Chapter 29

Optimization of Late Blight and Bacterial Wilt Management in Potato Production Systems in the Highland Tropics of Africa

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Abstract Late blight and bacterial wilt are two formidable disease constraints on potato and account for significant losses in Sub-Saharan Africa (SSA). In this chapter, various management techniques for late blight and bacterial wilt diseases are highlighted with examples drawn from diverse research. The modified disease management approaches include resistant cultivars, reduced fungicide applications, disease monitoring based on field scouting, cultural practices, post-harvest management and farmer training. Deployment of cultivars with resistance genes and quantitative resistance in addition to fungicide use has contributed significantly to sustained late blight management in tropical Africa. Similarly, cultural practices such as date of planting, disease-free tubers, roguing and bio-rational approaches (plant-derived extracts and phosphoric acid) have been used to a lesser degree. Disease monitoring and weather-based predictions in relation to fungicide applications have been utilized in conjunction with host-plant resistance. Similarly, bacterial wilt has been successfully managed through non-chemical means which include

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crop rotation, sanitation (removal of wilted plants, destruction of crop residues), and minimum post-emergence cultivation of potatoes. Small-scale seed plot technique, non-diseased tubers, soil amendments and less susceptible cultivars have been important components for integrated management of bacterial wilt disease. The holistic approach for control of late blight and bacterial wilt ultimately lead to increased potato production and better economic returns in the diverse potato production region of SSA.

29.1 Introduction

Potato (*Solanum tuberosum* L.) production in Africa as a whole has increased tremendously, from 1.3 million tons in the early 1960s to 16.7 million tons in 2007 (FAO-CIP 1995; Scott et al. 2000). Potato consumption is increasing in the developing countries and accounts for more than a third of the global harvest. The potato's ease of cultivation and high energy content has made it a valuable cash and food crop for millions of farmers in Africa. The crop has grown in importance as food in rapidly growing urban areas. Potato is the fastest growing major crop in the great lakes area of Uganda, Rwanda, Burundi, and Democratic Republic of Congo (East and Central Africa), where it has increased by about 250% since the mid 1990s (FAO-CIP 1995). In these production areas, potatoes play an important role as both cash and subsistence crop for highland farmers.

Broadly, there are three major potato production systems in tropical Africa. In the densely populated, high-potential highland regions (1,800–2,750 m) of eastern and central Africa, potatoes are grown by small-scale farmers (0.5–2 ha) for the fresh produce market and for home consumption. In these production regions, tuber yields range from 5 to 20 tons ha^{-1}, with average production of 8–10 tons ha^{-1}. In the highland tropics of East and Central Africa, inputs such as seeds, fertilizers, fungicides and some insecticides are utilized to a varying degree (Olanya et al. 2001a; Namanda et al. 2004; Nyankanga et al. 2004). The rates for chemical fertilizers and fungicide use vary widely among potato farmers, countries and production regions, but are generally low because the high costs of pesticides are prohibitive to many farmers (Ojiambo et al. 2001; Olanya et al. 2001b; Mukalazi et al. 2001; Muchiri et al. 2009). However, supply of some farm inputs such as seed is often unreliable or chemicals for pest control are used incorrectly. Seed inputs are primarily obtained from informal, local sources where production practices are often minimally regulated and the average seed quality is low. Late blight, bacterial wilt, and potato viruses are the most important biotic constraints contributing to low yield and significant losses.

In West Africa, potato is principally produced in Cameroon and Nigeria, where production of potatoes is an important small holder crop in higher elevations of the Cameroon highlands and the Jos Plateau, respectively (Fontem and Aighewi 1993; Fontem et al. 2001). Elsewhere in West Africa, potato is grown on a very limited scale as a high-value vegetable crop, and usually under irrigation production. In southern Africa region, potato is primarily produced in the Republic of South Africa.

In this region, potato is grown on a relatively large scale in this modern farming, high input system. Irrigation is an important component of potato production, where good-quality seed and other high inputs are used intensively. The average yield is relatively high and ranges from 15 to over 25 tons ha^{-1} in South Africa. Potato production in most developing countries is characterized by low yields (Scott et al. 2000).

Many factors other than disease cause yield instability in Africa. These include low soil fertility, water stress and frost. Although potato is the principal food security crop in the tropical highlands of sub-Saharan Africa, its sustained production is constrained by major pests and diseases, particularly late blight (LB), bacterial wilt (BW) and viruses. Late blight caused by *Phytophthora infestans* (mont.) de Bary occurs throughout the main potato growing regions in the tropical highlands and is by far the most important disease constraint impacting the crop (Fontem et al. 2005; Olanya et al. 2001a, b; Nyankanga et al. 2004). Whereas late blight can be controlled by fungicides, bacterial wilt lacks economically feasible chemical control strategies, resulting in both yield and quality losses.

Bacterial wilt (*Ralstonia solanacearum* (Smith) Yabuuchi) is also a major production impediment at lower elevations of less than 800 m above sea level (m.a.s.l) and higher elevations greater than 1,000 m above sea level (Kinyua et al. 2001, 2005). The disease is also important particularly in farming practices where solanaceous crops such as tomatoes, egg plants, and pepper is rotated with potato (Katafire et al. 2005). Early blight, caused by *Alternaria solani* occurs towards the end of the cropping seasons and in the drier production areas. Generally, the disease causes less damage on potato compared to late blight and bacterial wilt. Black scurf (*Rhizoctonia solani*) and black leg (*Erwinia spp.*) have also been reported as minor constraints to potato production.

Potato viruses similarly pose significant production constraints in various regions. The major potato viruses reported or documented in tropical Africa include: Potato leaf-roll virus (PLRV), Potato virus Y, and Potato viruses A, S, X, as well as alfalfa mosaic virus. The aphid-transmitted PLRV and PVY cause the most losses, especially in seed stocks retained by farmers and in situations where seed lots are obtained through the informal seed trade. Aphid-borne viruses are known to spread in rustic diffused light-storage facilities. PVX is also widespread and its incidence is high throughout all potato-growing areas, often reaching over 90% in some varieties.

29.2 Occurrence of Late Blight and Bacterial Wilt

29.2.1 Late Blight Occurrence and Economic Importance

Late blight is the most important potato disease in the tropical region of Africa. The disease has been reported in the potato growing countries of Sub-Saharan Africa ranging from East, Central Africa, and West Africa to Southern Africa. Disease distribution and severity is mainly confined to the highland regions

(1,800–3,000 masl) and on potato and tomato hosts. Variation in yield losses caused by late blight have been documented in several countries and have been shown to range from 30% to 75% on susceptible cultivars (Olanya et al. 2001a). Under experimental conditions at research stations, potato yield losses attributed to late blight range from 2.7% to 47% in Ethiopia (Bekele and Hiskias 1996). At Kalengyere Research Station in Uganda, yield losses of up to 20% have been reported in a season with low late blight pressure (Mukalazi et al. 2001). Similarly, yield increases in excess of 20% have been recorded under on-farm situations in Kiambu, Kenya (Njuguna et al. 1998). The disease is less significant in the drier areas of southern Africa. Generally, there is limited research on the importance of tuber blight in potato production in Africa (Nyankanga et al. 2007).

The primary sources of inoculum have not been adequately documented. However, the continuous cropping of potato and tomato during the year ensures inoculum presence year-around in tropical Africa. Potato is produced in the highland tropics in multiple cycles, with variations in the quantity planted generally following rainfall and climatic patterns and prevailing commodity prices. The low incidence of tuber blight and the lack of evidence for potato seed-borne infection suggests that tuber blight is not a significant source of primary inoculum in the tropics. Although late blight occurs mainly on potato and tomato, infection of wild hosts belonging to the *Solanum* spp. such as black nightshade (*Solanum nigrum* L.), hairy nightshade (*Solanum sarrachoides* L.), common morning glory (*Pharbitis purpurea* L) or asteraceous species by *P. infestans* may occur (Olanya et al. 2009; Fontem et al. 2004, 2005; Natrass and Ryan 1951). These hosts overlap geographically with potato and provide additional opportunities for pathogen survival and reproduction. Wild *solanaceous* hosts such as pear melon and wild tomato found in humid areas of Ecuador have been implicated in pathogen perpetuation during drier periods of the cropping cycle.

Population studies of *P. infestans* in Sub-Saharan Africa (SSA) have been conducted on isolates from Uganda, Kenya and S. Africa. Mating type tests with A1 tester isolates coupled with DNA analysis revealed that the fungal isolates from Uganda, Kenya and S. Africa are of US 1 clonal lineage, A1 mating type (McLeod et al. 2001; Mukalazi et al. 2001; Ochwo et al. 2002). Variation and lack of consistency in oospore production (10% selfing, 24% mating, and 15% non-oospore producers) have been detected among the isolates from Uganda and Kenya (Mukalazi et al. 2001; Vega-Sanchez et al. 2000). Similarly, variability in metalaxyl sensitivity has been detected among some isolates of *P. infestans* (Mukalazi et al. 2001).

29.2.2 Bacterial Wilt Occurrence and Economic Importance

Bacterial wilt caused by *Ralstonia solanacearum* is the second most important constraint to potato production in the tropical highlands of Africa (Kinyua et al. 2005).

Table 29.1 Presence of *Ralstonia solanacearum* races/biovars and importance in selected countries in some East and central Africa

Country	Races (biovars)	% crop losses*
Burundi	3 (2-A)	30–50
Ethiopia	2 (2-A)	45
Kenya	1, 3 (2-A, 2-T)	50–70 (seed)
Rwanda	3 (2-A)	-
Uganda	1, 3 (2-A)	26–100

*The crop losses resulting from bacterial wilt infections are for potato (*Solanum tuberosum* L.)

The important hosts for this pathogen include species in the family Solanaceae (potato, tomato, egg plant, bitter tomato, tobacco, black night shade, pseudo-apple), Musaceae (banana), Papilionaceae (ground nut) and Zingerbaraceae (ginger) (Hayward 1991). Bacterial wilt is principally soil-borne and primarily disseminated by infected seed tubers (Hayward 1991). The pathogen occurs in many tropical and sub-tropical potato production regions of Uganda, Ethiopia, Kenya, Madagascar, Rwanda, Burundi, Nigeria and Cameroon (Fontem and N'tchorere 1999; Hayward 1991; Boucher et al. 1992; Kinyua et al. 2005).

Two races and 3 biovars of bacterial wilt are known to occur on potato: Race1 biovar 3 and biovar 1, and Race 3 biovar 2 have been reported in the highland tropics (Priou et al. 2005). Race 1 occurs exclusively in tropical lowlands or sub tropical regions where soil never freezes (Denny and Hayward 2001). Race 3 biovar 2 was reported to occur in the same geographic region where late blight is endemic in potato production regions of Uganda, Kenya, Ethiopia, Rwanda, Burundi and Madagascar (Lemaga et al. 2005; Olanya et al. 2001a). Whereas bacterial wilt has been reported in Mali in West Africa (Coulibaly et al. 2002), no identification of the race or biovar has been published. Race 1 (biovars 1, 3, 4), is pathogenic on potato and on a broad range of hosts and are restricted to tropical areas, whereas Race 3, which has a narrow host range (potato and tomato) and a lower optimum temperature, occurs in cool upland areas of tropical regions and warm temperate areas. Due to this low temperature optimum, Race 3 or biovar 2 is the causal organism of bacterial wilt on potato and tomato in some African countries, such as Burundi, Egypt, Kenya, Libya, Reunion, South Africa, and Zambia (CABI/EPPO 1999). According to Elphinstone (2005), *R. solanacearum* Race 1 have been reported in at least 21 countries in Africa; biovar 2 Race 3 has been reported on potato in Burundi, Egypt, Ethiopia, Kenya, Libya, Reunion, Rwanda, South Africa, Tanzania and Uganda. Isolates collected from potato in Kenya, Nigeria and Cameroon were found to have the biovar 2T phenotype. In east and central Africa, races 1 and 3 and biovar 2T have been reported (Table 29.1). Research work conducted in Kenya and in Uganda showed that bacterial wilt disease is extensively disseminated by use of infected seed lots, lack of proper crop rotation and the increase in propagules of *R solanacearum* populations in infested soil (Ateka et al. 2001; Lemaga et al. 2001a, b; Katafire et al. 2005; Kinyua et al. 2005; Smith et al. 2005) (Table 29.1).

29.3 Management of Potato Diseases in the Highland Tropics of Africa

29.3.1 Host Resistance (Resistant Cultivars) and the Management of Late Blight

In the tropical highlands of Africa, host plant resistance is still the most economical and sustainable option for the management of potato late blight. Much of this is driven by the fact that year round availability of disease inoculum would dictate several fungicide sprays for adequate disease control. The use of fungicides for late blight control is, however, limited by the cost and potential detrimental impact on the environment (Hallberg 1989). Many of the traditional potato cultivars grown in the tropical highlands in Africa have very low to moderate levels of resistance to potato late blight.

Foliar resistance to late blight is governed by both qualitative and quantitative genes (Gees and Hohl 1988). Like in many other pathosystems, qualitative resistance for late blight is readily overcome by evolution of new pathotypes that are virulent and more aggressive to the existing qualitative genes (Fry 2008). Thus, several breeding efforts have been designed to breed for quantitative resistance. In the tropical highlands of Africa, the International Potato Center (CIP) in conjunction with the national potato programs in sub-Saharan Africa has undertaken research that has led to the development of genotypes that express horizontal (Landeo et al. 1997) and vertical resistance. The genotypes have been evaluated in multi-location trials in Cameroon, Uganda, Kenya and Ethiopia. Within these countries, some of these genotypes have been selected for adaptability to local conditions and for superior tuber yield and quality (Olanya et al. 2006). For example, at the Kenya regional center for CIP, the cultivars Asante and Tigoni (Table 29.2) were released from a CIP population bred for horizontal resistance free from Resistant (R) genes (Olanya et al. 2006). Similar efforts have led to the release of the cultivars Victoria and Rutuku in Uganda (Hakiza et al. 2000), and Genet and Awash in Ethiopia. The varieties Asante, Tigoni, Victoria and Awash have quantitative resistance to potato late blight, whereas Rutuku possesses qualitative resistance with one or two major *R*-genes. Differences in disease severity (AUDPC) have been detected among these potato cultivars in the tropical highlands and the relative ranking of genotypes have been reported to be consistent across years and locations (Olanya et al. 2006). Specifically, cultivars with major gene resistance (Cruza 148 and Rutuku) consistently show higher levels of resistance than varieties with horizontal resistance. However, cultivars with horizontal resistance (Tigoni, Asante, Genet) consistently had greater yield in presence of high disease pressure and may be more suitable in regions in the tropical highlands where late blight is known to be a common occurrence (Table 29.2).

One aspect of host resistance to late blight that has received little attention is tuber resistance. Unlike foliar resistance, the genetics of tuber blight resistance have

Table 29.2 Late blight severity (area under disease progress curve) and yield of potato cultivars evaluated for disease development at two locations in Kenya in 2001 and 2002

		Loreto		Kabete	
Year	Variety*	AUDPC (% disease days)	Yield (Mg ha^{-1})	AUDPC (% disease days)	Yield (Mg ha^{-1})
2001	Tigoni	703.4 b	17.8 a	23.8 b	41.9 a
	Asante	834.2 b	13.1 ab	18.8 b	45.1 a
	Nyayo	902.1 b	11.8 ab	322.6 a	32.5 b
	Rutuku	323.2 c	15.2 ab	42.4 b	28.7 b
	Genet	334.8 c	11.8 ab	57.9 b	43.1 a
	Kerr's Pink	2248.1 a	2.8 c	427.7 a	16.9 c
	Cruza 148	396.2 c	14.5 ab	42.2 b	35.4 ab
	Awash	980.8 b	9.5 bc	58.9 b	30.6 b
2002	Tigoni	2016.4 c	12.1 b	385.7 b	23.4 ab
	Asante	1799.1 cd	10.8 b	237.3 bc	23.8 ab
	Nyayo	1356.8 de	19.5 a	925.8 a	30.7 a
	Rutuku	193.3 f	13.9 b	36.9 c	12.1 bc
	Genet	952.2 e	12.0 b	378.6 b	23.1 ab
	Kerr's Pink	3086.0 a	3.5 c	1078.8 a	10.0 c
	Cruza 148	1067.5 e	10.4 b	305.8 bc	14.1 bc
	Awash	2612.5 b	5.8 bc	863.1 a	12.5 bc

*Asante, Tigoni, Victoria and Awash have quantitative resistance, whereas Rutuku and Cruza 148 possess qualitative resistance. Nyayo is a local cultivar whose inheritance to late blight is not known. Disease or yield values followed by the same letter are not significantly different at $\alpha = 0.05$ (Olanya et al. 2006)

not been studied extensively. In an effort to develop a model for tuber blight infection, a series of studies were conducted in the tropical highlands in Kenya to determine important weather and foliar resistance variables that influence tuber infection (Nyankanga et al. 2007). Soil temperature, precipitation, tuber depth, and foliar resistance were negatively correlated with incidence of tuber blight. Regression models using these variables had low predictive ability ($0.40 < R^2 < 0.46$) for the incidence of tuber blight. This model has been validated using data collected in the US (Nyankanga et al. 2011) but its utility under the tropical highlands in Africa has not yet been evaluated. From that research work, the cultivar Tigoni had consistently recorded lower incidence of tuber blight on potato (Nyankanga et al. 2011).

29.3.2 Management of Late Blight with Fungicides

Fungicide application strategies, timing, rates and mixtures are important for the management of potato late blight. Due to the continuous cultivation of potato that ensures abundant *P. infestans* inoculum for most of the year, disease control by use of fungicides is common in many agro-ecosystems. In the tropics of Africa, contact

Table 29.3 Effect of fungicide mixtures on late blight (*Phytophthora infestans*) disease levels and tuber yield at Tigoni, Kenya in 1999–2000

Fungicide mixtures (1999–2000)	Application rate (ha^{-1})	Disease severity (%)*	Total tuber yield ($Mg\ ha^{-1}$)**
Untreated control	–	98.5	5.5
Fenamidone+mancozeb	0.9 L	56.3	5.5
	1.0 L	55	15.5
	1.1 L	53.8	11.3
	LSD (.05)	2.7	18.4
Propamocarb HCL+mancozeb	2 L	40.0	18.7
	3 L	33.1	22.4
	4 L	26.8	23.6
	LSD (.05)	6.1	3.5
Mancozeb	1.5 kg	66.5	14.1
	2.5 kg	63.0	16.7
	LSD (.05)	3.6	2.7
Metalaxyl	2.5 kg	8.5	36.0
LSD (0.05)		21.5	6.3

*Disease severity refers to % leaf area diseased and **total tuber yield
Disease or yield values differ based on $LSD_{0.05}$ values (Muchiri et al. 2009)

(mancozeb), systemic (metalaxyl, propamocarb HCL) and protectant fungicides have been used routinely for the management of potato late blight. For example, mancozeb and a premix of metalaxyl+mancozeb have been widely used for late blight management in many tropical countries of Africa (Fontem et al. 2005; Ojiambo et al. 2001; Olanya et al. 2001b; Nyankanga et al. 2004). Published reports from various parts of the world have documented genetic changes in populations of *P. infestans* as more virulent and metalaxyl resistant strains became common (Davidse et al. 1981; Dowley and O'Sullivan 1981). In the tropical highlands of Africa, the presence of new clonal lineages (US 8, A2 mating type) has not been documented. However, various studies have shown that isolates of *P. infestans* are insensitive to metalaxyl particularly in tropical Africa where there is excessive use of metalaxyl (Ojiambo et al. 2001; Mukalazi et al. 2001; Fontem et al. 2005).

In field studies conducted on fungicide efficacy in the highlands of Kenya, late blight incidence and severity varied with the timing, frequency, rates and mixtures of fungicides used (Muchiri et al. 2009). In studies where mixtures of fungicide compounds consisting of fenamidone+mancozeb and propamocarb HCL+mancozeb at various rates, and application of metalaxyl and mancozeb were evaluated for control of late blight (US-1 genotype), disease levels differed significantly among treatments (Table 29.3). Propamocarb HCL+mancozeb significantly ($P < 0.05$) reduced foliar blight compared with mancozeb and the untreated control at the Tigoni location. Late blight severity was also significantly lower when mixtures of propamocarb HCL+mancozeb were applied at the rate of 4 L ha^{-1} at Tigoni (Table 29.3).

Similar results were obtained with identical set of treatments during the 2000–2001 cropping cycle. All fungicide treatments resulted in significantly lower late blight severity irrespective of the application rate. The application of metalaxyl resulted in

Table 29.4 Effect of fungicide mixtures on late blight severity (*Phytophthora infestans*) and tuber yield at Tigoni, Kenya in 2000–2001

Fungicide mixtures (1999–2000)	Application rate (ha^{-1})	Disease severity (%)*	Total tuber yield ($Mg\ ha^{-1}$)**
Untreated control	–	81.3	12.0
Fenamidone+mancozeb	0.9 L	13.8	16.9
	1.0 L	9.4	18.1
	1.1 L	8.8	20.1
	LSD (.05)	5.7	2.2
Propamocarb HCL+mancozeb	2 L	10.6	18.3
	3 L	5.4	18.8
	4 L	4.5	20.1
	LSD (.05)	5.9	1.8
Mancozeb	1.5 kg	63.5	14.9
	2.5 kg	51.4	15.7
	LSD (.05)	12.4	0.8
Metalaxyl	2.5 kg	8.0	21.9
LSD (0.05)		12.5	2.9

*Disease severity refers to % leaf area diseased and **total tuber yield in tons/ha. Disease or yield values differ based on $LSD_{0.05}$ values (Muchiri et al. 2009)

the lowest disease severity compared to all other treatments. In fungicide treatments where Propamocarb HCL+mancozeb were applied, moderate disease levels were recorded, whereas plants treated with mancozeb alone had higher late blight severity (Table 29.4). In both cropping years, propamocarb HCL+mancozeb and mancozeb alone resulted in significantly ($P<0.05$) greater yield than the untreated control. In 1999–2000, total yield ranged from 5.5 to 37 $t\,ha^{-1}$ whereas in 2000–2001, yield ranged from 12 to 21.9 $t\,ha^{-1}$.

The fungicide mixtures were effective in control of late blight compared with the application of mancozeb alone or the use on the untreated control suggesting that mixtures can work equally well for late blight management. Even though none of the fungicide mixtures or mancozeb were as effective as metalaxyl, metalaxyl should not be used excessively due to potential development of fungicide resistance. Elsewhere, mixtures of sytemic and protectant fungicides have also been documented for their effectiveness in the control of other oomycetes (Samoucha and Gisi 1987).

In addition to the use of mixtures of fungicidal compounds, combinations of protectant and systemic fungicides are frequently used for management of potato late blight in the highlands of East and Central Africa (Ojiambo et al. 2001; Mukalazi et al. 2001; Namanda et al. 2004), where repeated applications of 4–5 times per season is conducted for late blight management. Elsewhere in other parts of tropical Africa such as the highlands of Cameroon (West Africa), late blight is controlled by the intensive application of fungicides (Fontem et al. 2005). In such a potato production region, a premix formulation with copper oxide (Ridomil Plus) or with mancozeb (Ridomil MZ) is utilized for late blight control (Fontem et al. 2005). In general, fungicide efficacy on late blight in tropical weather conditions has been one of the rationales mentioned by farmers in using the product.

Table 29.5 Comparison of late blight disease and tuber yield at different planting dates at Kalengyere, Uganda in experiments conducted from 2002 to 2004

Cropping season	Planting dates	Final disease severity	Actual rAUDPC*	Potato yield (control plot) (Mg ha^{-1})	Potato yield in fungicide treated plots (Mg ha^{-1})
Season 1	1 Mar.	63.4	27.1	15.7	26.5
	22 Mar.	38.1	20.4	14.0	26.9
	13 Apr.	40.2	19.2	13.2	30.3
Season 2	1 Sep.	59.8	18.8	28.4	32.8
	22 Sep.	70.3	30.1	24.7	34.7
	13 Oct.	68.6	31.9	16.0	30.8
	3 Nov.	69.4	39.4	17.2	30.4

*Data represents average of three cropping years, *rAUDPC* relative area under disease progress curves (AUDPC/number of days disease was assessed)

29.3.3 Cultural Practices (Use of Disease-Free Seed Tubers, Manipulation of Date of Planting, Sanitation/Removal of Diseased Plants)

Cultural measures for late blight management in tropical Africa have been used in various ways. Given that potato culls or residue, volunteer plants, and infected tomato plants are sources of inoculum, their elimination will greatly reduce late blight risk. Various cultural practices have been shown to be effective strategies for late blight management in the Kenyan highlands (Nyankanga et al. 2004). Hilling of potato plants, dehaulming or vine kill to minimize tuber borne infections are most often used in tropical Africa. However, the removal of volunteer potatoes or infected tomato plants, or the spot treatment of pockets of disease development is not readily practiced by farmers. There is, however, a paucity of quantitative data concerning the contribution of these sources of inoculm to disease epidemiology in tropical Africa. There are virtually very limited use of containment policy or regulatory procedures that deal with late blight. In general, specific tolerance levels for late blight and visual inspections have proven inadequate for disease management in potato.

The use of cultural practices such as staggering of date of planting during the cropping cycle or manipulation of potato planting sequences in response to favorable environments for late blight have been documented as a late blight control strategies (Table 29.5). Manipulation of planting date, planting density and inter-cropping are often used as a disease escape strategy and to reduce build up of air-borne inoculums during the period of crop growth. In experiments conducted from 2002 to 2004, the effects of planting dates of potato cultivars on the development of late blight and potato tuber yield were evaluated at Kalengyere, Uganda. Potato cultivars with different levels of resistance to late blight were planted in two cropping seasons of each year. Contact and systemic fungicides were applied periodically to vary the levels of late blight disease in field plots. The results of this study showed that late blight severity varied among cultivars, planting dates and years.

Disease severity levels ranged from 38% to 70% among cultivars and years. Similarly, potato tuber yield ranged from 13.2 to 38 ton ha^{-1} across cultivars (Victoria, NAKPOT4 and NAKPOT5) in the untreated (control) plots, whereas in fungicide treated plots, tuber yield were in the range of 26.5–34.7 ton ha^{-1} during both cropping seasons. The cropping seasons and planting dates impacted tuber yield loss and the tuber yield loss attributed to late blight generally ranged from 40% to 57% and 13–49% during the first and second cropping seasons, respectively. Other cultural and cropping practices such as seed selection and removal of diseased plants have also been used (Olanya et al. 2010).

29.3.4 Integrated Techniques for Late Blight Management (Host Resistance + Fungicides, Weather-Based Diseased Monitoring, Calendar-Based Fungicide Applications)

Integrated disease management has been used in many host-pathosystems in diverse crops and regions of the world due to cost reductions, environmental and health stewardships and economic gains from the practice (Namanda et al. 2004). Integrated management of potato late blight is perhaps one of the best management options available for this devastating disease, particularly in growing regions where resources are limited (Namanda et al. 2004; Olanya et al. 2010). In tropical Africa, combinations of host resistance, fungicide applications, cultural measures, seed management, bio-rational approaches, and post-harvest management have been utilized to varying degrees. In research studies conducted to assess the effectiveness of fungicide application and host resistance for late blight control, it was shown that fungicide applications considerably reduced late blight in cultivars with high levels of late blight with corresponding increases in tuber yield compared to untreated plots or susceptible cultivars (Namanda et al. 2004). Disease scouting and weather monitoring prior to first fungicide applications resulted in significant economic gains compared to other strategies for late blight control. Similar strategies such as use of IPM, weekly, bi-weekly applications, and untreated control have been utilized in assessing the effectiveness of integrated late blight management. Strategies involving various combinations of resistant cultivars with potato cropping dates and fungicide management strategies also resulted in significant gains in disease control (Kankwatsa et al. 2002).

29.3.5 Bio-Rational Approaches – Plant-Derived Extracts (Tagetes Minuta), Phosphoric Acids

Amino butyric acid (BABA) and fosetyl–Al, foliarly applied at early stages of crop growth, can increase the resistance of potato foliage and tubers to late blight (Andreu et al. 2006). Phosphoric acid has been reported to inhibit sporulation of *P. infestans*

Table 29.6 Effect of plant extract (Stinging nettle), phosphoric acid and fungicide combinations on late blight severity (%) at Tigoni location in 2008 and 2009

2008	Disease severity (%)		rAUDPC (% disease days)*	
Treatment	Desiree	Tigoni	Desiree	Tigoni
Metalaxyl	10.2	3.9	13.0	4.0
Mancozeb	12.8	5.87	15.5	7.5
Phosphate	9.0	4.4	11.3	5.6
Stinging nettle (extract)	15.1	8.0	18.4	9.8
Metalaxyl+Phosphite	6.9	3.5	8.9	4.6
Mancozeb+phosphate	10.2	4.4	12.8	4.5
Mancozeb+extract	–	–	–	–
Untreated	33.6	13.6	39.4	16.5
Means	44.5	20.0	12.34	18.2
LSD (0.05)	2.7	1.7	6.6	3.2
2009	Disease severity (%)		rAUDPC (% disease days)	
Treatment	Desiree	Tigoni	Desiree	Tigoni
Metalaxyl	10.9	5.5	11.2	5.6
Mancozeb	27.6	12.5	27.1	12.6
Phosphate	10	5.9	10.3	5.8
Stinging nettle (extract)	28.4	12.7	28.2	13.1
Metalaxyl+Phosphite	8.8	4.7	9.1	4.8
Mancozeb+phosphate	13.8	7.1	14.1	7.1
Mancozeb+extract	24.8	11.1	25.2	11.4
Untreated	50	22.8	50.2	22.8
Means	44	20.0	12.34	18.2
LSD (0.05)	2.4	2.1	2.6	2.3

**rAUDPC* relative area under disease progress curves (AUDPC/number of days disease was assessed), Nyankanga et al. unpublished data

and phosphoric acid may have some fungitoxic activity after pathogen infection (Schwinn and Margot 1991). In experiments involving the use of plant extract from stinging nettle (bio-pesticide) for control of plant diseases, the extract was reported to be effective on *Phomopsis thea* of tea and also inhibited some oomycetes (Onyiango et al. 2005). In experiments conducted to evaluate the efficacy of phosphoric acid and extract of stinging nettle alone or in combination with other fungicides for late blight control in Kenya, alternating metalaxyl with phosphate fungicide had the most suppressive effect on relative area under disease progress curve (R.AUDPC) and percentage disease severity (Table 29.6). The application of phosphoric acid by itself resulted in significantly ($P<0.05$) higher tuber yield compared to metalaxyl treatment at the Tigoni location. The suppressive effect of plant extract from stinging nettle on late blight was relatively moderate when compared to the untreated control in 2008 and 2009.

A similar trend was obtained when treatment effects at Marimba location were compared. During 2008, suppressive effects for all treatments were greater on the cultivar Tigoni than on Desiree (Table 29.7). The lowest amount of late blight severity and AUDPC were recorded when combinations of metalaxyl+phosphate

Table 29.7 Effect of plant extract (Stinging nettle), phosphoric acid and fungicide combinations on late blight severity (%) at Marimba location in 2008 and 2009

2008	Disease severity (%)		rAUDPC (% disease days)*	
Treatment	Desiree	Tigoni	Desiree	Tigoni
Metalaxyl	10.4	4.4	16.4	5.5
Mancozeb	14.0	6.3	17.1	11.1
Phosphate	10.2	4.6	16.2	5.8
Stinging nettle (extract)	17.8	9.1	21.5	14.3
Metalaxyl+Phosphite	7.4	3.7	12.7	4.7
Mancozeb+phosphate	10.8	5.4	16.4	6.9
Mancozeb+extract	–	–	–	–
Untreated	40.1	18.0	49.1	24.3
Means	44.5	20.0	12.34	18.2
LSD (0.05)	2.5	2.3	8.4	5.2
2009	Disease severity (%)		rAUDPC (% disease days)	
Treatment	Desiree	Tigoni	Desiree	Tigoni
Metalaxyl	12.1	6.2	12.4	6.3
Mancozeb	29.1	13.3	24.7	12.9
Phosphate	11	6.2	11.4	6.4
Stinging nettle (extract)	30.5	13.7	30.4	13.9
Metalaxyl+Phosphite	9.6	5.3	10	5.5
Mancozeb+phosphate	15.88	8.1	16.4	8.1
Mancozeb+extract	29	12.8	28.9	12.1
Untreated	53.2	24.5	52.5	24.1
Means	44.	20.0	12.34	18.2
LSD (0.05)	2.8	2.2	3.1	2.7

**rAUDPC* relative area under disease progress curves (AUDPC/number of days disease was assessed), Nyankanga et al. unpublished data

were used and the greatest amount of disease was obtained in the untreated control. Similarly, disease severity (%) and AUDPC were lowest in treatment consisting of metalaxyl+phosphate. With the exception of the untreated control, the extract from stinging nettle was the least effective (Table 29.7).

29.4 Bacterial Wilt Management

29.4.1 Crop Rotation Practices

Potato cultivation in most tropical highlands in SSA is characterized by continuous planting of the crop on same piece of land sometimes with no crop rotation for several consecutive cropping seasons. Where crop rotation is practiced, the rotation cycles are too short to break the disease cycle. Additionally, volunteer potatoes are usually nurtured in rotation crops, taking the semblance of an intercrop, as a source

Table 29.8 The effect of one season rotations with various crops on bacterial wilt incidence at Kachwekano, Uganda in 1999

Treatment	Bacterial wilt incidence (%)	Total yield (Mg ha^{-1})	Market yield (Mg ha^{-1})	Market yield increase (%)	Total yield market (%)
Potato-onions-potato	12.4 (3.5b)*	2.04a	2.00a	80	98
Potato-peas-potato	5.0 (2.2b)	1.86a	1.85a	67	99
Potato-cabbage-potato	6.9 (2.61b)	1.77a	1.76a	59	99
Potato-sweetpotato-potato	3.8 (1.57b)	1.64ab	1.64a	48	100
Potato-millet-potato	3.2 (1.7b)	1.67ab	1.67a	50.5	100
Potato-carrots-potato	11.0 (3.3b)	2.04a	2.04a	84	100
Potato-beans-potato	7.4 (2.2b)	1.81a	1.81a	63.1	100
Potato-potato-potato	62.2 (7.8a)	1.24b	1.11b	–	90

*Values in parentheses are Square root transformed. Means followed by the same letter are not significantly different ($P<0.05$). Source: Lemaga et al. (2001a)

of the most needed food during a critical period of food shortage, thus, perpetuating the bacterial wilt pathogen. It is often difficult to find suitable crops that do not serve as symptomless hosts for *R. solanacearum* and best fitted in the rotation and farming systems of the highland tropics. Whereas potato is grown by most farmers, an equally high number of farmers grow beans that are known symptomless carriers of the BW pathogen. Farm survey data from southwestern Uganda revealed that 25% or more of the farmers planted beans after potato during the previous two cropping seasons and that 10–15% of the farmers plant potato on the same piece of land after just one season of crop rotation. Data also showed that 20–24% of the farmers either fallow their land or grow sorghum after potato. Crop rotation with sorghum or maize or establishment of fallow would be helpful in reducing or eradicating BW in previously infected fields, primarily if volunteer potatoes are destroyed and the dominant vegetation is composed of grasses.

Crop rotation experiments conducted in Uganda showed that a one season rotation of potato with cereals, pulses, vegetables and root crops in mildly infested fields (15–20%), significantly ($P<0.05$) reduced bacterial wilt incidence and significantly increased fresh tuber yield compared to plots continuously planted to potato (Table 29.8). Similarly, a two-cropping season (one-year) rotation with cereals and beans in a previous highly infested field (>90% incidence) reduced BW incidence by 50% compared to 80% BW incidence with continuous potato cropping (Lemaga et al. 2001a).

A two-year crop rotation study in Uganda involving wheat, peas and fallow for two cropping seasons after potato rendered a previously BW infested field free of the pathogen beyond detectable limits (Kakuhenzire et al. 2000). In Rwanda a two-year crop rotation also resulted in the production of BW-free seed tubers (Van der Zaag 1986). Crop rotation and fallowing, however, are beneficial if ground keepers are removed, volunteer potatoes destroyed and solanaceous crops are not planted before potato is planted again. There are also many symptomless hosts of *R. solanacearum,* including beans and other herbaceous weeds (Tusiime et al. 1997) and these should not be allowed to flourish in a rotation crop or fallow. Cereals and grasses have been reported to suppress bacterial wilt and inoculum build-up in the soil (Lemaga et al. 2001a). Some plant extracts of herbaceous species such as *Clotalaria, Tephrosia,* wild cabbage (*Brassica integrifolia*) and cissus (*Cissus araliodes*) suppress in-vitro growth of *R. solanacearum*. Soils amended with vegetable matter of *Clotalaria sp. and Tephrosia* sp. had low levels of BW severity and higher tuber yield than the controls.

29.4.2 Diverse Cultural Measures for Bacterial Wilt Management

Cultural practices that can limit the introduction, population increase or dissemination of bacterial wilt on potato include: destruction of crop residues and waste tubers, timely weed management and minimum post-emergence cultivation, removal of wilted plants, selection of healthy (non-diseased) plants, disinfecting farm tools, shoes and equipment used in potato fields, and reducing or preventing run-off from neighboring fields.

Haulms cut from infected potato and discarded in the field can be a source of inoculums or perpetuation of the BW pathogen in the soil. Disposal of such infected haulm can spread the disease to neighboring fields. Therefore, haulm from BW-infected potato plants and infected tubers should be destroyed in dumping pit where the bacteria can be destroyed through natural decomposition processes. Such dumping or refuse sites should be decontaminated and used exclusively for that purpose. Any volunteer potato that may grow at such a site should be destroyed with a systemic herbicide.

Some common weeds such as *Ageratum conyzoides, Amaranthus sp. Bidens pilosa, Oxalis latifolia, Polygonum napalense, Rumex abyssinicum* and *Tagites minuta* have been shown to be symptomless hosts of *R. solanacearum* (Tusiime et al. 1996, 1997). Such weeds should be removed from potato fields, particularly after potato cultivation. Improved fallows that would suppress such weeds are more appropriate than natural fallow systems having mixed plant species where some plants maybe symptomless carriers of *R. solanacearum* pathogen. It should be noted that in such areas, post-emergence cultivation should be done with care to minimize or prevent root damage. Wounded roots of potato plants can create entry points for the BW pathogen. Planting practices that utilized potato ridges can be optimized instead of instead of planting in flat fields and reconstituting ridges after crop emergence (Kinyua et al. 2005).

Harvest practices often leave some residual tubers below the soil in potato fields. Assessment of field soils after harvest conducted in Uganda revealed that 600–1,000 kg of potatoes per hectare may be recovered after the completion of harvest operation. Removal of residual tubers should be a routine practice that can greatly reduce the number of volunteer potato plants and potential *R. solanacearum* hosts for pathogen perpetuation. Volunteer potatoes that inevitably germinate, should be destroyed by rouging or spraying with a systemic herbicide such as glyphosate.

Table 29.9 Incidence of latent bacterial wilt infection in plants grown from seed from positive selection, farmer practice, small seed plot technique and improved seed in Uganda during 2010

Seed production practice	Sample size	Number of infected samples	Infected samples within production practice (%)	Total infected samples (%)
Farmer selection	25	9	36.4	8.5
Positive selection	22	3	14.1	2.9
Small seed plot	20	1	7.5	1.4
Improved seed	40	8	19.0	7.1
Total	107	21	19.9	19.9

Planting seed pieces is a principal source for dissemination of BW in many crops (Hayward 1991). Cropping practices that reduce the use of bacterial wilt infected seed can reduce pathogen dissemination in potato fields. The rouging of diseased/wilted plants can reduce the sources of infection and spread of the BW pathogen in the field, resulting in seed potato with minimum or no latent BW infection. However, the best practice would be to use healthy, certified seed if available. In the absence of this, small scale potato farmers can reduce BW in potato seed by selecting and marking healthy, vigorous and non-diseased potato plants for seed (positive selection). This practice reduces latent infection in seed tubers and minimizes or eliminates the incidence of BW in the progeny tubers. In general, seed health testing or detection of BW in seed by use of sensitive serological techniques (ELISA) should be done for seed lots. The assessment of latent BW infection in various seed potato production practices in Uganda showed that positive selection and small-scale seed plot techniques produced more healthy seed potatoes (Table 29.9). Both positive selection and small seed plot technique, however, are appropriate for small scale farmers planting less than 500 kg of seed per cropping season that is a common phenomenon in most tropical highlands.

The bacterial wilt pathogen can be spread among potato fields on contaminated farm tools and machinery. Hoes, cutlasses, and sickles used in BW infected field can spread the disease to a healthy field if used without being disinfected. Similarly, contaminated field shoes and boots can disseminate the disease in adhering soil unless they are decontaminated between potato fields. Farm machinery such as tractors and mowers should be thoroughly cleaned with a disinfectant after every farm operation to reduce or prevent pathogen dissemination.

29.4.3 Use of Healthy (Disease-Free Tubes) and Regulatory Measures

Various national potato programs in eastern and central Africa (ECA) have been producing and availing seed potato to farmers every year following strict quality standards, though in limited quantities. Quality seed as a tool to bacterial wilt management in the ECA region is hampered by the low seed potato production capacity.

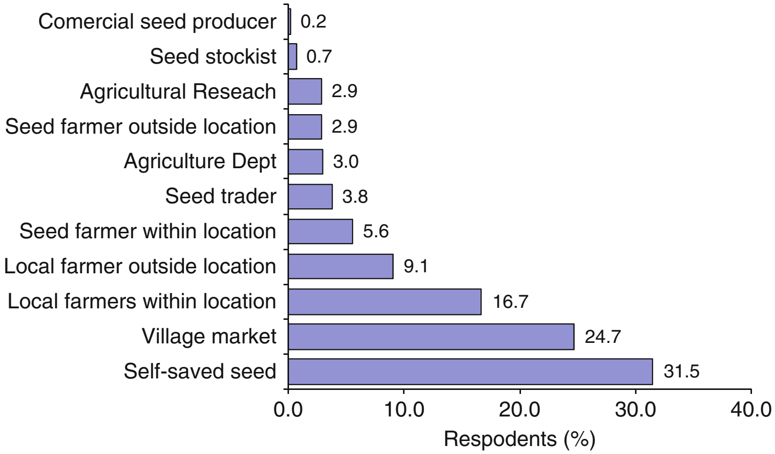

Fig. 29.1 Major seed potato sources among farmers in southwestern Uganda during 2009 cropping season. A sample size of 588 farmers responded

The quantity of mini-tubers produced on a regional scale in order to generate disease-free seed is still very low. Consequently, national programs usually bulk seed tubers for several field generations before adequate quantities are accumulated, increasing possibilities of acquiring bacterial and viral infections. Since 2000, all the major potato growing countries in ECA, with the exception of Rwanda, have been producing less than 150 t of basic seed for distribution to farmers annually. This means that most of the seed potato planted by farmers is from informal sources with high probability of disease infection. A 2009 farm family survey data in Uganda revealed that the majority of farmers plant seed potato obtained from sources with unknown health status. More than 30% of the farmers plant seed retained from previous harvest, whereas about 6% obtain quality seed from the agriculture department and agricultural research stations (Fig. 29.1).

Therefore to improve the supply of quality potato seed to farmers, the quantity of mini-tubers produced per annum in the potato growing areas of the highland tropics should be increased to reduce the number of field generations before seed reaches the ware potato farmer. This is being gradually achieved in some SSA countries, partly through adoption of aeroponics technology for mini-tuber production and optimizing seed potato production and distribution (Olanya et al. 2010). For example by using the aeroponics technology, Kenya produced 792, 656 mini-tubers in a single year compared to 39,791 mini-tubers produced by conventional methods during the same period. Increased seed supply, however; is likely to be hampered by inadequate implementation of seed quality regulations. Among the countries in the East and Central Africa, only Kenya has a functional seed potato inspection service. In other countries, the potato seed supply system is largely informal and national programs provide less than 1% of the national seed requirement.

Table 29.10 Effect of soil amendments on potato yields over three growing seasons

Treatment*	BW incidence (%)	Total yield (Mg ha^{-1})	Market yield (Mg ha^{-1})
S	28ab**	18.01a	16.63b
L	30ab	16.76bc	14.93bc
S+PK	19c	22.35a	20.280a
L+PK	26ab	18.79b	16.44b
S+P	26a	17.13bc	15.20bc
L+P	27ab	15.43c	13.31c
NPK	23ab	18.75b	16.92b
NP	16bc	16.61bc	15.20bc
Control	32a	11.24d	9.69d

**N* nitrogen, *P* phosphorus, *K* potassium, *BW* bacterial wilt, *L Leucaena diversifolia* (L.), and *S Sesbania sesban* L. (*Sesbania* and *Leucaena* were used to supply organic matter equivalent of 100 kg of N ha^{-1} either singly or combined with P and PK in this soil amendment experiment)

**Means followed by same letters within columns are not statistically different at $P < 0.05$ (source: Lemaga et al. 2005)

The impact of quality seed to reduce bacterial wilt is illustrated by a study conducted in Uganda for three consecutive cropping seasons, involving an improved package that consisted of bacterial wilt–free seed of a less susceptible variety, row planting with hilling at planting and minimum post-emergence cultivation that reduced BW incidence by 56% and increased marketable tuber yield by 29% compared to farmer practice (Lemaga 2000). The highest contribution to reducing wilting incidence and increasing marketable tuber yield was largely attributed to BW-free seed.

29.4.4 Soil Health and Soil Amendments

One of the principal components of integrated bacterial wilt management besides disease-free seed is BW-free soil. However, in tropical highlands, characterized by continuous potato cropping and seed tuber recycling, clean seed is limited and BW-free fields are not prevalent, the latter being exacerbated by land shortage. Continuous potato planting also depletes the soil of essential plant nutrients where malnourished plants are more susceptible to pest and disease attack than crops in rich soils (Katafire et al. 2005). In an experiment conducted in southwestern Uganda involving amending soil with either organic (*Leuceana* sp. and *Sesbania* sp.) or inorganic soil amendments or their mixtures resulted in high reduction in BW incidence, severity and increase in total and marketable tuber yield (Lemaga et al. 2001b). The benefits of soil fertility enhancement on reduction of BW incidence, severity and yield increase were more manifested where both organic and inorganic amendments were combined than where either of the nutrient sources was used (Table 29.10). Therefore, to get the full benefit of soil amendment, both organic and inorganic sources of plant nutrients should be combined to synergize each other (Lemaga et al. 2001b).

29.4.5 *Tolerance to Bacterial Wilt Disease and Use of Less Susceptible Cultivars*

Conventional breeding for resistance to BW has not developed stable varieties largely because of high interaction between cultivars, pathogen strains and the environment (Tusiime et al. 1996; French and de Lindo 1982). There are cultivars, for example Cruza 148, that are tolerant to BW, and could be grown in soil in fields infested with BW, however; their seeds are likely to transfer the disease latently to probably disease-free areas (Kakuhenzire et al. 2000). Previous research in Uganda during the 1990s revealed that cultivars with high levels of tolerance to BW showed some plasticity to pathogen attack over seasons and locations (Tusiime et al. 1996). In another research, it was shown that cultivars with high levels of tolerance to BW had high susceptibility to late blight (Kakuhenzire et al. 2000). Therefore, in tropical highlands and mid-altitude elevations, there is need to obtain a balance between BW and late blight resistance and cultivar acceptability in the market if such cultivars are to be widely adopted. Similar experiments conducted in Kenya also showed that cultivars had varying reactions to bacterial wilt in field experiments.

29.4.6 *Integrating Various Bacterial Wilt Management Techniques*

Individual components of BW management will not help to prevent or reduce the impact of disease in most crops prone to *R. solanacearum* infection, especially in fields that are already infested (Kinyua et al. 2001). It is more prudent to use disease-free seed as planting materials in BW-infested soils. However, among all BW management techniques, disease-free soil combined with healthy planting material and sanitation will delay or totally prevent infection of a potato crop particularly when other disease predisposing factors are operating at a low level. The efficacy of BW control technique also depends on the BW race common in the region because of differences in the host range and pathogen resilience (Priou et al. 1999; Hayward 1991). The various techniques for BW control have been weighted and shown to be effective for control of the disease and furthermore, they offer potential for the eradication of *R. solanacearum*.

29.5 Conclusions and Recommendations

Late blight and bacterial wilt remains the most formidable constraints to potato production and accounts for significant losses in tropical Africa. Although late blight can be effectively controlled through the use of fungicides, the economic costs associated with chemical use are prohibitive for the resource constrained farmers in those regions. Moreover, the deleterious impacts of chemical use to human health and environment make this a less attractive technique for control of potato diseases. Management efforts for late blight management have, therefore, been focused on host-plant resistance and integrated approaches. The combined approaches for late blight management that have been highlighted in this chapter include: resistant cultivars, reduced fungicide application, disease monitoring/prediction based on field scouting and weather criteria, bio-rational approaches, post-harvest management, regulatory techniques and farmer participatory training in holistic late blight management techniques.

The spread of bacterial wilt has continued to increase with high demand for potato forcing farmers to have short crop rotation cycles before potato is returned to the same piece of land and growing the crop beyond where it was traditionally grown. Bacterial wilt incidence and spread are further exacerbated by a warming environment due to climate change. Inadequate availability of quality seed, decreasing farm family land holdings and poverty are likely to impact on future incidence, severity and potato crop loss due to BW. Appearance of BW at high altitudes in the tropics where the disease has not been traditionally known, probably due to global warming and poor farm practices will reduce zones where disease-free seed can be produced.

To sustain potato production in tropical highlands in sub-Saharan Africa, and reduce bacterial wilt occurrence, new approaches to disease management and seed potato supply systems have to be developed and existing ones improved. One of the critical factors that should be addressed to improve the supply of quality seed potato is to reduce the number of unregulated field multiplication cycles before ware potato farmers can access seed due to tremendous seed degeneration that may occur. Seed potato production technologies such as: tissue culture and mini-tuber production in solid media, solid-free mini-tuber production technique in aeroponics, and private sector participation in seed production and multiplication should be optimized in order to reduce the costs of quality and quantity of potato seed. To improve quality seed potato supply as a tool for managing diseases such as LB, BW and potato viruses, harmonization of regulations and policies across the sub-Saharan Africa region can greatly facilitate seed trade and improve potato production in the region.

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