Relationships of Fungicide Application to Late-Blight Development and Potato Growth Parameters in the Tropical Highlands of Uganda and Kenya

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The impact of fungicide applications on late blight development, potato growth parameters, and yield was quantified at field sites in Kenya and Uganda during the 1999 and 2000 cropping seasons. In Kenya, three potato varieties were evaluated at two sites, at altitudes of 1800 m and 2200 m. In Uganda, three varieties were evaluated at one site at an altitude of 2400 m. Leaf, stem, root, and tuber biomass were sampled and quantified during the cropping season. Dithane M-45 fungicide was applied to the experimental plots at the onset of disease at intervals of 7, 14, and 21 days. Final tuber yields differed significantly by as much as 15% between fungicide-treated and untreated controls across the three sites. The severity of late blight differed among sites and between years as a result of variations in environmental conditions. Fungicide application intervals significantly affected disease progress, and the area under disease progress curve (AUDPC) was significantly lower in the fungicide-treated plots than in the control (unsprayed) plots. Tuber biomass accumulation was also significantly affected by fungicide applications. Varieties Tigoni and Rutuku have relatively higher levels of polygenic resistance to late blight and showed low levels of disease severity.

Late blight of potato (*Solanum tuberosum* L.), caused by *Phytophthora infestans* (Mont.) De Bary, is a devastating disease among small-scale farmers of the tropical highlands of East Africa (Haverkort, 1986). In Uganda, under good management but without fungicide sprays, yield losses attributed to late blight in susceptible varieties are estimated in the range of 40–60% (Mukalazi et al., 2001), with serious economic losses reported as a result of late-blight infection (Sengooba and Hakiza, 1999). Similarly, yield losses attributed to late blight in Kenya have been reported to be about 40–50% (Njuguna et al., 1998).

Previous research has indicated that periodic applications of protective fungicides for control of late blight reduce the rate of epidemic development of the disease (Van der Plank, 1967). However, geographical information system (GIS) data linked to disease forecast models reveal that less than optimum levels of fungicide are applied by most farmers in East Africa (Hijmans et al., 2000). With the exception of optimum or scheduled fungicide applications based on favorable weather conditions, the most economical option for disease management is the use

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of host-plant resistance (Olanya et al., 2001). A number of CIP genotypes are currently being evaluated in Kenya, Uganda, Ethiopia, and many other Sub-Saharan African countries with promising levels of resistance to late blight (El-Bedewy et al., 2001). The use of cultivars with durable resistance combined with scheduled applications of protective fungicides has been reported as useful for managing late blight (Simons, 1972), as well as other diseases (Van der Plank, 1963).

The impact of fungicide applications on disease development, accumulation of potato biomass, susceptibility, and yield in the tropical highlands of Africa has not been adequately documented. Information on the application of fungicides to commonly grown potato genotypes is essential to ensure efficient use of fungicides and to complement resistance to late blight. Within the East African region, potatoes are grown under various agroecological production systems with different soil types, management practices, and varieties (Adipala, 1999; PRAPACE, 1995). The objective of research reported here, therefore, was to collect standardized data on potato growth parameters from three distinctly different sites and to determine the impact of fungicide applications and late-blight development on the yield of potato varieties with different levels of resistance to *Phytophthora infestans*.

Materials and methods

Experimental sites and design

Field plots in Kenya were located at the University of Nairobi, Kabete Field Station (1800 m above sea level), and at Loreto (2200 m). In Uganda, the plots were located in Kalengyere Research Station (2400 m). At all three sites, plot measurements were 3 x 5 m (W x L), each consisting of four rows. A 3 x 4 factorial experiment (varieties x fungicide application intervals) was established in a randomized complete block design with three replications. Fungicide application intervals of 7, 14, and 21days and a control (no application) were tested. The test fungicide used in the study was Dithane M-45 (mancozeb). Potato varieties Tigoni, Asante/Victoria, and Kerr's Pink were planted in Kenya, whereas the varieties Rutuku, Asante/Victoria, and Kabale were planted in Uganda. The potato varieties used in this experiment have different levels of resistance to late blight: Rutuku and Tigoni have moderate resistance, Kabale is moderately susceptible, and Asante/Victoria and Kerr's Pink are susceptible. In all field plots, normal agronomic practices, such as adequate field and seed-bed preparation, hilling, and weeding were followed. Fertilizers (175 N, 175 P) were applied at the rate of 500 kg diammonium phosphate per hectare. Insecticides (metasystox or dimetheoate) were applied to control aphids and potato tuber moths when necessary (Table 1).

Potato growth data

About 40 days after emergence, 36 plants were randomly sampled from field plots. Twelve plants per variety were sampled at each assessment date and represented all the treatments. Fresh leaves, stems, roots, and tubers were obtained from each sample and weighed immediately to record fresh potato biomass. In addition, 100-gram subsamples of fresh leaves, stems, roots, and tubers were placed in paper bags and oven dried at 82°C for four days to obtain dry weights. Potato biomass was quantified four times during the cropping season at two-week intervals. At harvest, tuber numbers from each experimental plot were quantified and weighed; yield was expressed as tons per hectare (t/ha) for subsequent analysis.

Disease assessment and environmental monitoring

At the onset of late-blight symptoms, disease incidence and severity were quantified weekly in all plots. This was based on visual symptoms for late blight,

Table 1. Management practices used at each of the sites in evaluating late-blight development and potato growth parameters in 1999 and 2000.

Year	Management	Experimental site		
1999	practice	Loreto, Short rain	Kabete, Long rain	Kalengyere, Season "B"
	Planting date	29/10/1999	26/3/1999	16/10/1999
	Fertilizer application	Diammonium phosphate	Diammonium phosphate	Diammonium phosphate
	Insecticide	Metasystox	Metasystox	Dimetheote
	Fungicide	Dithane M-45	Dithane M-45	Dithane M-45
	Harvesting	02/2/1999	13/7/1999	11/1/2000
2000		**Loreto, Long rain**	**Kabete, Long rain**	**Kalengyere, Season "A"**
	Planting date	13/4/2000	12/4/2000	20/3/2000
	Fertilizer application	Diammonium phosphate	Diammonium phosphate	NPK
	Insecticide	Metasystox	Metasystox	Dimetheote
	Fungicide	Dithane M-45	Dithane M-45	Dithane M-45
	Harvesting	26/7/2000	26/7/2000	23/7/2000

using an assessment scale of 0–100%. At least five disease assessments were recorded. At crop maturity, the incidence of tuber blight was also quantified visually. Tubers that did not show visual symptoms were stored for three weeks and subsequently observed or plated to look for additional incidence of tuber blight.

At the three experimental sites (Kabete, Loreto, and Kalengyere), weather equipment (Hobo Pro Series, MA, USA, and Watchdog Data Logger, Spectrum Technologies, Plainfield, IL, USA) monitored environmental parameters such as temperature, relative humidity, rainfall, and hours of sunshine or photosynthetic active radiation. Additional data from the University of Nairobi weather station were also used.

Data analysis

Mean values of disease incidence and severity were calculated using SAS (1989). Similarly, area under disease progress curves (AUDPC) was calculated from values for disease severity, as described by Campbell and Madden (1990). The development and progress of late blight in fungicide-treated plots versus untreated controls were graphically compared using AUDPC. The effects of the intervals between fungicide applications on late-blight development were computed and compared for the different varieties using a GLM procedure (SAS, 2001), which considers the effects of factors such as location, year, and dates of assessment. This analysis was done separately for each genotype. Mean values for data on plant biomass and fresh and oven-dried weights of leaves, stems, roots, and tubers were calculated for each plot (SAS, 1989). A combined analysis of variance (ANOVA) was also used to investigate the effects of location and years (environment) on each variety. Similarly, graphical arrays of cumulative biomass (dry tuber weights) were used to compare potato development among varieties and sites. At each assessment period, mean values for the environmental parameters were calculated (SAS, 1989).

Results

Dynamics of late blight in relation to fungicide application

During the 1999 cropping season, disease severity at Kabete was low compared to Loreto (Figure 1) The final disease level (AUDPC) of Asante/Victoria was 250 (% disease days) at Kabete and 1200 at Loreto. During the 2000 cropping season, late-blight severity was very low at Loreto, especially in fungicide-treated plots. In the control (untreated) plots, the disease was highest in the susceptible variety Kerr's Pink (with an AUDPC value of 501.1), compared to Tigoni (AUDPC 163.9) and Asante/Victoria (AUDPC 201.6) (Table 2).

Table 2. Effect of fungicide (Dithane M-45) application intervals on disease severity and potato yields of potato at Loreto, long rains, and Kalengyere (season A, year 2000).

Application intervals	Variety[1]	AUDPC[2]	Yield (t/ha)	Tubers (no.)
Loreto, Kenya				
7 days	Tigoni	0.2	57.0	495
7 days	Asante/Victoria	0.4	59.8	349
7 days	K. Pink	0.7	42.0	343
14 days	Tigoni	0.4	54.0	462
14 days	Asante/Victoria	0.7	57.4	327
14 days	K. Pink	0.9	41.5	223
21 days	Tigoni	3.6	52.5	400
21 days	Asante/Victoria	5.2	56.0	254
21 days	K. Pink	10.1	40.3	195
Control	Tigoni	163.9	51.2	329
Control	Asante/Victoria	201.6	53.9	199
Control	K. Pink	501.1	35.2	17
Mean		2.5	50.5	339
LSD 0.05		2.9	4.5	65.3
CV (%)		64.06	9.33	28.58
Kalengyere, Uganda				
7 days	Rutuku	0.0	21.4	221.3
7 days	Kabale	23.5	19.5	144.7
7 days	Victoria	19.6	22.5	200.3
14 days	Rutuku	2.1	23.2	214.7
14 days	Kabale	52.5	19.5	176.0
14 days	Victoria	60.6	22.5	200.7
21 days	Rutuku	2.5	23.1	233.3
21 days	Kabale	69.3	19.5	172.3
21 days	Victoria	101.9	23.3	241.7
Control	Tigoni	90.3	21.0	234.0
Control	Asante/Victoria	185.9	17.3	164.3
Control	K. Pink	225.8	19.2	216.3
Mean		23.2	21.6	201.6
LSD 0.05		35.0	6.1	53.5
CV (%)		176.3	35.2	30.9

Note: Dithane M-45 (mancozeb) was applied at the rate of 3 kg/ha. A total of five applications were made during the cropping season. Experiments at Loreto were planted on April 13 and harvested on July 26. At Kalengyere, planting was on March 20 and harvesting was July 23.

[1] Varieties Rutuku and Tigoni are moderately resistant and Kabale is moderately susceptible, while Asante/Victoria and Kerr Pink are susceptible to late blight.

[2] AUDPC is area under disease progress curve (% of disease days) from six late blight readings.

Hardly any disease was detected in the fungicide-treated plots

In 1999, late blight severity was higher at Kalengyere (Uganda) compared to Kabete and Loreto (Kenya). The final AUDPC on the variety Victoria at Kalengyere was 2200 for the control treatment, with very low disease rates on plots treated with fungicide at seven-day intervals (Figure 1).

During season A of 2000, late blight was at a very low level in Kalengyere (Table 2). For Asante/Victoria in the untreated plots, disease levels at Kalengyere were comparable to those at Loreto. For Asante/Victoria, a combined ANOVA showed that fungicide treatments had a significant effect on late-blight severity, although there were variations in disease levels across sites and years (Table 3).

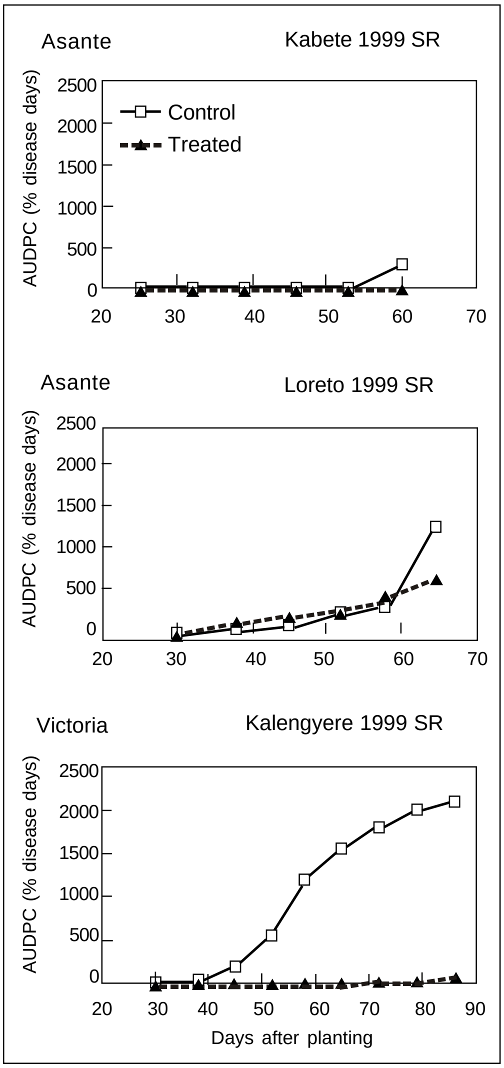

Figure 1. Progress of late blight of potato at Kabete (altitude 1800 m) and Loreto (2200 m) in Kenya and Kalengyere (2400 m) in Uganda during the 1999 cropping season. Application intervals of Dithane M-45 were 7 days and control treatment. ("SR" refers to short rain season and "LR" refers to long rain season.)

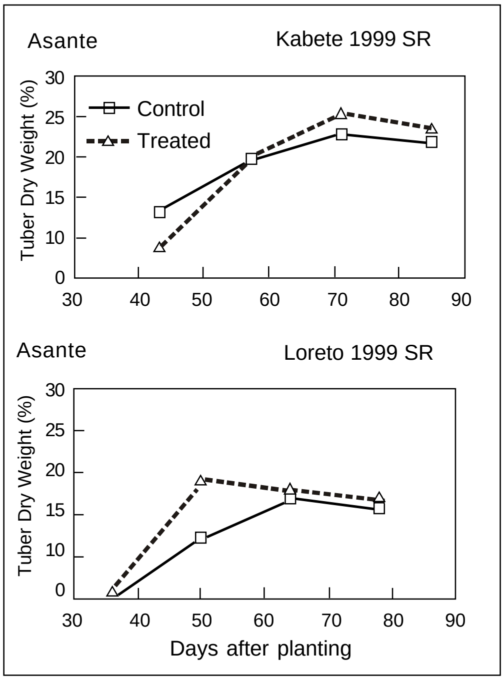

Figure 2. Average tuber dry-weight accumulation of potato variety Asante/Victoria obtained from replicated field experiments in Kenya during 1999 short rain season (SR).

Impact of fungicide applications on potato biomass

The effect of fungicide applications on dry tuber weight accumulation is shown in Figures 2 and 3 for all sites. During the 1999 cropping seasons, the percent of tuber dry-matter accumulation was higher in field plots treated with fungicide at seven-day intervals compared to the control plots at Kabete and Loreto. At Kalengyere, tuber dry-matter accumulation was significantly higher in the fungicide-treated plots than in the control. In general, the greatest level of tuber dry-matter accumulation of 20–25% was recorded in the fungicide-treated plots at Loreto and Kabete (Figure 2). Similarly, in 2000, tuber dry-matter accumulation was significantly higher at all sites in samples obtained from plots treated at seven-day intervals in comparison to samples from the control plots (Figure 3). The highest levels of tuber dry weight were recorded in samples from treated plots: Kabete (23%), Loreto (23.5%), and Kalengyere (20%).

Relationship of late-blight development to tuber yield and numbers on Asante/Victoria

An ANOVA on combined data from the two years of the experiment, across sites,

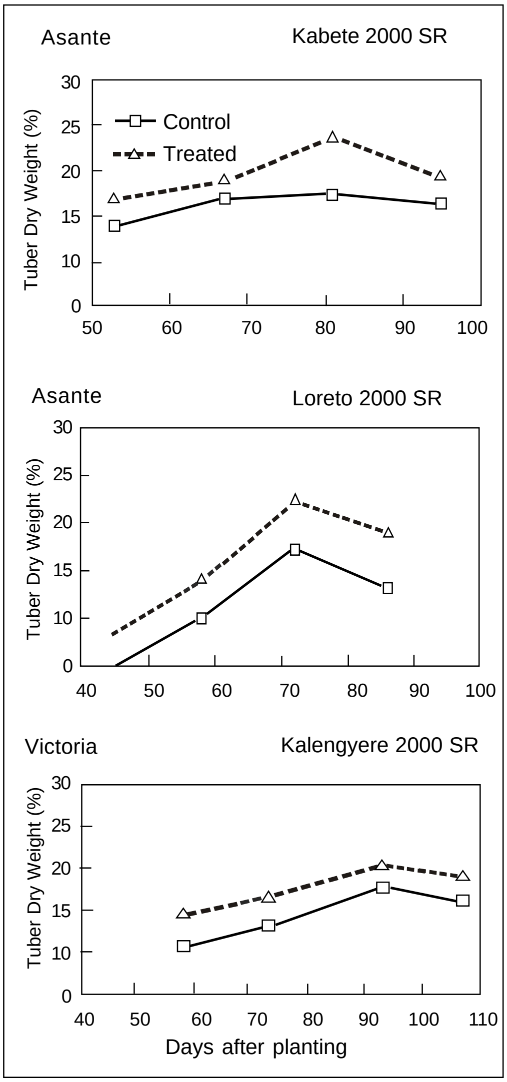

Figure 3. Average tuber dry-weight accumulation of potato varieties Asante/Victoria obtained from replicated field experiments in Kenya and Uganda during the 2000 cropping season (LR = long rain and SR = short rain season).

revealed that the intervals between fungicide applications had a significant (P = 0.05) effect on tuber yield (Table 3). Significant differences between sites were also detected. However, variations in yield were recorded within sites in different years. At Loreto in the 2000 long rains cropping season, Asante/Victoria had a yield of 59.8 t/ha and Tigoni yielded 57 t/ha; Kerr's Pink had a total yield of 42 t/ha.

At Kalengyere, the highest yield for 2000 season A was from Rutuku in the fungicide-treated plots (Table 2). Fungicide treatments did not significantly affect average number of tubers; however, tuber numbers attributed to treatment effects differed across sites and years.

Environmental variation among sites

Average monthly temperature, rainfall, and relative humidity were recorded at each site. Average temperatures were similar for all three sites during the cropping season, but the average relative humidity and total rainfall was not (Table 4). During the 1999 cropping season, mean relative humidity was much lower at Kabete than at Kalengyere and Loreto. During the 2000 cropping season, total rainfall was less than in the 1999 cropping season for all three sites. At Kalengyere and Loreto, environmental conditions were more conducive to disease development in 1999 than in 2000.

Discussion

Applying the protective fungicide, Dithane M-45, significantly reduced the development and severity of late blight and increased tuber yields. In general, disease was less severe in experimental plots with the fungicide applied at intervals of seven days, compared to the 21-day intervals or control plots. The low disease levels in Tigoni and Rutuku could be because both varieties have relatively high levels of horizontal resistance to the disease, compared to Asante/Victoria and Kabale. In this study, a combined analysis of variance was used for Asante/Victoria because it was the only variety that was planted in all cropping seasons. The lack of consistency in disease levels recorded across sites and seasons may be attributed to environmental variation among sites. In some cases, the early occurrence of the disease before the initiation of the spray program could account for inadequate disease control and confounding effects on treatments. Adjustment of fungicide

Table 3. Combined analysis of variance (ANOVA) on the effect of fungicide application intervals on late blight severity and tuber yield on Asante/Victoria variety (Victoria) planted at Kabete, Loreto, and Kalengyere sites during 1999 and 2000 cropping seasons.

Source	DF	F-Value	Pr > F
Late blight severity			
Year	1	3.67	0.1956
Location	2	1.25	0.04 a
Location*year	2	118.36	0.0001 b
Rep (year*location)	12	0.76	0.6887
Fungicide[1]	3	0.63	0.05 b
Fungicide*year	3	0.97	0.4676
Fungicide*location	6	1.09	0.4613
Fungicide*year*location	6	42.68	0.0001 b
Fungicide*rep (year*location)	36	3.24	0.0001 b
Assess.day-DOA (year*location)	28	93.77	0.0001 b
DOA*fungicide (year*location)	84	17.25	0.0001 b
Yield (t/ha)			
Year	1	38.09	0.0001 a
Location	2	7.74	0.0006 b
Location*year	2	29.76	0.0001 b
Rep (location*year)	12	1.58	0.1424
Fungicide	3	2.70	0.0466 a
Fungicide*year	3	0.47	0.7142
Fungicide*location	6	0.60	0.7223
Fungicide*location*year	6	8.25	0.0001 a
Rep*fungicide (location*year)	12	0.30	0.9867
Tuber numbers			
Year	1	0.09	0.7933
Location	2	2.20	0.3124
Location*year	2	15.02	0.0005 b
Rep (location*year)	12	2.05	0.0481 a
Fungicide	3	1.79	0.2496
Fungicide*year	3	4.09	0.0673
Fungicide*location	6	2.18	0.1829
Fungicide*location*year	6	1.08	0.3942
Rep*fungicide (location*year)	36	0.96	0.5476

a = Significant at 0.05; b = Significant at 0.01.

[1] Refers to application intervals of 7, 14, 21 days and control (no application) of the contact fungicide Dithane M-45.

application rates to complement the general resistance of a particular variety has been reported as one method of enhancing fungicide efficiency (Fry, 1977).

One of the principles of fungicide resistance management is that factors, which suppress the growth rate of disease on individuals relative to sensitive ones, will also slow the selection for resistant individuals (Milgroom and Fry, 1988). In his study on potato genotypes with low levels of resistance to late blight, Fry (1975) observed that it was possible to reduce the amount of fungicide required for adequate control by introducing varieties with increasing levels of durable resistance. In our experiment, a total of four fungicide applications was used regardless of the treatment interval (7, 14, or 21 days), with the same concentration of fungicide applied. Further research is required to determine the optimum number of applications, dosage, and timing with respect to disease on susceptible varieties relative to resistant ones. Once this has been determined, farmers should be able

Table 4. Average temperature, relative humidity, and rainfall at Kalengyere, Kabete, and Loreto sites during the 1999 and 2000 cropping seasons.

	Temp (C)	RH (%)	Total rainfall (mm)
Kalengyere, 1999			
September	16	86	88.3
October	15	85	126.3
November	16	85	120.7
December	17	87	42.2
Kabete, 1999			
September	18	64	26.1
October	19	62	11.4
November	18	76	348.0
December	18	73	229.3
Loreto, 1999			
September	16	89	36.0
October	17	85	61.1
November	16	89	398.2
December	16	83	234.1
Kalengyere, 2000			
April	16	87	114.0
May	16	86	52.2
June	16	85	1.3
July	16	85	22.4
Kabete, 2000			
September	18	57	33.5
October	19	64	18.4
November	19	59	187.7
December	18	56	111.3
Loreto, 2000			
April	18	78	195.2
May	16	84	73.3
June	14	83	37.5
July	13	82	23.1

Note: Planting and harvesting dates are shown in Table 1.

to increase fungicide efficiency by adjusting the number of applications, the dosage, and the timing to complement resistance levels. Unfortunately, for most of the potato varieties grown in sub-Saharan Africa, the relationships between environmental parameters, disease, fungicide use, and resistance have not been adequately studied (Olanya et al., 2001) to allow for reliable adjustments of fungicide applications to complement resistance. Niklaus et al. (2000) in their study on the evaluation of host resistance and weekly fungicide application observed that resistance of a susceptible variety Alpha was increased by 20% when a contact fungicide was applied. Further study is underway to increase the efficiency of fungicide use in sub-Saharan Africa by quantifying the relationships of dosage, number of applications, and resistance in susceptible, moderately susceptible, and resistant clones and varieties.

The beneficial effect on dry-matter accumulation of applying a protective fungicide is attributed to the indirect effect on late-blight development and subsequent availability of photosynthetic leaf area. The similarity of maximum tuber dry matter at Kabete and Loreto in 2000 may be attributed to the very low severity of late blight and the similar growing conditions during the season. The low dry matter recorded at Kalengyere may be attributed to the lower rainfall that year. Generally, the mean temperatures were lower at Kalengyere than at the other sites, which may account for the lower tuber biomass accumulation at Kalengyere relative to the other sites. In general, the rate of biomass or dry-matter accumulation appears to be similar across sites; however, there is no information on the number of days to tuber initiation.

The total number of tubers was not significantly affected by application intervals, but variations in tuber yields were recorded among varieties, with the tolerant variety Tigoni performing better than Asante/Victoria (Victoria) or the susceptible varieties, Kerr's Pink and Kabale. Victoria and Kerr's Pink were highly susceptible to late blight and early season infection, contributing significantly to the lower yields observed. Fry and Shtienberg (1990) reported that complete suppression of yield in susceptible varieties is possible if the disease occurs early enough.

Variations in climatic conditions were recorded across seasons and years at the testing sites. Average temperature appeared to be similar; however, relative humidity and rainfall were different. This variation in key environmental parameters could account for the differences seen in late blight disease levels. Subsequent variability in tuber yield could also be explained in terms of seasonal variations in environmental conditions. During the 2000 cropping season, adverse environmental conditions, which accounted for low yields, were noted. Similarly, late-blight severity (as measured by AUDPC) was greater in seasons or locations with low total yields.

Conclusions

We conclude that applications of protective fungicide have a significant deterrent effect on the development of late blight in some sites in tropical Africa, and a positive effect on accumulation of potato biomass. The magnitude of disease development and dry-matter partitioning appears to be dependent on the levels of resistance of the varieties and the frequency of fungicide applications. However, further data are needed to assess the contribution of cardinal factors such as temperature, photosynthetic active radiation, and rainfall in crop development (tuber initiation, rate of tuber bulking) in tropical Africa. Furthermore, elements such as the effect of planting and harvesting dates on disease development and potato biomass have not been adequately addressed in the tropical highlands of Africa.

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