Estimating potential impact of potato late blight resistant varieties in China with GIS

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Summary

Late blight of potato caused by *Phytophthora infestans* is known to be an important limiting factor in China, but disease pressure is highly variable and little is known of its variability in the different Chinese agro-ecosystems. Severity of late blight was estimated by linking a disease forecast model, SIMCAST, to a climate database in a Geographic Information System (GIS). The disease forecast model indirectly estimated late blight severity by determining how many sprays were needed during a growing season. Planting periods were established for different agroecosystems in the north for the spring season and in the rest of China for the fall and winter seasons. The model was run with parameters for susceptible and resistant varieties to analyse the potential impact of host resistance on fungicide use. The results indicated that late blight is least severe in the north and that in other regions late blight pressure is stronger for the fall than the winter. In all seasons there was a clear east-to-west gradient with little late blight pressure in the western area of the country and very high pressure in the central and eastern regions. Based on fungicide reduction, host resistance resulted in a simulated savings of more than US$742 million in spring-fall and US$1.1 billion in spring-winter.

Keywords: Potato late blight, Forecast model, Geographic Information System, SIMCAST.

Introduction

The International Potato Center (CIP) and partners have been involved in the development, diffusion and promotion of potato cultivars resistant to late blight (LB) for more than two decades. Although many of these varieties have been adopted to varying degrees in developing countries, estimating their impact is difficult for many reasons: i) LB resistance is quantitative, and the level of resistance of a given material is often not known; ii) LB affects farmers in many ways, including income lost to fungicides, direct losses to production and human health risks; iii) LB is strongly weather driven, and disease intensity is highly variable; iv) the actual degree of adoption of resistant varieties is often not well known for a particular country or area. For these reasons, the impact potential of host resistance is highly context-specific.

A potential solution to the problem of estimating the impacts of host resistance on late blight severity is agroecological zoning with a geographic information system (GIS). Zoning that is specific to a particular technology or production constraint can give realistic estimates of intensity and variation of the factor under study (Corbett, 1998; Wood & Pardey, 1998). This type of zoning has recently been facilitated by strong technological progress in computer hardware and GIS software, which has made the manipulation of large geo-referenced databases relatively straightforward. The availability of geo-referenced weather data makes the application of GIS based zoning possible for many areas of the world.

In this paper we describe the use of the late blight forecast model SIMCAST (Grünwald et al., 2002) linked to GIS to estimate the number of fungicide sprays needed for effective management of potato late blight. By running the model for both susceptible and resistant cultivars, the potential economic and environmental impact of host resistance can be explored geographically.

Materials and methods

The model

The LB model used in this study was SIMCAST developed at Cornell University. The model uses as daily variables average temperatures during hours of high relative humidity (Humtm), number of hours per day of high relative humidity (Humhr), and accumulated daily precipitation. To determine the first and second variable, SIMCAST uses a threshold of 90% of relative humidity; adjusted for the height of the sensing device. If a weather sensor is located inside the plant canopy, the threshold is 90%, and if it is outside, the threshold is 85% (Andrade-Piedra et al., 2005). In this research the 85% threshold was used because the weather data used in this study were taken from airports.

To predict the need of a fungicide application, the model considers a threshold of either accumulated blight units (BU) or fungicide units (FU) – whichever is reached first. The BU are determined based on Humhr and Humtm, providing an index of the disease severity; while FU are based on precipitation and represent fungicide washing or chemical degradation of the active ingredient.

Weather data

Weather stations with daily data for China were downloaded from the National Oceanic and Atmospheric Administration (http://www.noaa.gov/) for a period of 11 years (1994 to 2004). The selected variables were minimum temperature (Tmin, C°), maximum temperature (Tmax, C°), dew point (Tdew. C°) and precipitation (Pp, mm). The selection of weather stations was done in the next order. First, weather stations, which had more than 80% of data per variable per year, were selected. Second, daily averages data for the 11 years per variable were calculated. Finally weather stations which had daily missing data were eliminated. As a result, 465 weather stations with complete data were selected. From these, 89% had average data from 7 to 11 years, 8% for 4 to 6 years and 4 % for 1 to 3 years. The data of 465 weather stations were used to build daily weather surfaces for each variable.

Estimating hourly temperatura and relative humidity

Hourly temperature data were obtained using the methodology developed by Cesaraccio et. al. (2001), which uses daily values for minimum temperature, maximum temperature, minimum temperature of next day, sunrise and sunset. Sunrise and sunset times were obtained using the weather station latitude and the day number of the year. Daily dew point data and calculated hourly temperature (T) data were used to estimate hourly relative humidity (RH) (Chow et al., 1994). Hourly RH is the quotient obtained between the real vapor pressure and saturation vapor pressure. To calculate the real vapor pressure, daily dew point was used. To calculate the saturation vapor pressure hourly T was used.

Validation of methods used to estimate hourly temperature and relative humidity

Estimation processes were validated with a USA hourly weather database (US-EPA, 1997), using 48 weather stations located in potato-growing areas (Hijmans, 2001), and the hourly variables Tmin, RH, Tdew and Pp. Of the 48 weather stations, 46 had data for six years (1990 to 1995), and two had data for only two years. A total of 282 datasets were used to validate estimations of hourly T and RH data from Tmin, Tmax, and Tdew daily data.

The validation process was done in two steps. First, hourly data of T, RH and Pp were used to calculate the *observed simcast input data* (HumTm, HumHr and Pp). Subsequently, the model was run to obtain the number of observed applications for the 282 datasets. Second, hourly data of T, Tdew and Pp were used to calculate daily data of Tmin, Tmax, Tdew and Pp. Hourly T was obtained using daily Tmin and Tmax; while hourly RH was obtained from hourly T and daily Tdew. The hourly data of T and RH, and the daily PP were used to calculate the *estimated simcast input data*. The model was then run to obtain the number of estimated fungicide applications for the 282 datasets. This was done for both *observed* and *estimated input data.* Finally, the number of applications from *estimated input* was regressed on applications derived from *observed* input, using a simple linear regression. The slope was statistically compared to 1 using a T test, with the intercept set to 0. Goodness of fit to the model was evaluated with R^2.

Weather surfaces for China

The ANUSPLIN suite of programs (Hutchinson, 2006) was used to construct average daily weather surfaces for each variable (Tmin, Tmax, Tdew y Pp) on a grid cell size of 6-arc minutes in both latitude and longitude. A digital elevation model (DEM) was a prerequisite in the interpolation process; thus a DEM developed by USGS at 30-arc seconds resolution (approx, 1 km) was clipped and fitted to the resolutions mentioned above (Hutchinson, 2006). The latitude and longitude data used in ANUSPLIN were obtained from NOAA; while the altitude of the weather stations was obtained from the fitted DEM.

Weather surfaces and SimCast

Once the daily weather surfaces were created (Tmin, Tmax, Tdew and Pp), the method to obtain *estimated SimCast input data* was applied in each cell. Next the model was run according the potato cropping seasons.

Determining growing planting date and season length

In China, potato is cultivated across a wide range of agro-ecological zones (Gitomer, 1996). In the south, climate allows for several planting seasons, while in the north only one season is possible, which is established in the spring. In this paper, planting in the rest of China is assumed to take place in the fall and winter. Each season was considered to last 120 days, 20 days pre-emergence and 100 days after emergence. Simulation was initiated at emergence and run for a period of 100 days.

Economic and environmental analisys

Host resistance can potentially result in a savings by reducing the use of fungicide. To capture this potential in a geographical context, resistance was geographically linked to a potato production area to make an economic and environmental analysis. In China the average production of the years 1998, 1999, 2000 and 2005 (http://www.cast.net.cn/SINOPOTATO/statistics/2000-e.htm) was used. To make an economic and environmental analysis, basic criteria about fungicide use were considered. We assumed that all applications were made with the fungicide clorothalonil, which is the product originally used to develop SIMCAST. Clorothalonil is similar in efficacy to Mancozeb, which is the most widely used fungicide in most developing countries. Labor costs were estimated at $5 per ha. Two kg of Clorotalonil were used per ha per application, and fungicide cost was estimated at $22.

The quantification of environmental impact (EI) was obtained with a formula proposed by Gallivan et al., (2001). The EI was calculated by multiplying the amount of pesticide used (kilograms of active ingredient) by the environment impact quotient (EIQ), a score for the potential risk to farmworkers, consumers and the environment.

The EIQ for Clorothalonil was considered 40.1 (http://nysipm.cornell.edu/publications/eiq/files/EIQ_values.xls).

Results

Comparison of predicted and observed values

For the 48 weather stations used in this analysis, the prediction of LB severity using estimated hourly data from daily variables (Tmin, Tmax, Tdew) to obtain SIMCAST variables was similar to the observed hourly data (Figure 1). This analysis served to validate the use of daily weather from China as input data for SIMCAST. The slope of the simple regression line comparing observed and estimated values was not significantly different from 1 in any of the years tested; R^2 values ranged from 0.85 to 0.94.

Late blight distribution in China

The principal potato production areas in China are located in the north (Nei Mongol, Gansu), northeastern (Heilongijiang), central (Sichuan, Chongquing, Shanxii, Shaanxii, Hubei, Shandong, Hunan) and south central regions (Yunnan).

With the use of susceptible or resistant varieties in different growing seasons, there was a clear east-to-west gradient with little late blight pressure in the western area of the country and very high pressure in the central and eastern areas. Nevertheless, disease severity was reduced in all regions when the model was run with parameters for a resistant.

In the north, where only one crop is established in the spring, disease severity is low, and there is no disease in Gansu or Nei Mongol West. However, disease severity increased from Nei Mongol east to Heilongjiang. In the other potato-growing areas, the severity of the disease varied according to the growing seasons (winter or fall) and spatial scenarios (central to south central; and central east to central south).

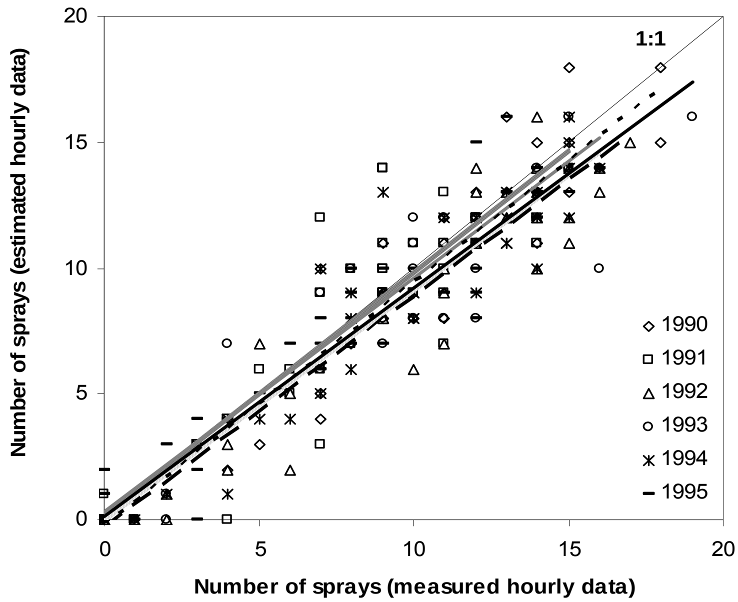

Figure 2. Observed and estimated fungicide applications needed to control LB obtained with the SIMCAST model using weather data of 48 locations from the US over 6 years. Observed applications were obtained with *measured* hourly data and estimated applications were obtained with *estimated* hourly data (from daily data) as described by Cesaraccio et al [1]. R^2 values for the linear regressions of each year averaged 0.92 with a minimum of 0.85 and a maximum of 0.94

In the central to south central region, estimated severity levels were higher in fall than in winter. In winter, the regions of highest severity included Guizhou, southeast Sichuan to southwest Chongquing and southern Yunnan. In fall, high severity reached a broad extension, including the provinces of Guizhou, Yunnan, Sichuan, Chongquing, Shanxii, Shaanxii, Hubei, Shandong, and Hunan. In the central east to central south region, where potato production is low, disease severity was higher in both seasons. The province of Guangdong was an exception because the severity level in winter was higher than in fall.

Economic and environmental analysis

Economic and environmental analyses were both based on the quantities of fungicide estimated necessary to control late blight. The economic aspect was determined by monetary cost and savings accrued due to use of a resistant cultivar, while the environmental aspect was determined by the percentage increment or reduction in the use of the chemical product due to use of a resistant cultivar. The economic and environmental aspects were analyzed in two ways: comparing the two growing seasons in the south and assessing the benefits of resistance.

Using a susceptible cultivar, the cost of controlling late blight nationwide was estimated at USD$1.09 billion in winter, and US$2.2 billion in fall. For example, in Guizhou, the estimated cost to control late blight was US$280 million in winter and US$388 million in fall. In other provinces —such as Xizang, Yunnan, Shaanxi, Shanxi, and Hubei— where the potato crop is smaller, the rate of fungicide application for the fall crop was generally twice that of the winter crop.

The economic and environmental impacts of the use of a resistant host were evaluated for a single season in the north (spring) and over two seasons in the rest of the country (winter and fall). The economic impact in the north was most significant, especially in the northeastern province of Heilongjiang, where savings due to the use of a resistant cultivar was US$54 million, and fungicide application was reduced by 50% (Figures 2A, 2B, 3A and 3B).

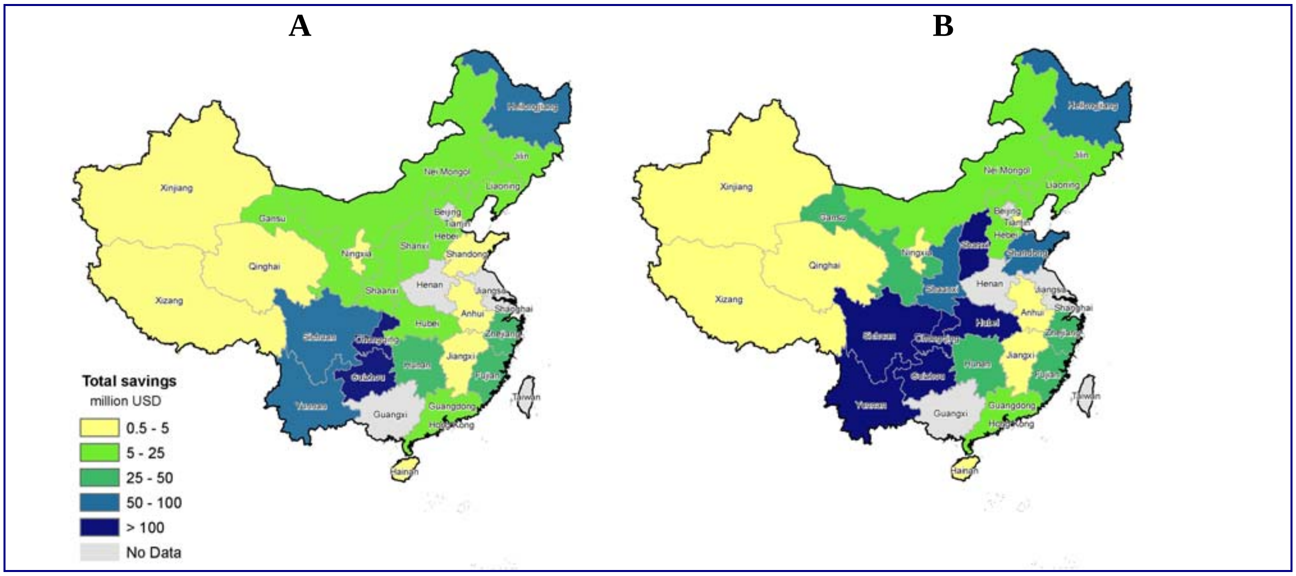

Figure 2. Total estimated savings in USD (millons) resulting from the use of a cultivar resistant to *Phytophthora infestans* in China in the winter (A) and fall (B) planting seasons

For the winter crop in other areas of China, the impact was large in Guizhou and Chongquing, where fungicide applications were reduced by 28% and 20%, respectively, resulting in monetary savings in each province of approximately $USD100 million. In the provinces of Jiangxi and Guandong, where potato is a less important crop, the use of a host-resistant cultivar resulted in a 50% reduction of fungicide applications (Figure 2A and 2B).

For the fall crop, the impact was large in Guizhou, Chongquing, Sichuan, Yunnan, Hubei and Shanxi, with reductions of fungicide use of 52%, 42%, 50%, 59%, 25%, and 10% respectively, and savings of $US100 million in each province. In the provinces of Anhui and Zhejian, areas of relatively minor potato production, the use of a host-resistant cultivar resulted in the reduction of fungicide application by 50% (Figures 2A, 2B, 3A and 3B).

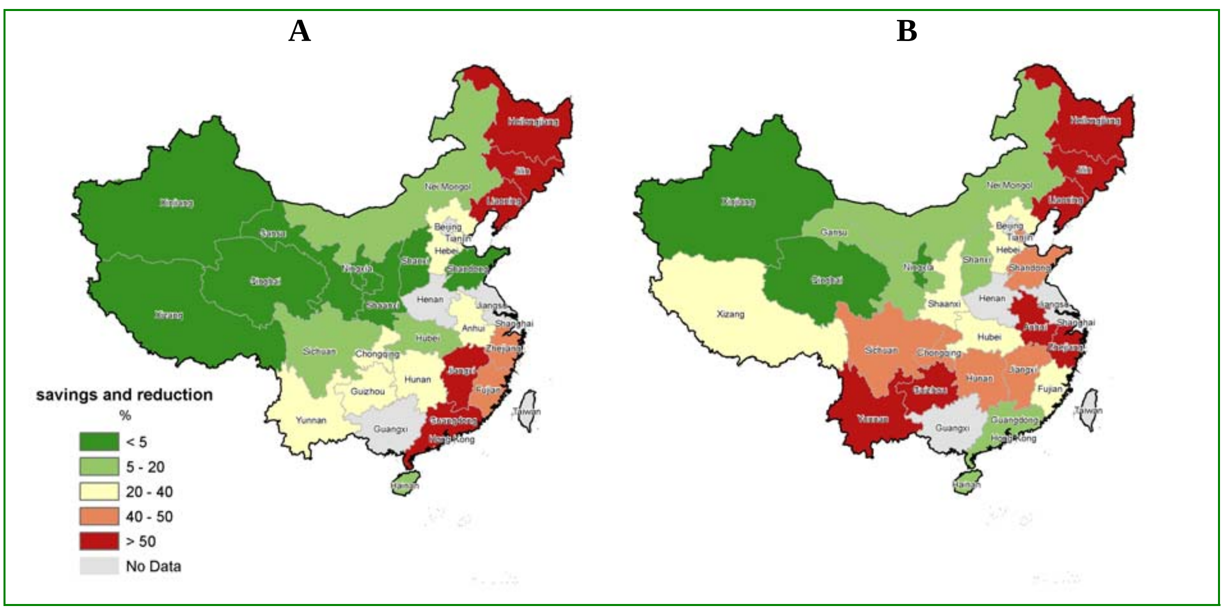

Figure 3. Percent reduction in the use of a fungicide due to the use of a cultivar resistant to *Phytophthora infestans* in China in the winter (A) and fall (B) planting dates

Table 1. Projected impact resulting reduced fungicide if a resistant cultivar is used to manage potato late blight in China

Type of savings	Spring and winter	Spring and fall
Fungicide (mt)	30,281	50,928
Value of fungicide saved (million USD)	76	127
Value of labor saved (million USD)	666	1,120
Total savings (millions USD)	742	1,247
Reduction of the fungicide use	32%	42%

Discussion

The success of a new method to create input hourly data for the SIMCAST disease forecast model was demonstrated. Previous studies have been done calculating hourly data from monthly data, while the approach described herein allowed us to use daily temperatures to obtain hourly data. As with the previous publication (Hijmans et al., 2000) where use of input data derived from monthly observed data gave acceptable results, our use of input data derived from daily observed data also gave good results (Figure 1). In fact, the R2 values from our regression analyses are slightly higher than that reported by Hijmans et al., (2000), which is perhaps to be expected as we estimated from data of higher (daily) temporal resolution.

Hijmans et al., (2000) provided a partial validation of the approach by comparing their estimates for number of sprays to a database of survey data which included this variable. Unfortunately, we do not possess such data to evaluate our results in China. Based on what workers in China have told us, the absolute number of sprays estimated by the model (not shown) may be high. This could possibly be explained by a number of factors, including, but not limited to, the real initiation date for disease (we assumed emergence), the actual level of resistance of the susceptible cultivar, and the aggressiveness of the local pathogen population. However, since the primary objective of our study was to make comparisons (either geographic, seasonal, or for host resistance level), we feel that the results we presented demonstrate valid tendencies. We propose that the results can be useful for priority setting for research and development aimed at LB remediation.

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