer of banana streak virus (BSV) (Nelson et al., 2006).

7.3.3.4 Mites

Mites are generally considered a minor but frequent pest of bananas. However, several mites of the genus *Tetranychus* can cause significant damage to banana, such as *T. urticae* and especially the banana spider mite *T. lambi* Pritchard and Baker (Morton, 1987; Pinese and Piper, 1994). In West Bengal, India, *Oligonychus oryzae* Hirst was found to be the more damaging mite species (Karmakar and Dey, 2006). Mite activity and damage are mainly confined to localized, dry conditions, such as the underside of old leaves. In severe infestations, whole leaves turn brown-gray and wilt, resulting in sunburned bunches and a reduction in plant growth. However, in warm weather and during severe outbreaks, mites may migrate to the bunches and damage fruits. Dry and warm conditions under plastic bunch covers are particularly favorable for the buildup of banana spider mites. Fruit damage is characterized by a silver-gray discoloration of the fruit tip, and fruits may dry out and crack when serious infestations occur (Morton, 1987; Pinese and Piper, 1994). Mites are also implicated in fruit speckling, a disease with unknown etiology that, particularly during the rainy season, has caused up to 70% rejection of export banana in Central America (Pasberg-Gauhl, 2002).

7.3.4 Foliage Feeders

A large group of foliage-feeding insects, originating from several taxa, can cause damage to banana. The economic damage they cause is usually limited, with populations remaining below economic injury levels through natural predation and parasitism. However, serious crop losses can occur.

7.3.4.1 The Banana Skipper

The banana skipper *Erionota thrax* L. is considered to be the main insect pest in Papua New Guinea (Kambuou, 2003). In Australia, it is a quarantine pest (Pinese, 1999), where it is sometimes referred to as the banana leaf roller due to its habit of rolling leaves to make shelters. Caterpillars secrete a protective, white, waxy covering inside the rolled leaves. The feeding and rolling destroys the leaves and significantly reduces the plant's leaf area. Leaf defoliation can occur quickly with only three caterpillars per leaf (Queensland Horticulture Institute, 2000). In Asia, from where the banana skipper originates, the parasitic wasp *Cotesia erionotae* Wilkinson effectively manages banana skipper infestations, which were previously a serious problem. In Malaysia, populations are kept in check by at least five primary endoparasitoids (Queensland Horticulture Institute, 2000; Okolle et al., 2006; Jones, 2009), while in Papua New Guinea, parasitoids have been introduced to manage outbreaks of leaf rollers in areas of the country (Kambuou 2003).

7.3.4.2 The Chinese Rose Beetle

The Chinese rose beetle *Adoretus sinicus* Burmeister is a minor but common pest on all major banana-producing islands in Hawaii and in the Pacific. The larvae reside in the soil and litter, with damage caused only by adult feeding. The adult is nocturnal and feeds primarily on leaf and intervenal tissue. It most commonly attacks young plants (Nelson et al., 2006).

7.3.4.3 Other Foliage Feeders

Caterpillars from the genera *Antichoris*, *Caligo*, *Opsiphanes*, and *Sibene* have been reported to partially defoliate banana plants in Central and South America (Jones, 2009). The larval stages of *Opsiphanes tamarindi* Felder can consume large areas of leaf, making it a potentially serious pest (Uquillas, 2002). Especially the tamarind owlet *Opsiphanes tamarindis* Felder, the owl butterfly

Caligo memnon Felder, and *Antichloris viridis* Druce are considered economically important pests in countries such as Venezuela (Ramirez et al., 1999). Bagworm (*Oiketicus kirbyi* Guilding) can be a problem in Central America, such as in Costa Rica. Females live for only a maximum of 14 days but can produce over 6,500 eggs during their adult life span. However, natural parasites usually limit outbreaks (Stover and Simmonds, 1987).

7.4 PEST INTERACTIONS

Of the wide range of pests observed on banana, the level of damage inflicted depends on numerous factors. Banana pests are often highly interactive, occurring within a complex ecosystem that ultimately influences the damage they cause. As such, there is need to avoid pest management solutions that tend to focus on a single pest without considering its relation and interactions to other factors. It is necessary that pest management options be holistic in their approach.

7.4.1 Ants

Ants have at times been heralded as natural enemies for biological control in conservation programs. For example, encouraging colonies of ants has been suggested as a means to manage *C. signipennis* (CABI, 2005). Myrmicine ants such as *Tetramorium guinense* F. and the big-headed ant *Pheidole megacephala* F. have reportedly contributed to the successful management of banana weevils in plantain in Cuba and are even encouraged to nest in pseudostem sections that can then be used for their dissemination (Gold and Messiaen, 2000).

However, whereas ants are antagonistic to most other insect taxa, they can be highly protective of some honeydew-producing pest species, such as scales, whiteflies, and aphids. Ants will seek out honeydew sources to protect the supply, effectively farming the source, which may include their aggressive defense of the honeydew-producing insects. For example, honeydew produced by *A. dispersus* attracts ants, which, in turn, offer protection to the whiteflies, aggravating its damage and indirectly contributing to quarantine problems for export fruits (Waterhouse and Norris, 1989; Nelson et al., 2006).

Of particular concern is the intimate relationship of ants with the banana aphid, which produces honeydew. Aphid populations prosper in the presence of ant colonies, and thus ants indirectly aggravate BBTV incidence, increasing the probability of BBTV spread by the aphids. In Hawaii, *P. megacephala* and, more recently, the long-legged ant *Anoplolepis longipes* Jerdon are primarily associated with the banana aphid. By moving round aphids feeding on banana plants, they contribute to the spread of BBTV. Even directly, *A. longipes* feeds on the surface of the banana fruit, causing scarring of the fruit surface and reducing marketability (Brooks, 2003).

7.4.2 Natural Enemies

Several banana pests that require significant population densities before damage occurs are maintained below damage thresholds by natural enemies. Particularly good examples of this are demonstrated with the spiraling whitefly and the banana skipper (Ramani et al., 2002; Okolle et al., 2006). However, broad-spectrum insecticide applications, when relied upon for management of many pests simultaneously, may cause secondary outbreaks of otherwise minor pests, especially following the use of aerial or cover sprays (Pinese and Piper, 1994). Historical Lepidopteran outbreaks in banana have been associated with pesticide-induced disturbance of their natural enemies, such as the localized outbreaks of the banana skipper in Malaysia (Okolle et al., 2006). In a related study in Costa Rica, Hymenopteran parasitoid abundance and species richness were inversely related to application rates of nematicide and insecticide (Matlock and De La Cruz, 2002).

7.4.3 Weeds

Weeds not only compete with the banana crop for water and nutrients but also provide important pest havens, both by providing shelter and, more importantly, by serving as alternative hosts, especially for polyphagous thrips, banana moths, whiteflies, and mites. Consequently, weed management is an important component in many banana production areas for the indirect management of pests. In Hawaiian banana orchards, weed management strategies involve the prevention of weed seed formation and using pre-emergence herbicides, with emphasis on weed management prior to canopy closure (Hawaii Banana Industry Association, 2010b).

7.5 INTEGRATED PEST MANAGEMENT

7.5.1 History and Context of IPM

IPM is a term widely used but often misused in reference to banana. In relation to the literature, researchers and practitioners tend to equate IPM with a list of control options for a particular pest (often still at the research phase and biased towards biological control), which is not IPM. The term IPM was first coined in 1972 following a speech by President Nixon to the U.S. Congress, and originally defined in 1975 by the Food and Agricultural Organization (FAO, 1975). Since then, IPM has become a frequently used and misused term, often without the needful consideration of the subtleties and implications of its true meaning or impact on modern agriculture (Kogan, 1998). IPM was originally envisaged as a concept to counter the excessive applications of pesticides, particularly insecticides. Although pesticides can, and have, greatly increased crop productivity, their use has led to unintended adverse effects on human health and the environment. Furthermore, pesticide resistance among the target pests can result in secondary pest outbreaks through their ill effects on natural enemies (Stephenson, 2001). Originally, IPM was entomocentric, and only much later were weed science and plant pathology included in IPM principles (Kogan, 1998). Numerous definitions of IPM abound, with the concept of decision-making central to most (Bajwa and Kogan, 2002). Based on an analysis of the various definitions spanning the preceding 35 years, Kogan (1998) proposed a consensual definition of current thought: "IPM is a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that take into account the interests of and impacts on producers, society and the environment."

7.5.2 Principles of IPM

The principles of IPM can be best explained by examining the terms of the acronym: integrated, pest, and management.

7.5.2.1 Integrated

"Integrated" refers to the harmonious use of multiple management methods to control single pests, as well as the impacts of these methods on multiple pests (Kogan, 1998). Management methods are traditionally categorized as chemical (for example, pesticides), cultural (such as intercropping), biological (for example, parasitoids), host plant resistance-based (such as breeding genetically modified organisms), and genetic (sterile insect release, for example). A mere list of categorized control options, however, does not necessarily enable the farmer to practice IPM. It is important to distinguish between preventive/prophylactic and curative management options. As IPM is founded on a decision-making process—namely, before economic damage levels are incurred—IPM implicitly relies on prophylactic management options (Bajwa and Kogan, 2002). The successful and harmonious integration of management options is a difficult, if not a near-impossible, task. Integration can be viewed as either vertical (that is, within a pest taxon, sometimes referred to as first level) or horizontal (that is, among pest taxa, sometimes referred to as second level). For example, an insecticide that affects both the target pest and its natural enemies represents a lack of vertical integration; similarly, application of a fungicide that is detrimental to the natural enemies of pests provides a lack of horizontal integration. Historically, the lack of such integration has been a major impediment to the implementation of IPM in agriculture (Ehler, 2006).

7.5.2.2 Pest

"Pest" refers to any organism causing crop damage, including invertebrate and vertebrate animals, pathogens, and weeds (Kogan, 1998). Pest is an anthropocentric term, and highly relative and dynamic. Any insect living in or on banana plants can, at some stage and in some locations, become a pest or cease to be a pest. As such, sampling and monitoring schemes are of paramount importance and are necessary components before IPM can be conducted. Even with a pest incurring identical levels of injury in different locations, the economic damage acceptance level can differ between production systems. This implies that sampling and monitoring schemes need to be adapted to be location, crop, crop system, and season specific (Stephenson, 2001).

7.5.2.3 Management

"Management," the most important term, refers to a series of decision rules based on ecological and economic considerations, and equipped with sound and specific information related to the pest and its management options. The key principle for this decision-making process is often the economic injury level (EIL) concept (Stern et al., 1959). EIL is based on economics: the study of the relationships between pest densities, host responses to injury, and resultant economic losses. EIL is a theoretical value that, if actually attained by a pest population, will result in economic damage. The EIL formula $[C/(V \times I \times D \times K)]$ is determined using five primary variables: cost of the management tactic per production unit (C), market value per production unit (V), injury units per pest (I), damage per injury unit (D), and the proportional reduction in pest attack (K). From the EIL, the economic threshold (ET) is calculated. The ET differs from the EIL in that it is a practical or operational rule, rather than a theoretical one. The ET is defined as the population density at which control action should be determined (initiated) to prevent an increasing pest population (injury) from reaching the economic injury level. The ET is effectively an action threshold and is more complex to calculate than the EIL. Besides information on the EIL, several other parameters need to be known to calculate the ET, such as pest and host phenology, population growth and injury rates, and time delays associated with the IPM tactics utilized. These parameters are also location, crop, crop system, and season specific, and require extensive research before their implementation.

7.5.3 Practical IPM as a Continuum

Decision making, based on pest populations, is the most critical element in any IPM program. Without the critical components of ET and EIL, there will be no decision making and hence no IPM. However, because ETs and EILs are difficult to calculate, the practical implementation of IPM has become less strict and is often applied as a continuum. For example, the U.S. Department of Agriculture (USDA) uses a four-tier approach. As a first line of defense, prophylactic cultural methods (rotation, resistant cultivars, and pest-free planting material) are encouraged. Once monitoring, identification, and action thresholds indicate that pest management is required and preventive methods are no longer effective, the least risky curative pest-management options are initially employed, including highly targeted pesticides, such as pheromones to disrupt pest mating, or mechanical control, such as trapping or weeding. If further monitoring, identification, and action thresholds indicate that less risky controls are not sufficiently effective, additional pest-management methods would be needed, such as targeted application of pesticides. Broadcast spraying of nonspecific pesticides is a last resort (Stephenson, 2001).

Practically, efficient and operational IPM programs exist for specific crops in specific locations. These programs take on a variety of formats: protocols, checklists, standards, and definitions. Many of these assign point values to each practice, facilitating use as a performance assessment tool (Green and Petzoldt, 2009).

7.6 IPM IN BANANA

7.6.1 IPM IN COMMERCIAL PLANTATIONS

Pest management in commercial banana plantations is primarily chemical based, using nematicides with insecticidal activity and applying specific insecticides to the plant base or on bunches. Management of *R. similis* to date has essentially been achieved through the application of carbamates (aldicarb, carbofuran, and oxamyl) and organophosphates (fenamiphos, ethoprop, and terbufos) (Berg, 1991). Cyclodiene insecticides, once widely used but eventually abandoned following the development of pest resistance and the emergence of environmental concerns, are now replaced by less persistent organophosphates. However, pests such as the banana weevil have demonstrated the ability to develop resistance to most pesticide classes (Gold and Messiaen, 2000). In Hawaii, to avoid pesticide resistance, the industry is actively developing a pesticide resistance program. The organophosphate diazinon, the primary pesticide used for thrips management, is being replaced with low-risk pesticides such as imidacloprid and spinosad (Hawaii Banana Industry Association, 2010b). Compared to smallholder systems, much focus is directed towards managing fruit and flower pests in commercial banana plantations, because there tends to be a zero-tolerance policy on damage or even presence for export markets (Jones, 2009), leading to much lower EILs and ETs.

In commercial plantations, IPM is especially sought to substitute for the excessive use of nematicides particularly of late, following the imminent removal from use of many nematicides (http://www.pesticideinfo.org/) and the increasingly strict regulations on the maximum permitted residue levels of imported fruit, vegetable, and cereal products (European Commission, 2007). Furthermore, most systemic nematicides are short lived (2–5 weeks) (Zum Felde et al., 2009), with rapid microbe-enhanced biodegradation greatly reducing their effect, following their repeated and consistent use (Moens et al., 2004), leading to an ever increasing but untenable number of applications.

Examples of true banana IPM schemes are rare but can be found in Hawaii. Their banana IPM protocol uses a combination of guidelines and point values to determine the level of IPM being utilized on a particular farm, which is constantly subject to change with new IPM developments. Pest management practices are grouped according to five categories (cultural, physical, mechanical, biological, and chemical) and each category is assigned a point value. Those practices that require more active management decisions or present reduced environmental risks receive higher point values. In practicality, points are low for pesticide-dependent practices while high for biologically dependent ones. A grower is certified as an IPM practitioner if he or she enrolls in the program and provides documentation that at least 70% of the total possible points is achieved. Although not applied for all pests, binomial pest sampling plans have been developed to allow for informed decision making regarding pesticide applications (Robson et al., 2006).

Currently, the public demand for quality products grown with environmentally responsible methods is strongly encouraging organic banana farming. Nonpesticide pest-management methods are paramount for the promotion and adoption of such cropping systems (Roditakis et al., 2006). There is the erroneous tendency to associate the production of organic banana with smallholder farmers, possibly because of the perception that they can least afford the pesticides used on conventional crops and are more likely to use naturally occurring inputs. Current price premiums for organic produce, only enjoyed in niche Western markets and required to offset increased production costs, are also decreasing, perhaps limiting organic banana production in the long run (Reid, 2000; Abele et al., 2007).

7.6.2 IPM in Smallholder Systems

7.6.2.1 Problems

Compared to commercial systems, smallholder banana systems are intrinsically different, making it virtually impossible to implement IPM, while adoption of IPM has remained low in the developed world, contrary to original expectations (Vereijken, 1989; World Bank, 2005; Ehler, 2006). Pest problem recognition, and more specifically species identification, is required as a basis for IPM. However, in resource-poor situations, the obstacles to pest problem recognition and species identification are often much greater than for commercial situations. For example, in Kenya, only 15% of the farmers had knowledge on the damage caused by banana weevils and none for nematodes or their damage symptoms, mostly mistaking their damage for that of banana weevils. Importantly, and of greater concern, was that both farmers and extension officers made this mistake (Seshu Reddy et al., 1999). In addition, pest profiles and their management cannot be simply transferred from developed countries, as banana clones are highly variable and differ from the commercial cv Cavendish types. For example, in East Africa, based on a comprehensive farm baseline study, several banana pests, such as banana weevils and plant-parasitic nematodes, may not be as important as traditionally assumed (CIALCA, 2009).

Government support and resources for IPM implementation at the national level in less-developed countries are often scarce or absent. Through the Cooperative Global Program, sponsored by the Food and Agricultural Organization (FAO) and the United Nations Environmental Program (UNEP), IPM strategies were targeted at cropping systems and regions, which included implementation, research, training, and education, and which have led to some success stories (such as the reduction of pesticide use against the brown plant hopper *Nilaparvata lugens* Stål on rice (*Oryza sativa* L.) (FAO, 1995). Since the 1990s, the Consultative Group for International Agricultural Research (CGIAR) has increased its attention towards crop protection in general and IPM in particular, away from host-plant-resistance breeding (Kogan, 1998).

Smallholder banana systems are typically low input/low output, or resource poor, meaning that pest-management practices are often limited at best. In Cameroon, for example, insecticide applications among smallholder banana farmers are negligible, because the returns are too low to allow meaningful investment into pest-management measures. Only management options that offer less capital investment, therefore, offer long-term sustainability (Tomekpe and Sadom, 2008).

7.6.2.2 Focus on Cultural Management

Mainly because of limited resources and availability of other options, pest management in smallholder systems is heavily dependent on cultural options. However, cultural control options against insect pests in smallholder systems differ markedly from those of commercial systems. For example, one of the characteristics of smallholder banana systems is the perennial nature of banana, creating difficulties for short-term rotation options, while annual or single-cycle cropping characterize some commercial systems. In addition, a combination of banana cultivars with varying levels of resistance is often present in the same field in smallholder systems (Seshu Reddy et al., 1999).

Most of the cultural management options available to smallholder farmers are simple and rely on good crop husbandry and habitat management—practices that encourage vigorous crop growth, which leads to less damage. These practices include deep planting, weeding, mulching, and the application of organic manure. For example, systematic trapping with pseudostem or rhizome pieces, as well as removal of crop residues, can also be effective in reducing populations of adult banana weevils (Masanza et al., 2006). Using crop residues as mulch is effective at decreasing nematode populations, especially when applied to low fertility systems (McIntyre et al., 2000). One of the most critical management options for borers and nematodes is the use of clean, healthy planting material. Tissue culture plantlets are widely used in commercial banana plantations for pest and disease prevention but less available or understood in smallholder systems. Where tissue culture is not available, removal of roots and emersion of cleaned (pared) suckers in hot water treatments can be highly effective against banana weevils and nematodes (Speijer et al., 1999; Gold and Messiaen, 2000), while adapting the system to a simpler system of using 30 s periods of immersion in boiling water can be equally effective against nematodes (Tenkouano et al., 2006; Viaenne et al., 2006).

Besides cultural management options, much research currently focuses on biologically based management options. How feasible or economical these will be to smallholder farmers remains to be seen. However, based on interviews, Mugisha-Kamatenesi (2008) observed that subsistence farmers around the Lake Victoria basin in East Africa commonly use botanical pesticides. Botanical compounds especially are seen as substitutes for costly pesticides. Applications of neem (*Azadirachta indica* A. Juss) in the field, such as neem oil for treating planting material or pseudostem traps, protect bananas from weevil and nematode attack, inhibiting weevil larvae development by up to 14 days (ICIPE, 1997).

7.6.2.3 Technology Transfer

As a consequence of the intrinsic differences between smallholder and commercial systems, the focus for pest management for smallholder farmers is on transfer of the basic technologies, mostly cultural based, to the farming communities and extension personnel. For example, in Zanzibar, pest management includes formation of farmers' groups, training of trainers, establishment of plots used for participatory action, and farmer field schools, which are used for demonstrating basic technologies, such as good crop husbandry (Rajab and Fundi, 1999). In Kenya, mobile training workshops were initiated on a trial basis, which proved very effective in information dissemination (Seshu Reddy et al., 1998). Global Plant Clinics is a recent initiative to link smallholder farmers with pest information. The initiative aims to improve access to effective plant health services by adopting similar approaches used in human health, through regular advisory services made available in local communities (Boa, 2007).

7.7 ADVANCES IN SEED-BASED MICROBIAL MANAGEMENT

Endophytes are organisms that, at some time during their life cycle, live within plant tissues yet cause no disease symptoms to their host (Petrini, 1986). Endophytes are natural and integral components of all plants. The relationship can be mutualistic: Endophytes protect the host plant against pests and diseases, and increase plant growth and vigor. Endophytes occupy a niche with relatively low competition from other microorganisms, provided they gain access initially. As such, endophytes have received increasing attention as biological control organisms in vegetatively multiplied crops, such as banana (Sikora et al., 2008). Tissue-culture banana plants are becoming increasingly used in banana production, even in smallholder systems, because of the advantages offered by these plants. Tissue-culture plants are free from pests and pathogens, simple and quick to multiply in larger numbers, and exhibit faster and more uniform growth in the field than sucker-planted fields (Vuylsteke, 1989; Mateille et al., 1994; Robinson, 1996; Dubois, Coyne, et al., 2006; Pocasangre, 2006).

However, because tissue-culture plants are propagated under sterile conditions, they are void of all beneficial organisms, including endophytes (Pocasangre, 2006). By selecting the best performing endophytic strains and reintroducing them early into tissue-culture plantlets, the natural equilibrium is somewhat restored, extending the benefits of clean planting material. Research into enhancing banana with endophytes started in the early 1970s (Sikora and Schlosser, 1973; Sikora and Schönbeck, 1975).

The use of endophyte-enhanced tissue-culture plants is a unique form of microbial pest control, mainly because it is seed based and thus circumvents many of the obstacles normally associated with augmentative biological control. Thus tissue-culture plantlets can be supplied to farmers already fortified with endophytes, eliminating the need for farmers to apply the biopesticides. Costs and know-how associated with formulation, distribution, application, and storage of endophytes can be transferred to commercial tissue-culture laboratories (Dubois and Coyne, 2006). As endophytes exist *in planta*, they offer great potential to manage cryptic pests and diseases. Furthermore, endophytes escape the rhizosphere community, where they would otherwise compete with the native flora and where they would be exposed to environmental factors that may adversely affect their efficacy. Avoiding this competition and exposure allows for low initial inoculation levels, improving consistency of endophyte performance and substantially reducing costs.

Endophyte-enhanced tissue-culture technology is sought after both in smallholder as well as commercial systems. In smallholder systems, the early stages of plant growth can be challenging because banana tissue-culture plantlets need higher levels of care and attention than conventional planting material. Where soils are depleted and pests and diseases abundant, tissue culture is only superior to conventional planting material if accompanied by significant field maintenance. Especially in the smallholder banana production systems, where high-input field maintenance routines are largely absent, endophyte enhancement creates more robust tissue-culture plants. In commercial systems, endophytes are also being investigated as replacements for nematicides (Zum Felde et al., 2009).

How endophytes protect bananas is only just beginning to be understood. The primary mode of protection of the endophyte *Fusarium oxysporum* Schlecht.: Fries against *R. similis* appears to involve a number of mechanisms, including induced resistance (Athman, 2006). Induced resistance is the activation of defense mechanisms in plants after contact with biotic initiators, such as endophytes. The endophyte triggers pathways that induce physiological changes in the plant, enabling a susceptible cultivar to express similar properties as a resistant cultivar (Dubois, Gold, et al., 2006). This mode of action is economically interesting because it may transfer host resistance across a broad range of pest groups. Also, endophytic inoculum can be further reduced and may not necessarily need to persist for long periods, as long as the resistance remains triggered. Furthermore, *F. oxysporum* seems to prime the banana plant against pests and diseases rather than inducing a constitutive response. The priming of plants in this way thus avoids waste and helps optimize the use of resources, a prerequisite for the implementation of the plant-enhancement technology (Heil et al., 2000).

Several groups of endophytes are currently under investigation worldwide. A first group is comprised of mostly hyphomyceteous fungi that are nonobligate endophytes, which have a saprophytic stage in the rhizosphere. *Fusarium oxysporum* is the most predominant endophytic taxon in banana (Hallman and Sikora, 1996; Dubois, Gold, et al., 2006) and offers great commercial potential, mainly due to the relative ease of inoculum production (Dubois, Coyne, et al., 2006). Endophytic protection of tissue-culture banana plants has been demonstrated in the field under both commercial and smallholder settings. In Panama, inoculation with *Trichoderma atroviride* P. Karst. protected tissue-culture banana plants from *R. similis* better than two applications of ethoprop and temephos nematicides, reducing *R. similis* population levels by 30–50% (Pocasangre et al., 2006; Pocasangre et al., 2007). In Kenya, inoculation with *F. oxysporum* reduced nematode population densities by > 45% and damage by > 20% over one growth cycle (JKUAT, 2008; Waithira, 2009). Mass multiplication mechanisms of promising strains are currently being researched, in coordination with private industry in East Africa and Central America.

A second group is the arbuscular mycorrhizal fungi (AMF), obligate symbionts of almost all higher plants, including most cultivated plant species (Abbott and Robson, 1984; Sikora et al., 2003). AMF not only antagonize banana pests but also improve plant growth and survival through water and nutrient uptake. Tissue-culture plants enhanced with *Glomus fasciculatum* Thaxter and *G. mosseae* Thaxter have demonstrated suppression of nematodes, such as *R. similis* (Umesh et al., 1988) and *P. goodeyi* (Jaizme-Vega and Pinochet, 1997). However, to obtain the inoculum needed for application, AMF need to be produced on living plants (Sikora et al., 2003), creating difficulties and expense in their production and application. Until recently, the use of AMF was not viewed to be commercially viable, although products are now beginning to appear on the market. As intercropping is such a common aspect of subsistence farming, some intercrops that favor AMF inoculum buildup, such as sorghum (*Sorghum* spp.), could be promoted (Elsen et al., 2003; Elsen et al., 2009).

Several entomopathogenic fungal products based on *Metarrhizium* spp. and *Beauveria* spp. are commercially available for use as insect biopesticides. Despite near 100% efficacy *in vitro* against pests such as the banana weevil (Kaaya et al., 1993), their efficacy in the field tends to be slow, erratic, and ultimately an expensive option. The development of efficient and cost-effective field delivery systems currently hampers their use in smallholder and commercial banana systems. Recently, it was demonstrated that such fungi can be applied as artificial endophytes in banana plants, reducing banana weevil populations and damage (Akello et al., 2007; Akello, Dubois, et al., 2008a, 2008b; Akello, Coyne, et al., 2008).

7.8 CONCLUSION

This chapter provides an overview of nonmicrobial pests of bananas. Pest profiles are highly variable and depend on region, clone, and crop system. Of particular importance is that recommendations for their management, and research leading to these, vary greatly between smallholder systems and commercially managed plantations. Whereas IPM is necessary and can lead to reduced pesticide reliance, especially nematicides, in commercial systems, the situation contrasts markedly with smallholder systems. For smallholder systems, ill-linked management options, some that are often unsuitable, should be avoided for use in IPM, and a focus on key basic issues, such as pest identification, cultural management options, and deployment of basic training for farmers and extension workers should prevail.

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