Relationship between potato late blight development and weather variables in the highlands of Southwestern Uganda

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Abstract

Field trails were conducted from 2002 to 2004 at Kalengyere Research Station, 2450 m above seal level, in southwestern Uganda to determine the effect of continuous potato planting on late blight (LB) epidemic behaviour over a cropping season. The experimental treatments consisted of three potato varieties and either three or four planting dates during the first or second rainy season, respectively per year. Ten potted, LB-infected potato plants were evenly distributed along alleys as infection sources. The date of LB onset per plot was recorded. Disease severity (%) was assessed every 3-10 days until 85-90 days after planting. No artificial disease control was used. Data revealed that the days from planting to disease onset was influenced more by the planting date than by potato variety. Disease appeared earlier during the first (Feb.-June) than the second (Sept.-Dec.) season. The days from planting to disease onset was significantly ($P<0.05$) related to accumulated hours with RH≤90% and accumulated rain days but computed from either 1st March or 1st September for the first or second rainy season, respectively. The point of inflexion of the disease progress curve was related to days to disease onset by a simple linear function. The function predicting the point of inflexion was able to predict disease onset in >70% of the studied epidemics. The study revealed that potato planted by 1st September can escape severe LB epidemics than one planted by 1st March, probably requiring no fungicides for disease control.

Keywords: Disease progress curves, logistic function, inflexion point, Kalengyere.

Introduction

The highlands in East Africa and perhaps elsewhere are cool, generally wet and humid, favouring growth of potato nearly all the year round. In the highlands of Uganda, can be planted in upper slopes, cool valley bottoms or reclaimed swamps but in different months per year (Low, 2000). This practice provides the crucial ware potato all year round, but also provides a bridge of late blight infection between the two main rainy seasons per year predisposing main season potato crops to spontaneous and severe late epidemic outbreaks. Relationships between late blight epidemic onset and weather factors, host resistance, fungicide use and basic cultural practices in Sub-Saharan Africa have been adequately studied (Olanya *et al.*, 2001). Such studies would allow designing fungicide deployment according to the nature of disease epidemic (Paveley *et al.*, 2000). Locally developed, zone-specific late blight prediction models can be useful guides in developing decision support tool (DST) for optimising fungicide use in potato production and disease management without compromising fresh tuber yields. They can be as simple as reference tables, a list of rules, flow charts and diagrams or as complex as computer generated empirical or simulated models. Late blight onset forecasts that would form a foundation for DST and a vital component of integrated late blight management (Forbes *et al.*, 2002; Dowley and Bourke, 2004) have been glaringly missing for tropical highland potato farming systems. An experiment was consequently designed with an objective to develop late blight onset prediction model befitting continuous potato planting commonly practised in highland tropics in relation to weather variables. This was envisaged as a basic decision tool for optimising fungicide deployment in potato crop and late blight epidemic development.

Materials and methods

Three *Solanum* potato varieties: Victoria (CIP 381381.20), NAKPOT4 (CIP 387121.4) and NAKPOT5 (CIP 381471.18) were planted at 21-day intervals during the first (Feb-July) and second (Aug.-Dec) rainy seasons in 2002, 2003 and 2004 at Kalengyere Research Station in Uganda. This site is located at 01°13.2′S, 020°47.8′E and 2,450 m above sea level on 134 ha of land. The area receives 1000-1500 mm rainfall annually and the mean monthly temperature is 16°C. The soil is volcanic Andosol, light and friable with pH ranging between 4.5 and 6.9 (Sendiwanyo, 1992). The climate, chemical and physical attributes of the sites make it ideal for potato cultivation throughout the year, hypothetically creating continuous presence of late blight inoculum. The crop rotation cycle at the research station takes 2.5-3 years involving potato, legume, cereal and 1.5to 2 year fallow but this does not totally void the land of volunteer potato; a good source of late blight inoculum for new epidemics.

The planting dates during the first rainy season were 1st March, 22nd March and 12th April. During the second season, the planting dates were 1st September, 22nd September, 13th October and 3rd November. By combining potato variety, planting date and seasons over three years, 60 disease epidemics were studied. For each planting date trial set, neither artificial disease inoculation nor disease control was done. Late blight infection was from naturally occurring inoculum. Experimental seed potato was obtained from disease-indexed lots of the national potato programme.

Experimental design and crop management

A split plot design was used. The date of planting constituted the main plot and potato varieties the sub-plot in order to reduce inter-plot effects. Each sub-plot was 4.5 m by 2.8 m and consisted of four rows spaced 70 cm apart. In each row, 15 fully sprouted seed tubers were planted at 30 cm apart within a row resulting in 47,620 seed sets ha^{-1}. Open alleys of 1.5 m and 2.0 m wide, were left between adjacent sub-plots and main plots, respectively. Compound N:P:K 17:17:17 fertilizer (YARA East Africa Ltd, Nairobi, Kenya) was applied at 100 Kg ha^{-1} as a single-dose side-band at planting. For each experimental set, three replications were used. The trials were kept free of weeds by hand-weeding. Insect pests were controlled with Agro-thoate 40 EC (TransAgro, Neukirchen-Vluyn, Germany) at 1.19 Kg a.i. ha^{-1} applied with a back-pack sprayer at 2-bar pressure. The crop was dehaulmed at full maturity, circa 90 days after planting (DAP) and harvested three weeks later.

Data collection

Percent crop emergence was recorded every three days from 12 DAP, as a ratio of number of hills where potato plant shoots had emerged to seed tubers planted. From 80-100% crop emergence, each potato plant was visually examined every 2-3 days to identify first late blight symptoms, determine the date of disease onset and initial disease severity (Y_o). Disease severity was subjectively recorded as percent leaf area affected (PLAA) from the middle-rows at sub-plot level every 3-10 days until the crop approached senescence to avoid confounding crop aging with disease attack. Hourly temperature (^{0}C) and relative humidity (%) were measured using an electronic, Hobo®, data logger placed within the crop canopy and downloaded with BoxCar Pro Version 3.51 computer programme (Onset Computer Corp, USA). Daily rainfall was recorded using a standard rain gauge installed within the Research Station.

Data analysis

Temperature and relative humidity (RH) data were processed with MS Excel (Microsoft Corporation, USA) and Polux (International Potato Centre, Lima, Peru) computer programs. The number of hours when the RH (%) and temperature (^{0}C) exceeded 90% or 16^{0}C, respectively, these being threshold values to support LB infection and epidemic development, were computed (Harrison, 1992; Forbes *et al.,* 2002). Also computed was number of hours when RH≥87% as a way of adjusting the leaf-wetness proxy.

Temporal characteristics of late blight epidemics were studied using disease progress curves and parametised with logistic function in FITCURVE alogarithm of Genstat 6.1 Release (Lawes Agricultural Trust, Rothamsted Experimental Station, UK). The logistic function is expressed as,

$$Y_L = A + C/(1+\exp(-B*(x-M)) \text{ or } A + C/(1+e^{-b(x-M)}) \quad \ldots\ldots \quad 1$$

where; Y_L is disease severity (%), '***A***' is the lower asymptote, '***B***' is the rate constant of the disease progress curve at the point of inflexion or point of maximum rate of disease increase ('***M***'). The parameter **'C'** is the curve constant related to residual disease. The upper asymptote is **(A+C)**, '***x***' is the exploratory variable (Payne, 2002; Mead *et al.,* 2003).

Accumulated hours when temperature and RH exceeded threshold values from either 1st March, or 1st September as reference planting dates or from the actual date of planting per trial set were computed, tabulated and used in disease onset prediction modelling. Similarly treated were daily rainfall and rain days. The number of days from planting to 80-100% crop emergence and late blight onset per crop cycle were computed.

Data queries were performed in MS-Excel and summaries generated where necessary. Correlation analysis was performed between number of days from planting to disease onset with the weather variables previously described. Multiple regression models were fitted to identify key weather variables that possibly influence the onset of late blight epidemics in a given crop cycle. Season, planting date and potato variety were included as fixed effects in regression models. The significance of fixed effects and their interactions were tested with analysis of variance. Differences among significant main effects and interactions were compared with standard error of mean. The multiple linear regression model for days from planting to disease onset was hypothesised as;

$$Y_d = Y_r + S + P + V + T_{16} + R_{(87,90)} + R_f + R_d + e \ldots\ldots 2$$

where $\mathbf{Y_d}$ is days from planting to disease onset, $\mathbf{Y_r}$, **S, V, P** and **V** are year, season, planting date and potato variety terms, $\mathbf{T_{16}}$ is accumulated hours of temperature ≤16°C, $\mathbf{R_{(87,90)}}$, is accumulated hours with relative humidity (RH) equal to or greater than either 87 or 90% , $\mathbf{R_f}$ is accumulated rainfall (mm), $\mathbf{R_d}$ is accumulated rain days and **e** is the error term.

Least squares regression technique was used in selecting the most appropriate regression models. Models with high reliability and few variables were preferred (Mead *et al.*, 2003; Stern *et al.*, 2004). Functional relationships were explored between late blight onset and other disease progress curve parameters fitted with the logistic function with Genstat (6.1 Release) statistical computer package following pertinent procedures.

Results

Comparison of late blight onset between the first and second rainy seasons indicated that, disease appeared earlier during the first than the second rainy season on the potato varieties used in this study (Table 1). Among the early-planted potato, late blight appeared 37-40 and 50-55 DAP during the first and second seasons, respectively (Table 1). Late blight during both seasons appeared significantly (P≤0.05) earlier in late- than early-planted potato (Table 1). Late blight also generally appeared significantly earlier on potato var. Victoria and averagely two days later on both vars. NAKPOT4 and NAKPOT5 more so among early planted potato in every crop cycle over seasons across the years (Table 1).

Table 1. Variability in days from planting to late blight onset across seasons among potato varieties at Kalengyere Research Station from 2002 to 2004

Season†	Planting date	Number of days from planting to late blight disease onset			
		Victoria	NAKPOT5	NAKPOT4	Mean
2002A	30 March	39.9±1.1	40.8±1.1	40.5±1.1	40.2±0.1
	18 April	31.9±1.1	33.8±1.1	33.5±1.1	33.1±0.1
2002B	1 September	52.0±1.0	54.0±1.0	53.6±1.0	53.3±0.0
	22 September	45.0±1.0	46.9±1.0	46.6±1.0	46.2±0.0
	13 October	34.6±1.1	36.5±1.1	36.2±1.1	35.8±0.1
	3 November	25.7±1.2	27.6±1.2	27.3±1.2	26.9±0.1
2003A	1 March	40.0±1.0	41.9±1.0	41.6±1.0	41.2±0.0
	22 March	33.0+1.0	34.9±1.0	34.4±1.0	34.1±0.0
	12 April	22.5±1.1	24.5±1.1	24.1±1.1	23.7±0.1
2003B	1 September	53.1±1.0	55.0±1.0	54.7±1.0	54.3±0.0
	22 September	46.1±1.0	48.0±1.0	47.7±1.0	47.2±0.0
	13 October	35.7±1.0	37.6±1.0	37.3±1.0	36.8±0.0
	3 November	26.8±1.2	28.7±1.2	28.4±1.2	27.9±0.1
2004A	1 March	38.5±1.0	40.3±1.0	40.1±1.0	39.7±0.0
	22 March	31.5±1.0	33.4±1.0	33.1±1.0	32.6±0.0
	12 April	21.1±1.1	23.0±1.1	22.6±1.1	22.3±0.1
2004B	1 September	51.6±1.0	53.5±1.0	53.2±1.0	52.8±0.0
	22 September	44.6±1.0	46.5±1.0	46.2±1.0	45.7±0.0
	13 October	34.2±1.0	36.1±1.0	35.7±1.0	35.3±0.0
	3 November	25.3±1.2	27.2±1.2	26.9±1.2	26.4±0.1

†Season A starts from last week February and ends in July while season B begins in the last week of August and ends in January of another year

Relation between late blight onset and local weather variables

There was generally high and negative correlation between number of days from planting to late blight onset and accumulated hours with relative humidity ≥87% or RH≥90%, accumulated hours with temperature ≤16^{0}C, accumulated rain days and accumulated rainfall all computed from either 1st March or 1st September per crop cycle (Table 2). Combined data across each season over planting dates had low correlation coefficients albeit negative (Table 2). Accumulated hours with RH≥87% and RH ≥90%, were collinear however, the later had a higher predictive index (0.67) than the former (0.53) and consequently removed from further analysis. Year ($\mathbf{Y_r}$), seasons (**S**), planting date (**P**) and potato variety (**V**) were included as fixed effects, and $\mathbf{T_{16}}$, $\mathbf{R_{90}}$, $\mathbf{R_f}$, $\mathbf{R_d}$ as quantitative predictors in equation 3

$$Y_d = Y_r + S+P+V+T_{16}+R_{90}+R_f +R_d +e \qquad (3)$$

The resultant model was highly significant (P<0.001) and explained 98.8% of the observed variation (Table 3). However, stepwise regression, removed the year (Y_r) and potato variety (P) terms with accumulated rainfall (R_f) and accumulated hours with temperature ≤ 16^{0}C (Table 3). The final model comprised of seasons (S) and planting (P) with accumulated hours with RH≥90% and accumulated rain days as variable predictors. The model accounted for 98.9% of the observed variability (Table 3).

Table 2. Correlation coefficients between days from planting to late blight onset and key weather variables at Kalengyere Research Station from 2002 to 2004

Weather variable	Correlation coefficients for days from planting to late blight onset						
	2002A	2002B	2003A	2003B	2004A	2004B	Combined
Accumulated hours RH≥87%	-0.746	-0.949	-0.536	-0.951	-0.809	-0.950	-0.549
Accumulated hours RH≥90%	-0.786	-0.948	-0.537	-0.953	-0.810	-0.950	-0.543
Accumulated rainfall (mm)	-0.860	-0.910	-0.551	-0.933	-0.873	-0.943	-0.287
Accumulated rain days	-0.614	-0.951	-0.541	-0.957	-0.813	-0.949	-0.336
Accumulated hours with temperature≥ 16 °C	-0.623	-0.948	-0.473	-0.945	-0.811	-0.949	-0.235

A scatter plot of fitted against observed values had a significant (P≤0.05) unit (1) gradient and R^2 was 96.8%. A plot of residuals against fitted values showed a random scatter, a non-significant (P≤0.05) intercept and R^2 was $1x10^{-6}$. This showed uniformity of residual variances and normality of the data suggesting that the fitted model provided a good description of the biological data (Table 3). Models for LB onset prediction were consequently fitted for each season and date of planting as a fixed effect.

Table 3. Analysis of variance from stepwise multiple regression model predicting number of days from planting to late blight onset in potato at Kalengyere from 2002 to 2004

Source of variability	d.f.	Sum of squares	Mean squares	Variance ratio	F prob.	R^2
Year	2	260.7	130.3	117.3	0.061	
Season	1	449.6	449.6	404.7	<.001	
Planting date	3	4244.3	1414.8	1273.5	<.001	
Variety	2	59.6	29.8	26.8	<.001	
Accumulated hours temperature ≤16°C	1	22.6	22.6	20.4	<.001	
Accumulated rainfall (mm)	1	174.4	174.4	157.0	<.001	
Accumulated rain days	1	111.2	111.2	100.1	<.001	
Accumulated hours with RH≥90%	1	11.5	11.5	10.4	0.002	
Residual	41	45.5	1.1			**98.8**
Dropping						
Accumulated rainfall (mm)	-1	-1.2	1.2	1.1	0.302	
Variety	-2	-3.3	1.6	1.5	0.241	
Accumulated hours temperature ≤•16°C	-1	-2.9	2.9	2.6	0.112	
Year	-1	-3.9	3.9	3.5	0.345	
Final model (Residuals)	53	5379.5	101.5			**98.9**

The difference in R^2 between common and separate gradients and y-intercepts for planting dates in each season was 0.01. Thus, for consistency in disease onset prediction for a given crop cycle in a season, a separate y-intercepts and gradients model procedure would adequately predict disease onset without serious effect on model output (Mead *et al*., 2003). Consequently, in both seasons, separate models per planting date were used to estimate partial regression coefficients for late blight onset prediction (Table 4).

Model parameter estimates indicated that the y-intercepts were not significant (P≤0.05). The rest of the partial regression coefficients for the predictors (X_i) were significant (P≤0.05), except for the last-planted potato crop during both rainy seasons (Table 4).

Table 4. Partial regression coefficients for predicting the number of days from planting to potato late blight onset during the first and second cropping seasons at Kalengyere Research Station, from 2002 to 2004

Rainy season	Parameter	Model partial coefficients†			
		1 March	22 March	12 April	-
First	Intercept	$-10.5^{0.636}$	$6.5^{0.66}$	$-14.3^{0.878}$	-
	Accumulated rain days (X_1)	$3.2^{0.01}$	$2.5^{<.001}$	$1.1^{0.8}$	-
	Accumulated hours-RH≥90% (X_2)	$-0.034^{0.05}$	$-0.062^{0.039}$	$-0.0002^{0.9}$	-
		1 Sept.	22 Sept.	13 Oct.	3 Nov.
Second	Intercept	$6.5^{0.558}$	$7.7^{0.43}$	$5.1^{0.962}$	$4.9^{0.808}$
	Accumulated rain days (X_1)	$1.38^{<.001}$	$0.82^{<.001}$	$0.69^{<.001}$	$0.48^{0.077}$
	Accumulated hours-RH ≥90% (X_2)	$0.014^{0.05}$	$0.012^{0.02}$	$0.006^{0.303}$	$-0.002^{0.722}$

†Superscripts on each partial coefficient are levels of significance

Relationship between late blight onset and point of inflexion of the disease progress curve

There was a high and positive correlation coefficient between days from planting to late blight onset and the point of inflexion (r = 0.822). The point of inflexion (days) of the disease progress curve can thus be estimated from late blight disease onset predictions.

A general linear regression model estimating the point of inflexion from the number of days from planting to disease onset with year, season, planting date and variety as factor variables was highly significant (P < 0.001) explaining 80.9% of the observed variability. However, stepwise regression showed that the point of inflexion was best fitted with a simple, highly significant (P < 0.001) linear function with days from planting date to disease onset as a lone predictor.

The model had a significant (P = 0.013) y-intercept (±2.15) and highly significant (P<0.001) slope (±0.105) and accounted for 88.8% of the observed variability (Figure 1). A plot of residuals against fitted values indicated a random scatter alluding to uniformity of residual variance. The plot observed against fitted values was a straight line with an intercept not significantly (P≤0.05) different from zero and a unit (1) gradient indicating a good fit of the model to the biological data.

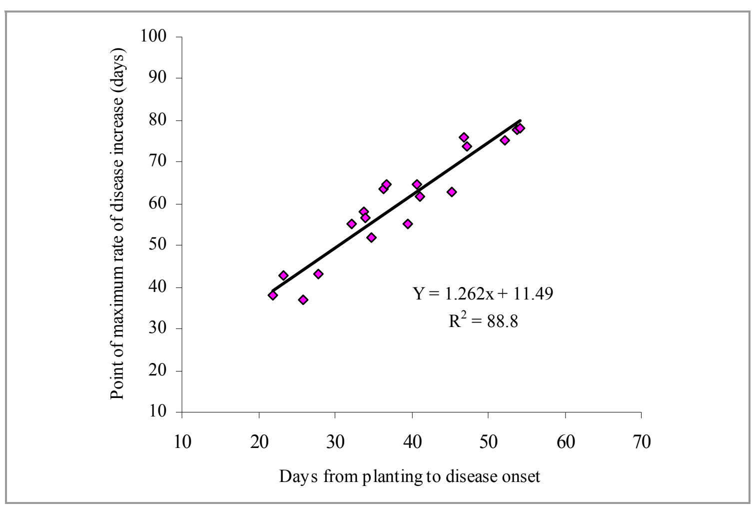

Figure 1. Relationship between days from planting to late blight onset and days to reach inflexion of the disease progress curve at Kalengyere Station from 2002 to 2004

Assessment of predictive precision of the model in estimating the inflexion of the DPC indicated that among 53 of the 60 epidemics whose parameters could be estimated with the logistic function, the model accurately estimated the inflexion in 24 (40%) of the epidemics, overestimated it in 15 epidemics (25%) and underestimated in 14 (23.3%) of the epidemics. However differences in inflexion estimate did not exceed twice the standard error of mean. The model was able to estimate the point of inflexion or some days before it in 71.7% of the studied epidemics.

Discussion

Late blight onset assessment among selected potato cultivars in natural field conditions in seasonal, continuous potato planting in the highlands of south western Uganda indicated that the date of planting had a strong influence on days from planting to disease onset than potato variety. However, LB appeared earlier during the first than second rainy season because the dry spell between the second and first rainy season between two successive years is shorter than between the first and second season in the same year. This offers more potato crop overlap, with more fields infested with late blight thus offering high inoculum loads early in the season. The number of days from planting to LB onset in a given potato crop decreased with delay in planting during both seasons. By the last planting date, disease was detected within 21-28 DAP and occasionally simultaneously among varieties irrespective of the previously observed resistance to LB in early-planted potato. Early disease onset among late-planted potato during each season may due to highly favourable weather for LB epidemic development soon after crop emergence coupled with probable high *P. infestans* inoculum loads.

Knowledge of disease onset is a crucial step in developing integrated disease management of potato late blight. There were high correlation coefficients between days from planting to LB onset and accumulated hours with, RH ≥ 90%, temperature ≤16°C, accumulated rainfall (mm) and accumulated rain days as predictors for LB onset. However, variables computed from 1st March or 1st September as seasonal reference planting dates but not from the actual date of planting per crop cycle best described the data. This approach is appropriate because fits the farming calendar and integrates previous weather events which have a strong cumulative influence on the plant growth, LB behaviour and future disease epidemic development (Harrison, 1992; Forbes, 2003; Andrade-Piedra *et al*., 2005b). Pooled data across seasons had low correlation coefficients for days from planting to disease onset. The two seasons therefore should be analyzed separately and models developed for more homogenous environments if they are to adequately predict disease onset than developing universal functions which may suffer from loss of precision in natural systems (Andrade Piedra *et al.,* 2005a).

Stepwise multiple regressions with the measured weather variables and experimental fixed effects indicated that the days from planting to late blight onset on a given potato crop was quantitatively related to accumulated hours with RH≥90% and accumulated rain days both computed from either 1st March or 1st September for the first or second rainy season, respectively. Estimated model gradients were significant (P≤0.05), except for late-planted potato. This indicates a probable loss of predictive accuracy in April- and November-planted potato, possibly due to uniformity in weather conditions favouring disease infection or very high viable disease inoculum. The y-intercepts of the models though not significant (P≤0.05) decreased with delay, and probably had little or no effect on the model output since any of the quantitative variables in optimal potato growing conditions may not have a zero-value in an entire crop cycle.

The point of inflexion of the disease progress curve is a key parameter of disease development. Early attainment of the inflexion in a young potato would lead to serious disease attack in a crop with limited foliage resulting in high yield losses unless control measures are instituted. Late attainment of the point of inflexion irrespective of the disease severity may not grossly affect tuber yield. The duration from planting to attaining the inflexion (***"Y"***) was linearly related to days from planting to disease onset ***'x'*** by $Y = 1.262x + 11.49$. The exploratory values of ***'x'*** can be determined from the previous weather-dependant disease onset prediction models. The significant (P = 0.013) y-intercept in this model indicates that the value of x can never be zero. The estimated date of disease onset and point of inflexion can thus be used to institute, defer or completely ignore disease control depending on the stage of crop growth. This would permit use of control measures when they have highest benefit. .

Conclusion and recommendations

This study demonstrated that late blight onset in a given potato crop in the highlands of Southwestern Uganda can be predicted from accumulated hours with relative humidity ≤90% and accumulated rain days. However, data must be computed from beginning of the rainy season in a farming calendar of this agro-ecosystem here taken as 1st March and 1st September for the first and second rainy seasons, respectively. Prediction of disease onset was linked to a model predicting the date of attaining inflexion of the disease progress curve. These functions can be iteratively used in designing a disease escape strategy or deployment of the crucial fungicide sprays that are vital in successful late blight control. Estimates of the point of inflexion would also prevent using fungicide when the crop is approaching maturity and further disease increase will have little or no effect on gross tuber yield. The LB onset prediction model however, suffered from loss of precision among late-season planted potato where disease tended to appear soon after crop emergence probably due to high and viable inoculum loads. Variation in inoculum density over a rainy season was not included in this study and would thus be an important component in future late blight epidemiological studies for tropical highland potato cropping system. Finally, these models were developed with empirical data over three years and were not tested on independent data. It is crucial that they are tested in independent experiments in this and similar agro-ecological zones.

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