Chapter 13
IPM Vegetable Systems in Uganda

Jeninah Karungi, J. Mark Erbaugh, Robinah N. Ssonko, Jackline Bonabana-Wabbi, Sally A. Miller, and Samuel Kyamanywa

Abstract Smallholder famers in Sub-Saharan Africa (SSA) have been encouraged to produce horticultural crops as an agricultural and rural development strategy to enhance incomes and improve household nutrition. In Uganda, intensified production of marketed vegetable crops has led to changing agricultural practices, including crop and input-intensification, a changing set of pests, and increased use and reliance on synthetic pesticides to manage these pests. Beginning in 2002, the IPM CRSP team in Uganda implemented a participatory IPM program with smallholder farmers to develop and disseminate alternative pest management strategies for managing priority pests and reducing pesticide usage on tomato. The major pest constraints addressed were late blight, bacterial wilt, viruses, bollworm, aphids, thrips and white flies. Baseline farmer surveys indicated that farmers were spraying a variety of pesticides 12–24 times per growing season. The component technologies developed into a package and disseminated to farmers included a bacteria wilt resistant tomato variety MT56, mulching, staking, and a minimum spray schedule of 3–4 pesticide sprays per season. Impact assessments indicated that yields were 40 % higher when the package was used and reduced production costs (by reducing the number of sprays) that led to higher net revenues for IPM-practicing tomato farmers. Use of MT56 and mulching led to a 21 % reduction in production costs and led to an internal rate of return of 250 % if adopted. Use of tomato variety MT56 reduced production cost by 21 % with a Benefit: Cost ratio of 770. Other IPM technologies developed included grafting using bacterial wilt resistant rootstocks; seedling production using low tunnel systems for pest/vector exclusion; and good nursery management practices.

J. Karungi (✉) • R.N. Ssonko • J. Bonabana-Wabbi • S. Kyamanywa
School of Agricultural Sciences, Makerere University, 7062, Kampala, Uganda
e-mail: jkarungi@caes.mak.ac.ug; jkarungitumu@yahoo.com; jtumutegyereize@gmail.com; rmirembe@caes.mak.ac.ug; jbonabana@caes.mak.ac.ug; skyamanywa@gmail.com

J.M. Erbaugh • S.A. Miller
Department of Plant Pathology, The Ohio State University,
227 Selby Hall, 1680 Madison Ave., Wooster, OH 44691, USA
e-mail: erbaugh.1@osu.edu; miller.769@osu.edu

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Introduction

Over the past two decades, smallholder famers in Sub-Saharan Africa (SSA) have been encouraged to produce horticultural crops to enhance incomes and improve household nutrition (Delgado et al. 1998; Doward et al. 2004; Weinberger and Lumpkin 2005; World Bank 2007). The demand for horticultural produce is being driven by urbanization, increasing incomes, exports and a growing awareness of the nutritional benefits of such crops (World Bank 2007). Vegetables are an important source of many essential micronutrients including vitamins A, C and K, folate, thiamine, carotenes, several minerals, and dietary fiber. This is especially pertinent for SSA where one-third of preschool children suffer from vitamin A deficiency (WHO 2007). Increased demand has led to increased employment opportunities through expansion of value chain suppliers and increased agro-processing and marketing of processed foods. Thus, diversifying smallholder production systems into horticultural production has been advocated as an agricultural and rural development strategy in sub-Saharan Africa.

The emphasis by many governments and foreign donors in East Africa (EA) on intensifying the production of marketed vegetable crops for domestic, regional and international markets has led to changing agricultural practices, including input-intensification, that have induced a changing set of pests leading to increased losses, and a resultant increase in the use of synthetic pesticides. In turn, increased pesticide usage has led to pest resistance and resurgence, increased cost of production, food safety and human health concerns, and a decline in bio-diversity (Puz-y-Mino et al. 2002; Matthews et al. 2003; Ntow et al. 2006; Ngowi et al. 2007). Horticultural production worldwide accounts for 28 % of global pesticide use (World Bank 2007). This has created a strong demand for IPM research and the development of alternative management strategies that are less reliant on synthetic pesticides.

In Uganda, land under vegetable production increased by 30 % during the period of 1993–2003 (Ssonko et al. 2005). Among the main vegetable production constraints are insect pests and diseases and most producers of these crops rely on synthetic pesticides as their primary method of pest control. Pesticide use has increased in Uganda because pesticides are perceived to be effective in protecting higher value crops and alternative pest management practices are unavailable. Past agricultural research efforts largely focused on pesticide efficacy trials and ignored the development of pest management alternatives (IPM CRSP 2007; Karungi et al. 2011). However, there are growing concerns regarding pesticide usage including pest resistance, increased production costs, and negative impacts on human health and the environment. For vegetable production in Uganda to be sustainable, the IPM

CRSP engaged in an integrated pest management research program to develop safer and more effective pest management alternatives that reduce or supplant the use of synthetic pesticides and maintain high productivity levels.

Integrated pest management (IPM) is promoted as an alternative to sole reliance on chemical pesticides. Its primary goal is to manage destructive pest populations using a variety of practices including pest monitoring, biological controls, host plant resistance and cultural practices while attempting to reduce or eliminate the use of chemical pesticides. These component practices are then combined to form a pest management system. It is considered to be a cost effective, environmentally friendly and appropriate technology for small holder African producers.

Except in cases of higher value export crops, for example cotton, many attempts to implement IPM in developing countries over the past three decades have met with limited success (World Bank 2007; Orr 2003; Morse and Buhler 1997). A variety of policy, research and socioeconomic factors are acknowledged to have constrained IPM adoption. Others have indicated that the central problem is one of transferring IPM knowledge and systems to farmers (Erbaugh et al. 2007; Rajotte et al. 2005; World Bank 2007; Dent 1995). Increasing farmer participation in the development and implementation of IPM programs emerged as a strategy for increasing the relevance and adoption of IPM, particularly among smallholder farmers (Erbaugh et al. 2002; Yudelman et al. 1998).

Prioritizing Tomato and Developing an IPM Research Strategy

The IPM CRSP (Collaborative Research Support Program, currently known as IPM Innovation Lab) began implementing a participatory IPM program with tomato growers in Uganda in 2002. Tomato was selected as a focal crop for project activities because it was the most highly ranked horticultural crop in a 2006 regional survey of crop priorities conducted by the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) and because it met two other important project criteria. First, tomato is an important commercial (cash) crop that is grown predominately by small scale producers (2 ha.) including women for home consumption and domestic markets (Mwaule 1995; Mukiibi 2001; Kasenge et al. 2002; Ssonko et al. 2005). Second, baseline assessments of small scale producers in Uganda found tomato production to be associated with the excessive use of synthetic pesticides with producers commonly reporting the application of pesticides 12–24 times per season (Akemo et al. 2000). These same assessments indicated that farmers were unaware of alternative means of managing pests and thus were totally reliant on synthetic pesticides as their sole means of pest control.

Participation, as an agricultural development strategy, emerged in recognition that traditional top-down technology development and transfer programs were having only limited impacts at the farm level. Involving farmers in the research process,

through their participation, was advocated as a method to adapt and improve the appropriateness and adoption of agricultural technologies. An objective of farmer participation in agricultural research, or what is known as (PAR), is to work with farmers to develop appropriate agricultural technologies to meet their production needs. This objective was particularly relevant to the IPM CRSP program in Uganda because farmer knowledge of pests and pest management alternatives to synthetic pesticides were lacking. Increasing farmer participation in the IPM CRSP program through their engagement in each step of the research process, from problem identification to on-farm trials, emerged as an important strategy for increasing the relevance and use of IPM, particularly among small-scale tomato growers in Uganda. This approach was called participatory IPM (PIPM) by the IPM CRSP.

Two objectives guided our PIPM approach: First, was to work with farmers to develop appropriate agricultural technologies to meet their production needs. This objective was particularly relevant to IPM programs in Uganda because effective pest management alternatives to synthetic pesticides were not available – or on the shelf. A second objective emerged as important in our work with small scale farmers, and that was to raise their knowledge and understanding of biological factors and ecological interactions, so as to improve their capacity to manage pests and diseases and to produce a healthy crop. Since both objectives require information and knowledge sharing among farmers, scientists and extension agents to be effective, our IPM program came to be increasingly linked to participatory research and extension approaches.

Establishing Tomato Priorities

The initial farmer and biological baseline assessments (see Table 13.1) conducted by the IPM CRSP and other development partners established that low tomato yields were mainly attributable to the high incidence of pests and diseases, lack of improved varieties, and growers lacking knowledge of alternative pest management practices and good agricultural practices for growing tomato (Mwaule 1995; Akemo et al. 2001; Kagezi et al. 2001; Ssonko et al. 2005; Ssekyewa 2006; Table 13.1). The baseline assessments established that the most important diseases and arthropod pests were Late and Early blights (*Phytophthora infestans* and *Alternaria solani*); bacterial wilt (*Ralstonia solanacearum*); root knot nematodes (*Meloidogyne* spp.); African bollworm (*Helicoverpa armigera*); thrips (*Thrips* spp. and *Frankliniella* spp.); whitefly (*Bemisia tabaci*); aphids (*Aphis* spp. and *Myzus persicae*); and mites (*Polyphagotarsonemus latus* and *Tetranychus* spp.) (Mwaule 1995; Akemo et al. 2001; Kagezi et al. 2001; Ssonko et al. 2005). Later country surveys determined that the most prevalent tomato viruses were *Tomato mosaic virus* (*ToMV*), *Tobacco mosaic virus* (*TMV*), *Cucumber mosaic virus* (*CMV*), *Tomato yellow leaf curl virus* (*TYLCV*) and potyviruses with incidences in farmers' tomato fields ranging between 11 % and 88 % (Ssekyewa 2006; Arinaitwe 2013).

Table 13.1 Farmers reports of tomato production constraints in Central Uganda

Problem	Local name	% of farmers reporting problem
Blight	Kubabuka	100
Wilting	Okuwotoka	100
Mixing pesticides	Okutabula eddagala	100
Blossom end rot	Okuvunda muntobo	80
Correct spraying methods	Enfuyira entuufu	60
Insect pests e.g. boll worm	Obusaanyi, etc.	100
Cutworms and crickets	Akawuka akassala obuboga obuto- kasanyi	100
Flower abortion	Ebimuli bikunkumuka	80
Thrips	Obuwuka obudugavu nga butono	80
Stunting, leaf distortion, curling, crinkling, mosaic	Okugengewala	60
Expensive sprayers	Ebbomba tezigulika	80
Poor market prices	Katale kafu	100
Purely vegetative tomato growth	Temulisa	100

Source: Akemo et al. (2000)

The IPM CRSP farmer baseline assessment conducted in the central region districts of Wakiso and Mpigi determined that the predominant management practice used by tomato growers to control the pests and diseases was synthetic pesticides (Akemo et al. 2000). A wide range of pesticides was identified with the most commonly mentioned being Permethrin (Ambush©), Fenitrothion (Sumithion©), Dimethoate, Nurelle-D© (combination of Cypermethrin and Chlorpyrifos), Cypermethrin (Sherpa©), Chlorpyrifos (Dursban©), Dithane M45 (Mancozeb©), Metalaxyl, and Ridomil© (Mancozeb + Metalaxyl) and the herbicides Salute (Trifluralin) and Zancor (Metribuzine) (Akemo et al. 2000). Very few farmers used herbicides, with most indicating that they weeded by hand or used hoes, depending on the growth stage of the plant. Fungicides were the most commonly used pesticides because fungal blights, especially late blight (*P. infestans*), were prevalent and if left unsprayed resulted in crop losses greater than 75 % (Akemo et al. 2000). Farmers' indicated that they routinely sprayed fungicides with the majority spraying as often as twice per week throughout the tomato growing season. Some farmers also indicated that they used fungicides to control bacterial wilt although there is no known chemical control yet available for this disease. Pesticides were commonly mixed in backpack sprayers by hand and the practice of mixing several pesticides together into a "cocktail" was common. Additionally, the majority of the farmers was unable to read pesticide labels and application rates were arbitrarily measured using table spoons and bottle tops (Akemo et al. 2000). Only a few farmers used specialized protective clothing while spraying.

Farmers were only vaguely familiar with health problems related to pesticide exposure with a few mentioning nausea following spraying and several women indicating that men do the spraying because it was unhealthy for pregnant women to do

so. Farmers' were generally unaware of the long-term health risks from exposure to pesticides including the potential for cancer development and endocrine disruption resulting from exposure to fungicides containing mancozeb (Novikova et al. 2003). The dithiocarbamate family of fungicides is also suspected to have reproductive (Restrepo et al. 1990) and mutagenic effects in human cells (Puz-y-Mino et al. 2002). The farmer practice of excessive, unsafe use of pesticides eventually led the IPM CRSP team to develop a short field-based course for farmers on safe and correct pesticide usage and safety. This course was provided four times in Uganda and then was taken and used with growers in Kenya and Tanzania.

Developing Components of an IPM Package for Tomato

From 2002 to 2014, the IPM CRSP (IL) team in Uganda developed and disseminated alternative pest management options for managing priority pests and reducing pesticide usage on tomato. The IPM package for tomato that was eventually developed consisted of nursery management practices (soil sterilization), a bacterial will resistant tomato variety MT56, mulching, staking and three sprays per season.

Bacterial wilt (*Ralstonia solanacearum*) was the most important and consistent pest constraint on tomato causing up to 100% crop loss in some areas of Uganda. It is perpetuated in the soil and can be carried from one field to another on shoes, farm implements or vehicles and through irrigation and surface water. Management of *R. solanacearum* is difficult owing to its wide host range, the latency of the pathogen and lack of chemical controls. There are no chemicals known to be effective against the disease. Most of the commercially grown cultivars in Uganda such as Roma, Marglobe, Heinz, Moneymaker, Onyx and local Nganda were highly susceptible (Akemo et al. 2001). As a result, control strategies for *R. solanacearum* relied on manipulating cultural practices and host plant resistance. One novel approach investigated by the IPM CRSP was grafting susceptible, yet market preferred tomato lines, onto resistant root stocks.

Resistant Varieties

The search for resistant germplasm focused on the bacterial wilt disease caused by *R. solanacearum*. In 1987, a research program on tomatoes was initiated at Makerere University with a view of developing tomato varieties that would be high yielding and well adapted to various ecological conditions of Uganda. Twenty three introduced tomato cultivars formed the foundation of the research. MT56 was one of introduced cultivars. It was brought in from the Ohio Agricultural Research Development Center (OARDC) Tomato Breeding Program in the USA. MT56 and MT55 proved to be among the cultivars with the greatest potential in terms of yield parameters and resistance to *R. solanacearum* (Rubaihayo and Rusoke 1992). As a result of their performance, MT55 and MT56 formed the basis for future work by the IPM CRSP. In 1999,

in an on-farm trial laid out in a RCBD with four replications, MT55, MT56, Redlander (from Australia), and a local tomato as a control were evaluated. Results from participatory trial evaluations with farmers indicated that they preferred MT56 because of its heavy flowering and fruit setting (Akemo et al. 2000).

Confirming the Performance of MT56 in Different Agro Ecological Zones in Uganda

Over a 10 year period, research conducted in Uganda by the IPM IL continued to demonstrate the performance of MT 56 and its superior resistance to *R. solanacearum*. In 2010, the IPM IL in Uganda set out to confirm the performance (adaptability, stability and survival) of MT56 for a release application as a commercial tomato variety. A randomized complete block design (RCBD) was used to set up multi-location trials with five tomato genotypes (MT56 vs. four commercial varieties grown in the country: Tenjeru, Marglobe, Moneymaker and Roma) and replicated three times in six different agro-ecological areas of Uganda. The results from the multi-locational trials showed that MT56 was consistent in resistance to bacterial wilt and the best performer in terms of yield and survival among the genotypes and was stable across all sites evaluated (Fig. 13.1; Asiimwe et al. 2013). The trials confirmed and verified MT56 resistance to *R. solanacearum* in different locations in the country. This information, and required verifications including the validation of performance in different seasons and different agroecological zones; and compilation of genetic background and variety description were submitted to the Ugandan National Varietal Release Committee in 2012. MT56 has made a great impact in the central region of Uganda (New Vision daily paper, March 6, 2012).

Grafting

Another option for managing bacterial wilt developed by The IPM CRSP Uganda team was grafting susceptible tomato lines onto resistant root stocks. This practice had been applied extensively in Asia, but was relatively new to the East Africa region (Matsuzoe et al. 1990; Ibrahim et al. 2001; Black et al. 2003). In Uganda, this work began with on-station field trials to assess the performance of bacterial wilt susceptible tomato grafted onto three indigenous solanaceous (*Solanum* spp.) rootstocks (Magambo et al. 2003). The indigenous rootstocks used were *Solanum complycanthum* (locally known as Kitengotengo), *Solanum indicum* (Katunkuma) and *Solanum* sp. (Katengotengo). 'Onyx', a susceptible commercial variety was used as the scion. Ungrafted 'MT 56' and 'Onyx' were included as bacterial wilt resistant and susceptible checks, respectively. A randomized complete block design was used with three replicates. Data was collected on pest and disease incidence, growth and yield parameters from ten plants per plot.

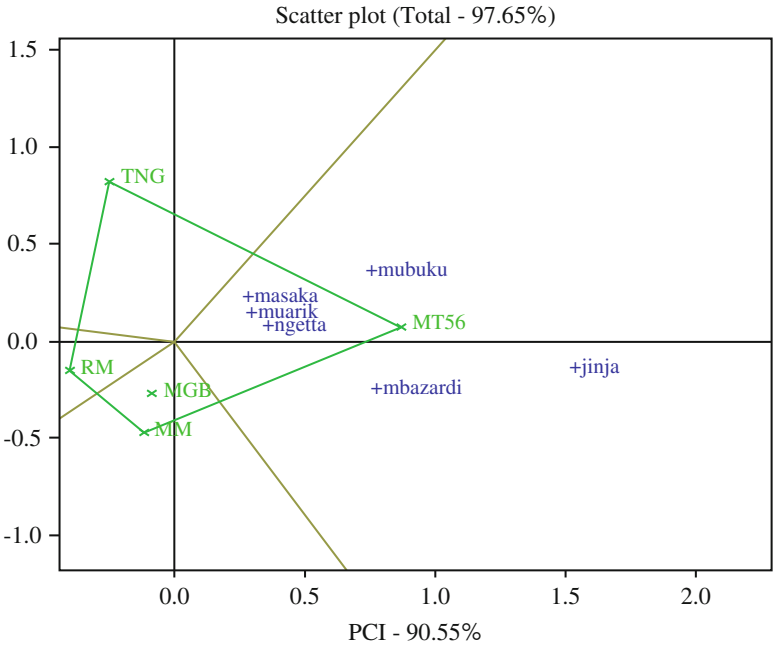

Fig. 13.1 A scatter GGE biplot for tomato yield (kg/ha) obtained from the five evaluated genotypes across the six evaluation sites (Where: *MGB* Marglobe, *TNG* Tengeru-97, *RM* Roma, *MM* money maker; Locations (districts): mbazardi = Mbarara, Ngetta = Lira, muarik = Wakiso, mubuku = Kasese, Masaka and Jinja) (Source: Asiimwe et al. 2013)

All rootstocks united readily with the tomato variety although an overgrowth occurred at and above the graft union, indicating higher growth rate and/or vigor of Onyx compared to that of the rootstocks. Results indicated that grafting significantly affected the incidence of *R. solanacearum* on tomatoes (Fig. 13.2). Bacterial wilt incidence was highest on un-grafted Onyx, the susceptible tomato variety, followed by Onyx grafted on *S. indicum* root stock. The lowest incidence was on Onyx grafted on Kitengotengo, although this was not significantly different from that of tomato variety MT 56 and Katengotengo. Additionally, fruit yield per plant was significantly different for the different treatments (Fig. 13.3). The highest fruit yield and was recorded on MT56 plants while the lowest was on ungrafted Onyx. All ungrafted Onyx plants were destroyed by *R. solanacearum* in the early stages of growth and therefore did not produce any fruit. Tomato variety MT 56 produced the highest yield of 2.84 kg/plant, which was more than three times ($P>0.05$) higher than that of the grafted plants.

These results indicated that although the indigenous solanaceous rootstocks, *Kitengotengo* and *Katengotengo* conferred bacterial wilt resistance to the commercial tomato variety through grafting, they appeared to have a negative effect on tomato yields. The recommendation was that grafting using these indigenous solanaceous rootstocks was an economically viable IPM practice for areas where soils were infested with bacterial wilt disease, and bacterial wilt tolerant or resistant tomatoes were not readily available.

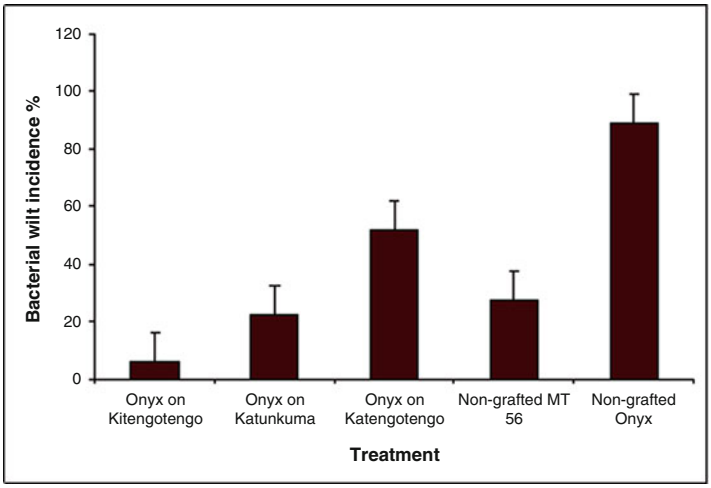

Fig. 13.2 Effect of grafting on incidence of bacterial wilt on tomato (Source: Ssonko et al. 2011)

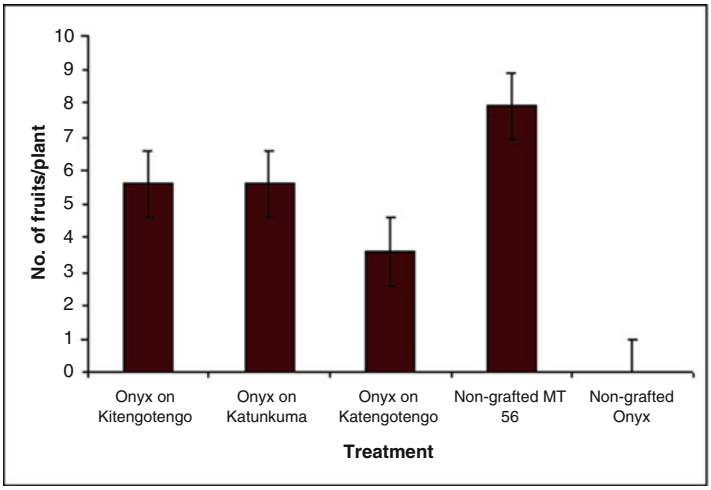

Fig. 13.3 Effect of grafting on tomato yield (Source: Ssonko et al. 2011)

Later grafting efforts focused on using MT56 as rootstock for popular but highly susceptible tomato varieties in the country. In a study, five treatments: Heinz 1370 VF, Money Maker, Marglobe, and Tanya were grafted onto MT56 and along with non-grafted MT 56 used in a randomized complete block design with three replications. Results indicated that MT56 made strong unions with other tomato varieties. Results on fruit yield indicated that the mean weight per fruit of tomatoes varied significantly among the treatments (Fig. 13.4). Un-grafted-MT 56 had the highest weight per fruit compared to the other tomato varieties grafted on MT 56 (Ekepu 2013).

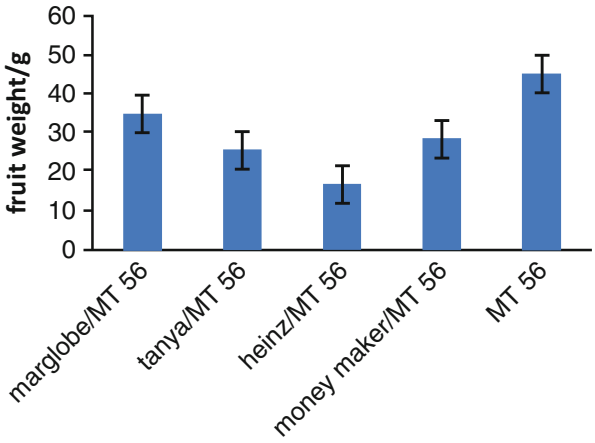

Fig. 13.4 Effectiveness of grafting tomato-on-tomato

MT 56 was later transferred to the Kenya IPM IL site and used as a bacterial wilt resistant rootstock for grafting onto commercially preferred varieties because the fruit shape of MT 56 was less preferred in Kenyan markets. Grafting trials with MT 56 in Kenya again indicated that grafting significantly reduced the incidence of *R. solanacearum* and increased fruit yield. This has resulted in the variety being widely disseminated in Kenya as a rootstock and the emergence of small entrepreneurs who specialize in producing the grafted seedlings.

Cultural Practices

Mulching and staking of tomato were introduced as cultural practices to reduce mechanical disease transmission, suppress weeds, modify soil temperature and conserve moisture. For these reasons, mulching is considered to be a good agricultural practice. Mulching is less well known as a soil borne disease prevention practice. Mulching around tomato plants can prevent the transmission of fungal and bacterial pathogens by reducing the impact of rain drops and the concomitant splashing of disease spores and bacterium onto plants. This is important because major fungal diseases affecting tomato in Uganda including Late and Early blights (*P. infestans* and *A. solani*), and Fusarium wilt (*Fusarium oxysporum* f. sp. *lycopersici*) have spores that form on the surface of leaves and can be transmitted by wind or rain. Infected plant material can serve as a future source of inoculum and remain in the soil for long periods of time.

Beginning in 2005, a series of on-station and on-farm trials were conducted to assess the effects of cultural practices in managing insect pests and diseases. The cultural components were first assessed individually and then later trials combined these components. The individual treatments were: (i) mulching (using straw mulch), (ii) staking tomato plants, and (iii) untreated tomato plants as a check. MT 56 was the tomato variety used in the study. The treatments were arranged in a randomized complete block design with three replications.

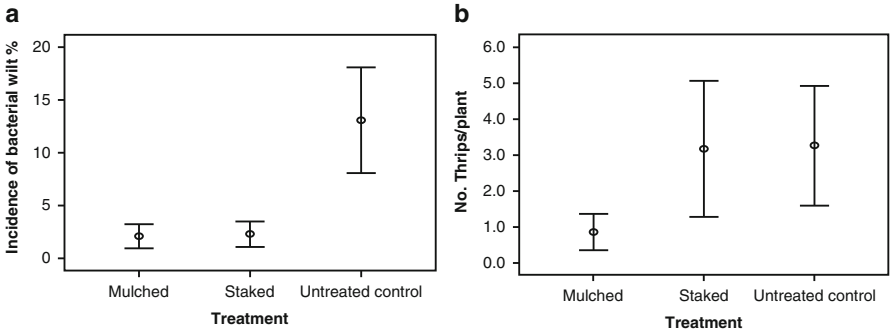

Fig. 13.5 (**a**) Incidence of bacterial wilt on tomato in the different treatments over three seasons. (**b**) Occurrence of thrips on tomato in the on-farm treatments

Results from three rounds of on-station trials indicated that bacterial wilt and fruit yield were significantly affected by treatments ($P<0.05$). Mulching and staking of tomato plants greatly reduced incidence of bacterial wilt on tomato, when compared with the untreated plants (Fig. 13.5a). Mulched plants gave the highest fruit yield followed by staked plants and the untreated plants yielded the least. Results from on-farm validation trials indicated that the treatments significantly affected thrips population ($P<0.05$). Thrips populations were lowest on mulched plants and highest on untreated plants though populations on the latter were not significantly different from those of staked plants (Fig. 13.5b). Mulching also reduced the occurrence of weeds; reduced irrigation frequency from three to one watering per week; reduced the incidence of soil borne fungal diseases and was associated with reduced use of fungicides.

Tomato Viruses and Low-Tunnel Systems for Virus Disease Management

A field survey was conducted to assess the incidence and severity of viral diseases in tomato fields in eight major growing districts in Uganda (Arinaitwe et al. 2013). The most frequently found viral diseases were *Tomato mosaic virus (ToMV), Tobacco mosaic virus (TMV)*, *Cucumber mosaic virus (CMV)*, Potyviruses and *Tomato yellow leaf curl virus (TYLCV)*. Results showed that about 15 % of the surveyed fields had a virus disease incidence of >90 %.

The IPM IL team conducted trials to evaluate the effect of row covers and screen house seedling production on whitefly infestation and transmission of *TYLCV*. The incidence of viral diseases in Uganda is attributed to the prevalence of insect vectors, notably aphids (*CMV*) and the white fly (*TYLCV*). Insect barrier row covers (= low tunnels) have been shown to successfully reduce whitefly population levels, and reduce or delay the incidence of whitefly transmitted viruses (Natwick and Durazo 1985; Karungi et al. 2013). Studies on tomato (Abaasa 2010; Jurua et al. 2014) in

Uganda showed that insect proof row covers used in the nursery and in the field can greatly reduce insect vector and virus disease incidence. Results over two growing seasons in 2013 showed that for the duration of the application, insect proof plastic row covers kept aphids and white flies off the protected plants and reduced the occurrence of vectors. Also, the row covers significantly reduced incidence and severity of *Cucumber mosaic virus (CMV)* and *Tomato yellow leaf curl virus (TYLCV)*.

In Kenya seedlings produced in a screen house and then transplanted to the field were compared to seedlings produced in unprotected nurseries. The screen house seedlings were generally more vigorous, had lower whitefly infestations and lower incidences of virus. The highest yield (34 t/ha) was recorded from the seedlings raised in the screen house. The lowest yields were recorded for seedlings produced in unprotected nurseries (20 t/ha).

Reduced Pesticide Applications

In order to reduce the number of spray applications on-station trials were conducted to assess the effect of different spray schedules on pest/disease incidence and crop yield. The experiment used a randomized complete block design with six treatments that were replicated four times. The treatments were: (**T1**) spraying once every week with a mixture of Dimethoate and Agrolaxyl chemicals to control both insect pests and disease, (**T2**) spraying the mixture once in vegetative growth and once during flowering, (**T3**) spraying the mixture twice during flowering and twice during fruiting, (**T4**) weekly application of Agrolaxyl fungicide sprays only, (**T5**) weekly application of Dimethoate insecticide only, and (**T6**) untreated/unmulched. Results on fruit yield and cost-effectiveness of the different spray schedules indicated the most profitable spray schedule was where two sprays of the mixture of the fungicide and insecticide were applied once in vegetative and flowering stages. Weekly sprays with the fungicides brought negative returns (Table 13.2).

Table 13.2 Mean yields of marketable tomatoes and marginal returns for the different pesticide spray schedules

Treatment	Yield Kg/ha	Yield gain over control Kg/ha	Gross returns* (Ug.Sh/ha)	Cost of sprays (Ug.Sh/ha)	Net returns* (Ug.Sh/ha)
T1	1343	869	1,738,000	1,252,571	485,429
T2	1240	766	1,532,000	313,143	1,218,857
T3	1261	787	1,574,000	776,286	797,714
T4	1026	552	1,104,000	1,200,000	−960,000
T5	1100	626	1,252,000	52,571	1,199,429
T6	474	–	948,000	–	–
L.S.D	529.9	–	–	–	–

*Market price of tomatoes was 2000/= per kilogram; In calculating net returns other input costs were kept constant apart from costs associated with pesticide (chemical) usage (Source: Tumwesigye 2012)

Participatory Field Assessment of Tomato IPM Components

For two consecutive seasons in 2013 (A and B), the Kiwenda Tomato Growers Association hosted the tomato IPM modified Farmer Field School (FFS) in Wakiso district. The IPM treatments tested by the school combined component technologies at different levels including: (**1**) Staking+mulching+3 sprays a season+MT56 tomato variety; (**2**) Mulching+3 sprays a season+MT56; (**3**) Weekly sprays+MT56; (**4**) Mulch+MT56 and (**5**) MT56 only (control). The sprays were a fungicide (Agrolaxyl) and an insecticide (Dimethoate). The treatments were set up in randomised block design with three replications. These were set up in 5×5 m plots. The plants were planted at a spacing of 60×45 cm. Data was collected to establish the effect of the packages on insect pest and disease occurrence and severity, and on yield. Results indicated that the IPM packages significantly affected occurrence of aphids, white flies and leaf miners as well the severity of late blight and viral diseases on tomato (Table 13.3). Marketable yield was also significantly affected by the treatments with IPM technologies significantly increasing fruit yields over the untreated; and yielding comparably or sometimes even higher than the weekly sprayed plots (Table 13.4).

Impact Assessment of Tomato IPM Activities in Uganda and East Africa

In Uganda, the major constraints addressed were late blight, bacterial wilt, viruses, bollworm, aphids and white flies. Baseline farmer surveys had indicated that farmers were spraying a variety of pesticides 12–24 times per growing season. The technologies developed into a package and disseminated to farmers included a bacterial

Table 13.3 F statistics for the combined analysis of the effect of IPM technologies and sampling date on insect pest infestation and disease severity on tomato at the Kiwenda FFS

	F statistics					
Source	d.f	Aphids/ plant	Whiteflies/ plant	Leafminers/ plant	Late Blight severity	Viral disease severity
Treatment	4579	4.549***	26.810***	5.516***	13.001***	6.316***
Sampling date	3579	1.362	14.153***	4.650**	161.278***	27.438***
Treatment × Sampling date	12,579	3.673***	3.826***	1.373	6.689***	3.001***

Values with asterisks indicate significance: ***0.001; **0.01; *0.05; whereas values without asterisks indicate no significance

Table 13.4 Effect of IPM treatments on yield (number of fruits per plant) at the Kiwenda FFS in 2013

Treatment	2013A	2013B
Staking+mulching+3 sprays a season+MT56 tomato variety	8.70 a	19.40 a
Mulching+3 sprays a season+MT56	7.93 a	19.07 a
Weekly sprays+MT56	9.67 a	10.63 b
Mulch+MT56	8.10 a	4.53 c
MT56 only (control)	4.23 b	2.43 c
Mean	7.73	11.21
LSD	2.934	3.091
P-Value	0.005	<0.001

Means in a column followed by the same letter are not significantly different at $P < 0.05$

wilt resistant tomato variety MT56, mulching, staking, and a minimum spray schedule of 3–4 pesticide sprays per season. Impact assessments indicated that yields were 40 % higher when the package was used and reduced production costs (by reducing the number of sprays) that led to higher net revenues for IPM-practicing tomato farmers. Use of MT56 and mulching led to a 21 % reduction in production costs and led to an internal rate of return of 250 % if adopted. Use of tomato variety MT56 reduced production cost by 21 % with a Benefit: Cost ratio of 770 (IPM IL 2014).

Based on the reduced number of sprays (from 12 per season to 3), profitability was increased by $500 per hectare for tomato producers. A rough estimate of the extent of tomato production in the agro-ecological zones where trials were conducted is 2000 ha. Given the cost savings from reduced spraying, the potential increase in profits is $1 million if all the farmers in the agro-ecological zone adopted the IPM practices. In addition to these potential benefits it is expected that the benefits from reduced human exposure to pesticides and their adverse health impacts, as well as reduced environmental impacts would be substantial.

Economic surplus modeling was used to estimate benefits from adoption of six IPM technologies developed by the IPM IL project in East Africa to improve tomato production. Results indicate that IPM adoption results in yield increases ranging from 54 to 268 % depending on the adopted technology. IPM technologies reduced costs ranging from 70 % (in the case of grafting and high tunnels in Kenya) to about 6 % (mulching in Uganda). The study shows that the internal rates of return for six technologies exceeded the market interest rate implying that all were worthwhile interventions with positive net present values that ranged from $820,000 onwards. Summing over the six interventions, the aggregate undiscounted impacts each computed over a 20-year period amount to $526 million achievable between 1994 and 2014 (IPM IL 2014).

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