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On-farm evaluation of fungicide spray options to control potato late blight in South-western Uganda

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Abstract

Production of potato (*Solanum tuberosum* L) in the highlands of Eastern Africa is increasingly being threatened by devastating epidemics of late blight (*Phytophthora infestans* (Mont.) de Bary). Use of fungicide sprays is a feasible control strategy against this epidemic but appropriate spray intervals during crop growth have not been determined. An on-farm experiment was therefore, conducted to establish the appropriate spray interval for a contact (Dithane M45) fungicide in Uganda. Results showed that during the blight-favourable seasons yields were higher with 7-day spray interval than 14 and 21 day but economic analysis revealed that 2 and 3 sprays of Dithane M45 on tolerant and susceptible cultivars, respectively resulted into optimal yields. Overall, monitoring disease and then spraying (2 sprays) contained late blight severity to levels that yielded the most economic benefit.

Key words: Economic returns, host resistance, Mancozeb, *Phytophthora infestans, Solanum tuberosum*

Introduction

Late blight, caused by *Phytophthora infestans* (Mont.) de Bary, is the most important constraint to potato production in the highlands of Eastern Africa (Hakiza, 1999; Olanya *et al*., 2000). During the last 20 years, this disease has increased globally (Fry and Goodwin, 1997). Yield losses due to late blight damage are estimated at 30-40% in years of intermediate disease severity but up to 80% in the years of an epiphytotic (Anoshenko, 1999). In Uganda late blight is considered the most important biotic constraint to potato production, and total crop failure is not uncommon (Adipala, 1999). The situation is aggravated by the fact that the farmers are resource-poor, with limited capacity to control the disease. Moreover, there is continuous supply of inoculum due to all year round cultivation of the crop coupled with favorable weather (Kankwatsa *et al*., 2002). Also, production in many of these areas is characterised by dependence on local cultivars, absence of elite late blight resistant clones, and lack of information on more economic late blight management practices. As such, some farmers attempt to control the disease with numerous fungicide applications, but this increases cost of production and has environmental and health hazards. Thus, development of an economically viable and sustainable integrated disease management (IDM) option is considered key to management of late blight in sub-Saharan Africa (Olanya *et al*., 2000). Also, although host resistance is central to disease management, fungicide application is needed to enhance host resistance and achieve high economic returns. Determination of an appropriate spray schedule can aid to achieve more efficient use of fungicides (Mackenzie, 1981; Niklaus and Fry, 1999).Thus, the objectives of the study was to identify appropriate fungicide spray schedules for potato cultivars with different levels of tolerance to late blight.

net benefit (i.e., the change in net benefits) divided by the marginal cost (i.e., the change in costs) expressed as a percentage was computed to evaluate changes from one technology to another by expressing the relationship of total variable costs against the net benefits.

Results

Mean monthly rainfall averaged 9.9 mm, 3.5 mm and 5.4 mm for the 1999B, 2000A and 2000B seasons, respectively. Minimum and maximum temperatures averaged 10.4° C and 21.3° C, respectively, while relative humidity averaged 87%, 86% and 85% for the 1999B, 2000A and 2000B seasons. These conditions coupled with the different levels of fungicide application resulted in varied levels of late blight.

Effect of fungicide treatments on late blight severity

Late blight attacked all cultivars irrespective of the fungicide application regime. There were significant ($P = 0.05$) 2-way interactive effects of cultivar and fungicide spray regimes, indicating that the level of late blight control depended on both cultivar tolerance to late blight and spray regime (Fig. 1). The sprayed plots had less disease severity than the unsprayed, and weekly (high spray regime) had the lowest disease severity compared to 14 day, 21 day and monitored (2) spray options on all cultivars. Also disease progress on the unsprayed Kisoro and Victoria (susceptible) were significantly higher than on Rutuku and Nakpot 3 (tolerant) cultivars. The unsprayed potato clearly show that there

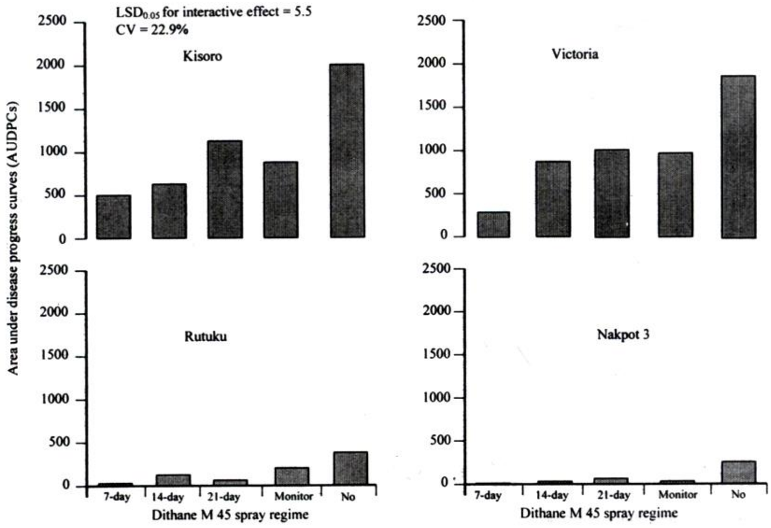

Figure 1. Late blight severity (AUDPCs) on four cultivars with varying levels of resistance under different fungicide spray schedules. Only two sprays were applied in the monitored treatment, the first and second at 10 and 31 days after crop emergence; the 7, 14 and 21- day spray intervals resulted in 12, 6 and 3 sprays, respectively.

was significant difference between tolerant and susceptible cultivars, with mean AUDPCs of 303 and 151 on Rutuku and Nakpot 3, compared to 1990 and 1877 on Kisoro and Victoria respectively.

Effects of fungicide spray interval on tuber yield

Table 1 shows that all the 7-day fungicide spray interval treatments resulted in the highest tuber yield as compared to yields accruing from 14 day, 21 day and monitored (2) spray schedules. The results also indicate that there were significant (P = 0.05) differences in yield losses between sprayed and unsprayed plots but the extent of loss depended on fungicide-spray interval and varietal susceptibility. Yields obtained from the 21-day and monitored spray schedules (both sprayed twice) were similar. Although higher tuber yields were obtained from tolerant cultivars (Rutuku and Nakpot 3), fungicide application increased their yields considerably. Also, although the unsprayed plots of resistant cultivars Rutuku and Nakpot 3 recorded relatively high yields, the magnitude of yield addition due to increase in the number of fungicide spray applications was lower than that of susceptible cultivars such as Victoria. Furthermore, without fungicide usage, a farmer recorded over 90% tuber loss on a susceptible (Kisoro) compared to only 40% on a tolerant (Rutuku) cultivar (values computed from Table 1).

Table 1. Effect of fungicide application on tuber yield of four cultivars with varying levels of tolerance to late blight in four on-farm sites.

Variety	Treatment	Tuber yield (mt ha^{-1})				
		Nyamiyaga	Butego	Rusyekye	Kataraga	Mean t ha^{-1}
Kisoro	7 day	13.8	24.0	17.7	18.4	18.5
	14 day	14.4	18.0	12.7	15.3	15.1
	21 day	9.3	11.0	12.3	21.0	13.4
	Monitoring	9.7	14.0	13.0	12.0	12.2
	No spray	3.8	0.7	2.0	1.9	2.2
Victoria	7 day	14.9	32.3	21.0	22.6	22.7
	14 day	13.7	18.5	18.4	17.0	16.9
	21 day	7.4	13.9	14.5	11.8	11.9
	Monitoring	7.7	14.8	17.8	13.3	13.4
	No spray	3.1	1.7	3.0	2.6	2.6
Rutuku	7 day	17.4	30.4	12.1	18.1	19.5
	14 day	16.1	29.2	9.8	20.1	18.8
	21 day	15.9	25.0	8.9	13.6	16.6
	Monitoring	15.3	25.3	11.9	17.5	17.5
	No spray	7.2	9.6	9.0	5.4	8.3
Nakpot 3	7 day	10.7	22.7	16.7	14.7	16.2
	14 day	9.7	16.9	15.2	15.8	14.4
	21 day	12.5	21.1	11.8	14.6	15.0
	Monitoring	11.0	21.0	15.5	15.7	15.8
	No spray	9.4	10.6	8.5	10.7	9.8
LSD0.05		3.9	6.1	6.4	5.6	5.5
CV=%		20.5	18.2	30.1	19.5	22.9

* Pooled data for three seasons.

Economics of fungicide sprays on potato

The cost of each spray varied with the stage of crop growth, i.e., during the early (emergence to vegetative), middle (premodia to flowering) and late (pre- senescence) crop growth stages. The number of sprays averaged 6, 3, 2, and zero for the weekly, fortnightly, monitored and unsprayed treatment, respectively. During the late blight favourable seasons the average variable cost of these spray regimes were US$ 62.3, 62.3, 56.8 and 0 for the weekly, fortnightly, monitored and host resistance (no spray) schedules, respectively .

To determine the economic viability of these spray regimes, an economic assessment was conducted. This evaluation was done using the farm gate prices of 100-kg bag, which is the standard measure of marketing ware potato at farm level in the study area. There was variation in price according to variety, Kisoro, Victoria and Nakpot 3 were sold at an average price of Ug.Sh.100,000 (US$ 56), 388575.5 at Ug.Sh.108,000 (US$ 60) and Rutuku at Ug.Sh.110,000 (US$ 61) per tonne (10 x 100 kg bag). The cost of individual spray varied according to a particular growth stage, i.e., Ug.Sh.79,560 (US$ 44,2), Ug.Sh.124,920 (US$ 69.4) and Ug.Sh.131,940 (US$ 73.3) for early, flowering and post-flowering stages, respectively. Thus, the total average cost of late blight control using a contact fungicide in a late blight favourable season was Ug.Sh. 672,840 (US$ 373.8), Ug.Sh.336,420 (US$ 186.9), Ug.Sh.204,480 (US$ 113.6) for the 7-day (6 sprays), 14-day (3 sprays) and monitored (2 sprays), respectively.

Partial budgets

Tables 2 and 3 show that it is profitable to spray against late blight but benefit depends on the potato variety (level of resistance). Partial budgets analyses indicate that the spray regimes (number of fungicide sprays) affected the value of inputs associated with the experimental variables with weekly spray option resulting in the highest total variable costs, in comparison to the fortnightly, tri-weekly and monitored sprays, respectively, and no variable costs for the unsprayed plots. Even though the tri-weekly and monitored spray schedules resulted in 2 sprays each, spraying when necessary (monitoring) resulted in lower total variable costs and higher net benefits. Although the gross benefits for varieties Kisoro, Rutuku and Nakpot 3 were higher when the crop was sprayed weekly, the net benefits were lower when the crop was sprayed following the fortnightly and monitored spray schedules. Whereas net benefits continued to increase after 2 sprays on susceptible cultivars such as Victoria, in the cases of tolerant varieties e.g., Rutuku, beyond 2 sprays the net benefits declined. The low net benefit from no spray control confirmed that use of host resistance alone may not be adequate. Surprisingly, the net benefits accruing from the unsprayed resistant Nakpot 3 cultivar were higher than the weekly sprayed plots.

Dominance analysis showed that sprays involving more than 2 sprays of a contact fungicide were dominated on resistant cultivars such as Rutuku and Nakpot 3 under fortnightly and weekly options. But, the same control options were not dominated on susceptible cultivars such Victoria, that is, the farmer could spray more than twice on a susceptible cultivar. Therefore, it was not economical to spray the resistant cultivars more than twice.

Net benefit and marginal analysis

Table 3 shows that spraying twice under monitored sprays resulted in the highest marginal rate of return for all cultivars and it was the only economic fungicide spray option for resistant cultivars (Rutuku and Nakpot 3). For every (US$) dollar invested in fungicide purchase and its application, farmers recovered the original dollar and approximately an additional US$ 2.5 for susceptible cultivars (Kisoro and Victoria), but only US$ 1 for resistant cultivars when the crop was sprayed following the monitoring schedule. However, when the farmer sprays susceptible cultivars thrice (fortnightly), the additional

Table 2. Partial budget for integration of host resistance and minimum fungicide use for management of late blight on four cultivars.

Cultivar	Fungicide spray regime				
	Weekly (7 sprays)	Fortnightly (3 sprays)	Tri-weekly (2 sprays)	Monitoring (2 sprays)	No spray (0 spray)
Kisoro (susceptible)					
	18.5	15.1	13.4	12.2	2.2
	16.7	14.0	12.1	11.0	2.2
	56	56	56	56	56
	44.9	44.9	44.9	44.9	44.9
	2.8	2.8	2.8	2.8	2.8
	8.3	8.3	8.3	8.3	8.3
	102	51	31	31	-
	113.2	56.6	34.4	34.4	-
	56.6	28.3	17.2	17.2	-
	102	51	31	31	-
	373.8	186.9	113.6	113.6	-
	749.8	628.6	343.3	493.9	98.8
	376	441.7	229.7	380.3	98.8
Victoria (susceptible)					
	22.7	16.9	11.9	13.4	2.6
	20.4	15.2	10.7	12.1	2.6
	56	56	56	56	56
	44.9	44.9	44.9	44.9	44.9
	2.8	2.8	2.8	2.8	2.8
	8.3	8.3	8.3	8.3	8.3
	102	51	31	31	-
	113.2	56.6	34.4	34.4	-
	56.6	28.3	17.2	17.2	-
	102	51	31	31	-
	373.8	186.9	113.6	113.6	-
	916	682.5	480.4	543.3	116.7
	542.2	495.6	366.8	429.7	116.7
Rutuku (resistant)					
	19.5	18.8	16.6	17.5	8.3
	17.6	16.9	14.9	15.6	8.3
	61	61	61	61	61
	49.9	49.9	49.9	49.9	49.9
	2.8	2.8	2.8	2.8	2.8
	8.3	8.3	8.3	8.3	8.3
	102	51	31	31	-
	113.2	56.6	34.4	34.4	-
	56.6	28.3	17.2	17.2	-
	102	51	31	31	-
	373.8	186.9	113.6	113.6	-
	878.2	843.3	743.5	778.4	414.2
	504.4	656.4	629.9	664.8	414.2
Napkol 3 (resistant)					
	16.6	14.4	15.0	15.8	9.8
	14.4	13.0	13.5	14.2	9.8
	56	56	56	56	56
	44.9	44.9	44.9	44.9	44.9
	2.8	2.8	2.8	2.8	2.8
	8.3	8.3	8.3	8.3	8.3
	102	51	31	31	-
	113.2	56.6	34.4	34.4	-
	56.6	28.3	17.2	17.2	-
	102	51	31	31	-
	373.8	186.9	113.6	113.6	-
	745.3	583.7	606.2	737.6	440.0
	371.5	396.8	492.6	624	440

return obtained for every dollar drops to about US$1. Whereas the weekly spray schedule on Victoria was not eliminated in the dominance of the contact fungicide (Dithane M45) analysis, the 25% marginal rate of return shows that it was not viable either to apply 6 sprays on susceptible varieties since the marginal rate of return below 50% is considered uneconomical (CIMMYT, 1988).

Discussion

The presence of late blight in all the seasons confirms Walter (1993) assertion that the climate of Eastern Africa favours the disease all the year round. The appearance of late blight symptoms in the first 10-12 days leads to severe epidemics and 80-100% foliage damage on early maturing varieties and 70-80% for medium and late varieties (Anoshenko, 1999). Walter (1993) also observed that under favourable conditions, lesions may appear on leaves 3-5 days after infection. In this study, late blight lesions appeared on the leaves between 12 and 15 days after crop emergence on Victoria and Kabale (susceptible) and 21 to 24 days on Rutuku and Nakpot3 (tolerant) cultivars. And, 100% leaf damage was recorded on Victoria in 1999B (September to December) and 2000B (September to December) seasons. In these two seasons, rainfall averaged 9.9mm, temperature 15.6°C and relative humidity 87% in 1999B; and 5.4mm, 15.6°C and 84.3% in 2000B. These conditions were conducive for late blight epidemics.

Further, according to Harrison (1992) and Low (1997) severe late blight epidemics occur during heavy rains, presence of moisture on potato leaves extending for at least 8-10 hours for several consecutive days, cool temperatures (less than 20°C) and high relative humidity (more than 80%). Although season 2000A recorded similar average temperatures and relative humidity, rain period was short and average rainfall was less than 4 mm per day and was received mostly early in the season. Thus, the weather conditions were favourable for disease development in the early stage of plant growth but the lesions could not progress because of limited leaf wetness.

Table 3. Marginal analysis of four cultivars subjected to different fungicide spray treatments.

Variety	Treatment	TVC	NB	Change in TVC	Change in NB	MRR
Kisoro	No spray	-	98.8	-	-	-
	Monitoring	113.6	380.3	113.6	281.5	248
	Fortnightly	186.9	441.7	73.3	61.4	84
	-Weekly					
Victoria	No spray	-	193.1	-	-	-
	Monitoring	113.6	429.7	113.6	313	276
	Fortnightly	186.9	495.6	73.3	65.9	90
	Weekly	373.8	542.2	186.9	46.6	25
Rutuku	No spray	-	414.2	-	-	-
	Monitoring	113.6	664.8	113.6	250.6	220
	- Fortnightly					
	- Weekly					
Nakpot 3	No spray	-	440.0	-	-	-
	Monitoring	113.6	624.0	113.6	184.0	162
	- Fortnightly					
	- Weekly					

- Dominated values not included; TVC = Total variable costs; NB = Net benefits; MRR = Marginal Rate of Return i.e. Change in Net Benefits/ Change in Total Variable Costs x 100%.

The results, however, show that during seasons of high late blight severity, plots provided with adequate fungicide yielded well. Yield losses averaged 14.1m t ha^{-1} (51%) on Rutuku, a tolerant cultivar and 18.5 mt ha^{-1} (77%) on Kabale, a susceptible cultivar (Table 1). The yield differences between sprayed and unsprayed plots justify the necessity of fungicide application in the control of late blight. For example, the yield of Kabale (susceptible) increased from less than 5 t ha^{-1} to about 18 t ha^{-1} when sprayed weekly for six times. The importance of host resistance in controlling late blight severity was also demonstrated in the unsprayed plots. For example, the yield of unsprayed Kabale (susceptible) averaged 5 t ha^{-1} in late blight favourable seasons of 1999B and 2000B, while in case of Nakpot 3 (resistant) the yield averaged 11 t ha^{-1}. The corresponding yields for the two cultivars when sprayed twice under monitored regime were 13.5 and 15 t ha^{-1}; respectively. Thus, there was markedly reduced yield loss in resistant cultivars, as compared to the susceptible cultivar. These results justify the need to incorporate resistant varieties in late blight management. This was because resistant varieties delayed the disease development and therefore the need for first fungicide spray. After 2 monitored sprays, disease severity was controlled at about 5% as compared to more than 15% for unsprayed Rutuku (resistant) and Victoria (susceptible), respectively. However, the results also indicate that sole use of fungicide or host resistance (no spray) may not be adequate for control of late blight; greater benefit accrued where both factors were combined, which agreed with Parry (1990) finding that management of late blight requires an integrated approach.

The unsprayed plots had lower net benefits than the sprayed plots which is consistant with Neiderhauser (1999) assertion that fungicides must be used to control late blight. Hakiza (1999) also argued that fungicide application is an integral part of potato late blight management. However, the high total variable costs as a result of weekly sprays indicate that such a spray schedule is prohibitively expensive but also environmentally unfriendly (Landeo, 1993). Higher net benefits from tolerant cultivars Rutuku and Nakpot 3 showed the importance of cultivar tolerance in late blight management. The lower net benefits resulting from weekly than fortnightly spray schedules (Table 3) indicate that even on a susceptible cultivar like Kisoro weekly fungicide application is not economically viable. Contrastingly, the higher net benefits under fortnightly than monitored sprays justified spraying a susceptible cultivar like Kisoro (Table 3) thrice. Table 3 also indicates that 2 monitored sprays on a tolerant cultivar such as Nakpot 3 result in the highest net benefits which agrees with Clayton and Shattock (1995) that resistant cultivars provide an opportunity to reduce amounts of fungicide needed to control potato late blight. Fry and Shtienberg (1990) also reported that host resistance and forecasting considerably reduce the production costs. Furthemore, Niklaus and Fry (1999) have suggested that monitoring for disease occurrence and then spraying as opposed to calendar sprays, result in higher benefits from fungicide applications.

According to Maniford and Norton (1987), a necessary condition for taking a control action is that in which the economic benefit is greater than the economic cost. Whereas the partial budget analysis (Table 2) showed that high net benefits were achieved under high (frequent) fungicide usage, the dominance analyses showed that use of more than 2 sprays with a contact fungicide was only economical on susceptible (Kisoro and Victoria) but not on resistant varieties like Rutuku and Nakpot 3. These results concur with those of Fry (1975) that growing resistant varieties reduce the need and amount of fungicide sprays. The marginal analysis also confirmed that beyond 2 sprays the marginal rate of return starts to decline and it became less than 50% when a susceptible cultivar like Victoria was sprayed 6 times. Although marginal analysis also showed that susceptible cultivars such as Victoria needed more than 2 sprays, as earlier suggested by Christine (1999), the marginal rate of return declined to 25% beyond 3 sprays which is below the recommended minimal marginal rate of return (CIMMYT, 1988). Nevertheless, though the high fungicide usage (6 sprays) was not economically viable, it agreed with CIMMYT (1988) that farmers choose less risky options to protect themselves against risks of loss.

The dominance of tolerant varieties after 2 sprays confirmed that two sprays for tolerant cultivars are the most economic, and that for susceptible varieties like Victoria the marginal rates of return increasingly became uneconomical after 3 sprays. The results of this study strongly support the hypothesis that late blight monitoring can reduce the frequency and use of fungicide sprays in potato production.

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