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Forecasting of Potato Late Blight Disease Using Alternative Sets of Meteorological Data and Disease Epidemiology

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ABSTRACT

Phytophthora infestans (Mont) de Bary, the causal agent of late blight of potato is one of the most important plant pathogens. The disease can occur in a wide variety of climatic conditions and can be very devastating if it does not managed properly. To reduce yield losses, different protective measures are used, including fungicide treatment. Uncontrolled and excessive fungicide applications cause environmental pollution. Accordingly, crop protection strategies optimizing the number of treatments are of great interest. Prediction of potato late blight epidemics was studied in two different locations of Adana. Meteorological data (hourly) were recorded by an iMETOS® automatic weather station installed in the field and were compared with regional station Winstel, Blitecast and Ullrich-Schrodter models. Three disease warning models were compared to forecast the development of potato late blight in Adana between 2013 and 2014 first time. In the Çukurova region, the Winstel model yielded more accurate results in predicting infection conditions compared to the other two models. Studies provided that, the conditions of potato late blight disease formation in the region were determined and the use of the Winstel early warning system following the regional conditions and biotechnical methods which will be alternative to chemical control were provided by the regional farmers.

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Patates Mildiyösü Hastalığının Epidemiyolojisi ve Hastalık Tahmininde Farklı Meteorolojik Sistemlerin Kullanım Olanakları

ÖZET: *Phytophthorainfestans* (Mont.) de Bary'ın neden olduğu Patates Mildiyösü tüm dünyada ürün kayıplarına neden olan önemli bir hastalıktır. Hastalık, çok çeşitli iklim koşullarında ortaya çıkabilir ve kontrol edilemezse bitkinin tamamen kurumasına ve tüm yapraklarının dökülmesine neden olmaktadır. Çukurova Bölgesi'nde hastalıkla mücadelede ürün kayıplarını en aza indirmek için fungisit uygulamaları dahil olmak üzere çeşitli koruyucu önlemler kullanılmaktadır. Fungisitlerin kontrolsüz ve çok sayıda uygulanması çevre kirliliğine neden olmaktadır. Bu nedenle ilaçlama sayısını optimize eden bitki koruma stratejileri büyük ilgi görmektedir. Çalışmalar, 2013 ve 2014 yıllarında, iklim verilerini değerlendirerek bölge koşullarında en doğru enfeksiyon tahminine olanak veren erken uyarı modelinin belirlenmesi amacıyla yürütülmüştür. Bu amaçla yaprak ıslaklık süresi, hava sıcaklığı, yağış ve nispi nem değerleri anlık olarak ölçülmüştür. Patates mildiyösü hastalığının tahmin çalışmaları, Adana ilinde ticari patates yetiştiriciliğin yoğun olarak yapıldığı 2 farklı alanda iMETOS® elektronik iklim istasyonunun bulunduğu tarlalarda yürütülmüştür. Bölgede ilk defa yapılan bu çalışma kapsamında Ullrich Schrodter, Winstel ve Blitecast modelleri karşılaştırılmalı olarak uygulanarak bölge koşullarında en doğru enfeksiyon tahminine olanak veren erken uyarı modeli belirlenmiştir. Çukurova bölgesinde Winstel modelinin diğer iki modele göre en iyi sonuç gösterdiği tespit edilmiştir. Çalışmada elde edilen bilgiler

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yardımıyla Patates Mildiyösü hastalığının bölgede epidemi oluşturma koşulları belirlenerek bölge şartlarına en uygun olan Winstel erken uyarı sistemi ile kimyasal mücadeleye alternatif olacak biyoteknik yöntemlerin bölge çiftçisi tarafından kullanımı sağlanmıştır.
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INTRODUCTION

Potato late blight (PLB), caused by *Phytophthora infestans* (Mont.) de Bary, 1876, was responsible for the occurrence of the destructive Great Irish Potato Famine during the first outbreak in Europe in the early 1840s (Bourke, 1991). *P. infestans* is a serious and destructive disease of potato in the world, including the Çukurova region in Turkey. Fungicides used against PLB disease represents approximately 50% of the total amount of annual used fungicides. The low yield and quality caused by this disease account for huge economic losses. Overall, potatoes are produced in 7000 ha area in Çukurova region, and an average of 12-14 fungicide application were done against this disease seasonally.

Intensive chemical control of potato crops against PLB is realized in most of Europe with large potato production. Recently, up to 20 fungicide applications have been used to manage disease in many Europe countries (Schepers and Spitz, 2006; Hansen et al., 2007).

Both potato cultivation and seed potato production are very important in the Çukurova region. The humidity of the region cause an increase of yield loss and consequently more of fungicide applications causing a large economic and environmental damage. With the early warning study conducted in the region for the first time, it was tried to prevent unnecessary pesticide use. Decision support system (DSSs) used in the control of the disease in potato plant protection support to determine the proper first application date and the following treatments. This lets the number of fungicide treatments to be reduced and plays an important role in both the price efficiency of chemical control and also in environment protection. In these systems, the relative humidity, air temperature and leaf wetness duration can be determined and the probability of an outbreak is predicted. The first successful forecasting model was the negative prognosis of *P. infestans* Ullrich and Schrodter in 1966. DSSs have been developed after the years and are readily available and purchasable (McCown, 2002). In the Euroblight website a list of 12 DSSs is presented, all for the management of one pathogen, *P. infestans* (http://www.euroblight.net/ EuroBlight.asp). A list of 16 DSSs for late blight management is currently on the website of the University of California (UCIPM Online; http://www.ipm.ucdavis.edu/disease/database/ potatolateblight. html) (Shtienberg, 2013).

The reliable weather dependency of PLB has been used as an elementary for several types of models to determine how to effectively control the disease with fungicides. The models evaluated how favourable the conditions for disease development are based mainly on observations of weather condition. There are some similar examples of such PLB control systems (e.g. Smith, 1956; Ullrich and Schrödter, 1966; Krause et al., 1975; Hansen et al., 1993; 1996; The Negfry-system (Hansen et al., 1993; 1996). Such so-called DSSs have the potential of reducing the fungicide inputs while maintaining an acceptable level of control.

In Çukurova, losses of yield is reported about 40-80% depending on the cultivars and weather conditions.

Because of controlling of the late blight requires-frequent fungicide treatments, cost for controlling of this disease in potato is higher than to other crops. Due to high disease pressure in the highland tropics, some farmers apply fungicides more than ten times per growing season (Gunacti et al., 2016).

In this study, the Ullrich-Schrodter model (Ullrich and Schrodter, 1966), Winstel model (Winstel, 1993) and Blitecast model were compared by using them to predict the progress of PLB in the potato growing areas of two locations in Adana Province between 2013 and 2014. In the current study, in Çukurova, which is the most important producer of potato cultivation, the basis for the initiation of biotechnical control with the PLB disease was prepared.

MATERIALS and METHODS

This study was conducted in 2013 and 2014 to determine the early warning model, which allows for the most accurate prediction of infection by evaluating the climate data. For this purpose, the leaf wetness duration, air temperature, rainfall and relative humidity values were measured instantly. The trials were carried out in two periods in the fields where electronic observatory station was established in two different fields in Seyhan and Yüreğir districts of Adana. Depending on the climatic conditions in Adana province, planting of potatoes is done between 15 December and 15 January. Climatic data were recorded between planting and harvesting periods.

Early-Warning Models

In this study, Ullrich-Schrodter, Winstel and Blitecast models were used as a comparison in the estimation of the outgrowth of late blight disease. As predicted by the models, all models were started to work together with the grow of potato plants. According to the study of the models, the phenological period of 3 weeks before the harvest was entered and the study of the models was terminated by entering the phenological period of harvest. With the start of the study, field inspections were carried out regularly and the date of the first symptoms of late blight were recorded. The studies were conducted at two stations established in 2 different potato fields in Sarıhuğlar and Kürkçüler locations in Yüreğir and Seyhan districts between 2013 to 2014. For both climate stations, plots were designed for the experimental area in potato fields. Potato cv. Marfona were planted in the experimental area. To observe the emergence of the disease, 1 m safety strip was left between the control plots and both experimental areas. To isolate from farmer spraying, the trial plots were divided in the opposite direction of the dominating wind of the field. A spraying area of 50 m^2 is reserved for each model. Climate stations have been installed on 10.01.2013 at both locations and activated immediately. Mancozeb+Metalaxyl-M (64+4 % effective ingredients, Ridomil Gold) and dimethomorph+mancozeb (9+60 % effective ingredients, Acrobat) fungicides were used as given by the models.

Ullrich-Schrodter Model

The model is used to assessment hourly temperature, leaf wetness and rainfall. It is a 'negative prognosis' model which forecast when late blight epidemics are not likely to occur. Beginning at crop emergence, daily and risk rate over a week are evaluated. Risk rate is then calculated with the model's table Hansen (1993), Ullrich and Schrodter and Fry models established by the combination of the model in the Ullrich-Schrodter temperature (˚C), leaf wetness (%) and rainfall (mm / h) data are used. The daily index values were evaluated by taking the climate data together with the plant output in the field. When the total index value is 160, the model gives a warning. The first application was made when the total index value was 160 and the daily index value was 8 and above.

Winstel Model

This model was made up of 2 stages and temperature (ºC) and leaf wetness (%) or leaf wetness data are used. In the first stage, climatic data were calculated to determine the conditions for infection. After the infection condition was determined, the second phase was started. At the second phase, the spraying time was determined (Winstel, 1993). Treatment should be beginning when phase 1 is followed by phase 2. Phase 1 forecasting infection when the following requirements are met daily average temperature between 10 and 23 °C and then at least 10 h of temperatures higher than 10 °C and leaf wetness higher than 90 %. Phase 2 forecasting pathogen growth when the maximum daily temperature is between 23 and 30 °C for two successive days and must occur after at least 24 h but not later than 10 days after the first phase.

Blitecast Model

Blitecast was designed as a computerized synthesis of both the Hyre and Wallin models and has been used successfully forecasting late blight in the USA and Europe (Krause et al.,1975). Firstly, part of the program forecasts the initial occurrence of PLB 7-14 days after the first accumulation of either '10 rain-favourable days' according to Hyre's criteria (Hyre, 1954), or the accumulation of 18 severity values according to Wallin's model (Wallin, 1962). Secondly, the program suggests fungicide sprays based on the number of rain-favourable days and severity values accumulated during the previous seven days. Fry et al.(1983) modified Blitecast to schedule fungicide applications more precisely once the initiation of chemical sprays to manage late blight has begun. They incorporated levels of host resistance and weathering of fungicides with Blitecast to suit this system for applying chemicals on both susceptible and resistant cultivars. Daily minimum and maximum temperature values (ºC), relative humidity 90 % and above (hours), maximum and minimum temperature values (ºC) and 24-hour precipitation (mm) data were used in this study.

RESULTS and DISCUSSION

Studies in 2013 season

Potatoes were planted at Kürkçüler station in Seyhan district on 07.01.2013 and Sarıhuğlar station in Yüreğir district on 10.01.2013. The climate data obtained from iMETOS®climate devices had been collected with the cultivation of potato plants (Fig.1 and Fig. 2).

The Ullrich-Schrodter model, one of the early warning models, increased the index value of 160 diseases and the daily index value of more than 8 in the Sarıhuğlar climate station on 24.02.2013, while the Kürkçüler station reached this value only at 23.03. 2013 (Table 1). After the first warnings were received in the experimental areas of the model, the first spraying was made. A second warning was received at Kürkçüler station on 18.04.2013. Two further warnings were taken at the Sarıhuğlar station on 05.04.2013 and 21.04.2013, and 2nd and 3rd spraying were carried out in the area related to the warnings (Table 1).

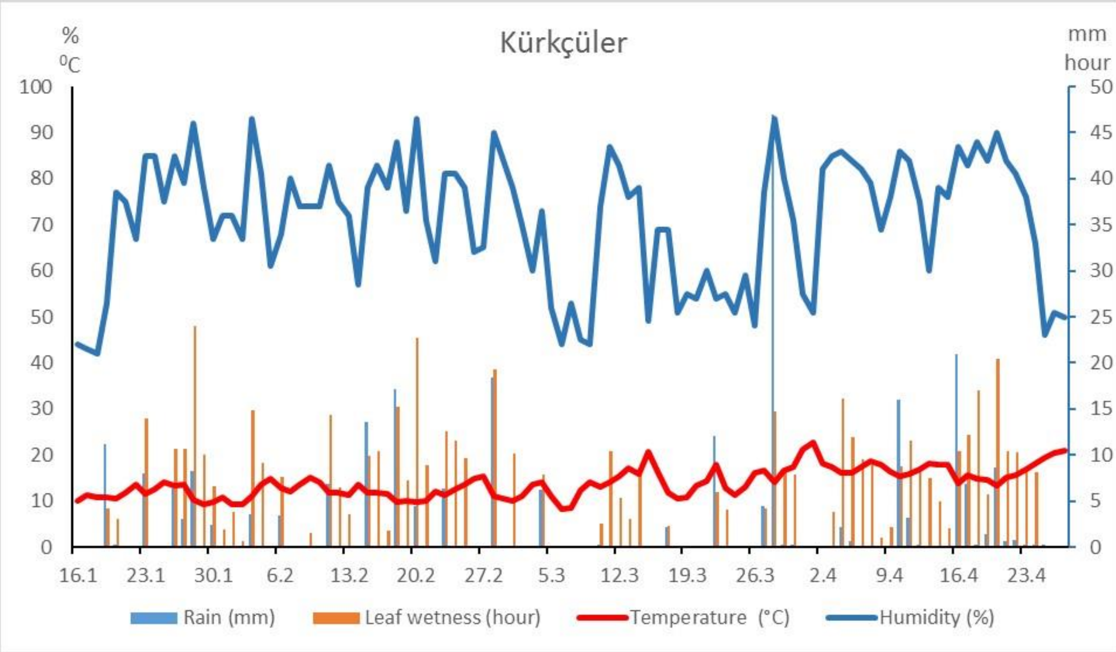

Figure 1. Climate data from Kürkçüler village of 2013
Şekil 1.Kürkçüler köyüne ait 2013 yılı iklim verileri

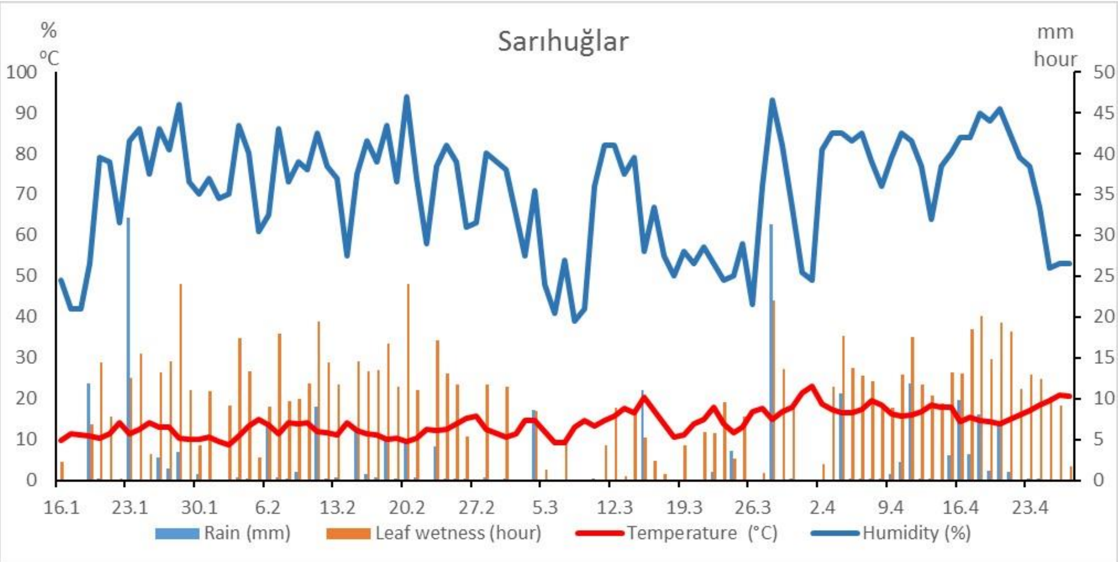

Figure 2. Climate data from Sarıhuğlar village of 2013
Şekil 2.Sarıhuğlar köyüne ait 2013 yılı iklim verileri

The Winstel model was alerted for the risk of infection at the Sarıhuğlar station on 13 times. According to Kürkçüler station data, the infection risk has reached the expected level 11 times in 2013. In March and April, following risk warnings, maximum temperatures reached appropriate values for infection. A total of 4 pesticides were applied in the experimental plot belonging to the model on March 15, March 29, April 12, April 26, of 2013 at Sarıhuğlar station. At the Kürkçüler station, spraying was applied to the experiment area on March 15, and April 5, and April 19 of 2013 when the model gave the spraying warning (Table 1).

Sarıhuğlar station for Blitecast model has warned 4 levels 8 times in 2013. In the data obtained from the Kürkçüler station, the warning level was calculated as level 4-6 times in 2013. A higher warning level has not been reached at both stations. Considering the number of rainy days and plant development period within 7 days before the warnings, the pesticide was applied to the plots allocated for the model in both stations on April 24, 2013. The early symptoms of the disease were observed on April 26, 2013, in the control plots (Table 1).

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Table 1. Disease occurrence dates according to DSSs models and disease occurrence at Sarıhuğlar and Kürkçüler stations in 2013
Çizelge 1. 2013 yılında DSS modellerine göre Sarıhuğlar ve Kürkçüler istasyonlarında hastalık görülme tarihleri

Sarıhuğlar				Kürkçüler			
Ullrich-Scrodter	Winstel	Blitecast	Date of observation in the field	Ullrich-Scrodter	Winstel	Blitecast	Date of observation in the field
24.02.2013	23.01.2013	4.02.2013	26.04.2013	23.03.2013	23.01.2013	4.02.2013	24.04.2013
05.04.2013	24.01.2013	29.03.2013		18.04.2013	26.01.2013	28.03.2013	
21.04.201	10.02.2013	4.04.2013			28.01.2013	29.03.2013	
	11.02.2013	5.04.2013			23.02.2013	18.04.2013	
	15.02.2013	10.04.2013			12.03.2013	20.04.2013	
	23.02.2013	11.04.2013			3.04.2013	21.04.2013	
	12.03.2013	18.04.2013			5.04.2013		
	28.03.2013	21.04.2013			10.04.2013		
	3.04.2013				12.04.2013		
	10.04.2013				17.04.2013		
	12.04.2013				24.04.2013		
	17.04.2013						
	19.04.2013						

Studies in 2014 season

Potatoes were planted at Sarıhuğlar station on January 5, 2014 and at Kürkçüler station on January 7, 2014. The climate data were started to be taken with the cultivation of potato plants (Fig. 3 and Fig. 4). The Ullrich-Schrodter model has reached the index value of 160 diseases at Kürkçüler station on March 3, 2014, but no application has been made for this model since the daily index has not reached 8 times required for the application. There was no warning about the model at Sarıhuğlar station (Table 2).

In the Winstel model, the risk of spreading for 2 hours or more following the 10-hour infection warning was determined as a warning threshold for the application. For the Winstel model, a warning was received 4 times for the risk of infection at Sarıhuğlar station. According to Kürkçüler Station data, Infection risk was seen 3 times in 2014. Following the disease risk warnings in March and April, high temperatures reached the appropriate values for infection.

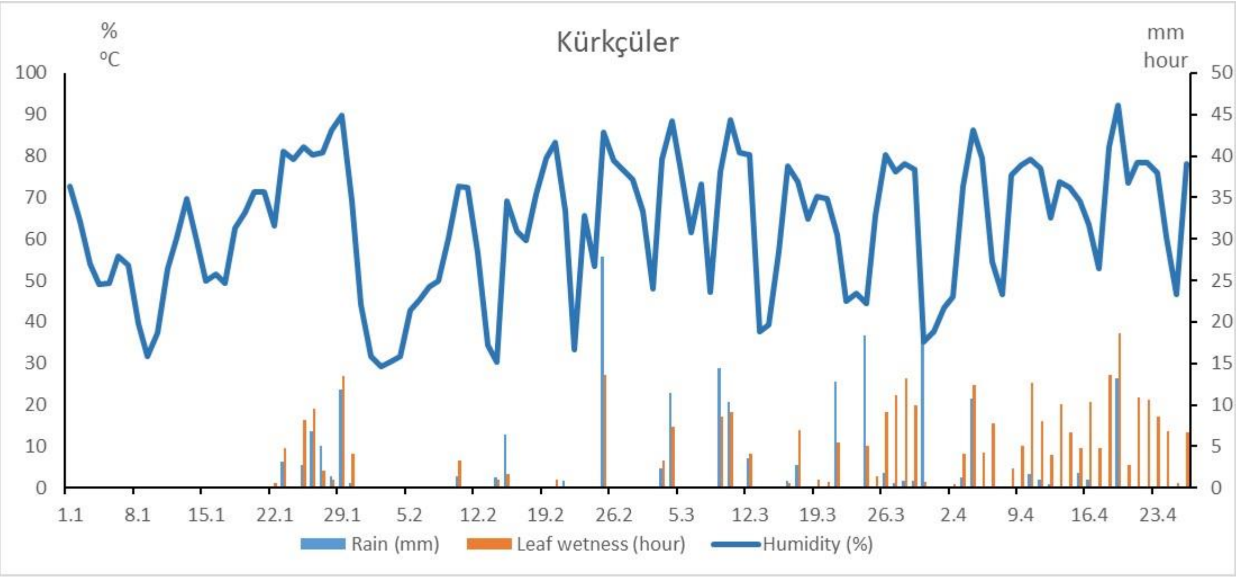

Figure 3. Climate data from Kürkçüler village of 2014
Şekil 3. Kürkçüler köyüne ait 2014 yılı iklim verileri

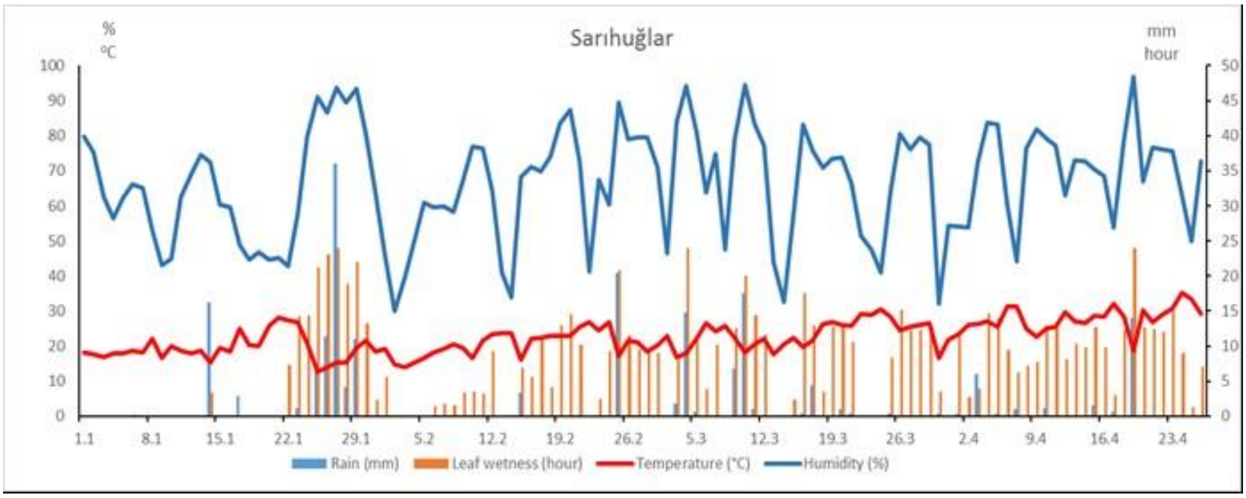

Figure 4. Climate data from Sarıhuğlar village of 2014
Şekil 4. Sarıhuğlar köyüne ait 2014 yılı iklim verileri

Table 2. The dates of disease prediction according to DSSs models and disease occurrence at Sarıhuğlar and Kürkçüler stations in 2014
Çizelge2. 2014 yılında DSS modellerine göre Sarıhuğlar ve Kürkçüler istasyonlarında hastalık görülme tarihleri

	Sarıhuğlar			Kürkçüler			
Ullrich-Scrodter	Winstel	Blitecast	Date of observation in the field	Ullrich-Scrodter	Winstel	Blitecast	Date of observation in the field
	04.03.2014						
		24.02.2014	17.04.2014	3.03.2014	9.03.2014	23.03.2014	26.04.2014
	10.03.2014	5.04.2014			12.04.2014	18.04.2014	
	19.03.2014						
		21.04.2014			21.04.2014		
	04.04.2014						

A total of 3 pesticides were applied to the experimental plots of the model on March 4, March 19, and April 4 of 2014 at Sarıhuğlar station. At the Kürkçüler station, on March 10 and April 12 of 2014 when the model was given a warning of spraying, spraying was applied to the plot in the experimental area (Table 2).

In the Blitecast model, the spray threshold is calculated by considering the number of rainy days. The total 10-day precipitation amount was more than 3 cm and the 5-day average temperature is less than 25.5 °C or the total density value according to the Wallin scale was more than 18; it was accepted that the first symptoms of the disease would be observed after 7 to 14 days. Until the report preparation date in 2014, Blitecast model did not give any model warning because the amount of rainfall required for spraying was never reached and no spraying was done for the plot allocated to this model.

The first symptoms of the disease in control plots were observed on April 17, 2014. In this study, which was conducted to determine the prediction-warning model that provides the most accurate prediction of infection by evaluating the climate data in the conditions of Çukurova region, the dates of the prediction and warning for the infection of the three models and the infection rates in the region were compared. For the development of late blight disease, first of all, fungal spores should be germinated. For this purpose, high-temperature and high relative humidity, such as suitable temperature, free water film on the plant surface, dew and precipitation is required. Humid conditions for the penetration of the pathogen should persist for a certain period. Secondary spores (zospores) that occur after sports germination should be able to perform a successful penetration. The presence of free water film on the leaf increases the efficacy of *P. infestans* as in many leaf pathogens. Therefore, the duration of the leaf wetness is widely used as a critical determinant of the risk of epidemiology in early warning systems (Agrios, 1997; Harrison, 1992; 1995).

Ullrich-Schrodter model; this model was tested during the two breeding periods; the infection conditions could not be predicted correctly. The model warned the total index value of 160 in Sarıhuğlar location 3 times (February 14, April 5 and April 21 of 2013) and twice in the Kürkçüler location (23.03.2013 and 18.04.2013). When the warnings were made, the relevant plots were treated, but the disease occurred on the control plots on April 26, 2013, long after the warning dates. In both stations, the Ullrich-Schrodter model was treated according to the total index value of 160 for the prediction of the first infection signs and the unnecessary application was made. In 2014, 160 disease index values were reached at the Kürkçüler station on March 3, 2014, but since the daily index did not reach 8 times for an application, no application was made for this model.

There was no warning about the model at Sarıhuğlar station. Blitecast model; this model could not accurately predict infection conditions during the two sowing periods. To give a model warning, the total density value should be 18. During the studies, the total severity value of both stations did not reach 18. The model was late in predicting infection conditions in this period. In other breeding periods, it did not give any warning. However, in the controls performed during these periods, disease symptoms were detected in the fields. According to these results, it was seen that Blitecast model does not yield correct results in predicting the conditions of infection in Çukurova region. Winstel Model; in both periods, the model was more suitable than the other two models in predicting infection conditions. After infection of the plant by a pathogen, a certain incubation time is required for the disease symptoms on the plant. After the model gave a warning, the first signs of PLB disease were determined at the end of the incubation period in the potato fields in both years. Temperature is very important in the life cycle of *P. infestans*. The temperature can significantly affect spore germination, mycelial growth rate, inoculum formation and viability. Temperatures below 20 ºC induce sporangium germination indirectly at an optimum temperature of 12-13 ºC. Temperatures above 20 ºC promote optimal direct germination at 24 ºC (Harrison and Lowe, 1989; Sato, 1994). The incubation period of the pathogen is also important in the incidence of diseases. During the incubation period, the pathogen develops and spreads within the host tissues. The temperature of the incubation period increases as the temperature increases and decreases. The incubation period of *P. infestans* is 3.5 days at 22 ºC, 13 days at 12 ºC and 10 days at 30 ºC. Incubation time plays a key role in the starting of chemical control of disease (Baykal, 1995; Ullrich and Schrodter, 1966).

More than 25 models are used for the forecast warning of PLB in the world. The fact that there are so many models is due to both the characteristics of the agent and the diversity of ecology in the regions where potatoes are grown. For this reason, while different models are used among countries, sometimes different models are used even within the country. In the Çukurova region, the Winstel model was more accurate in predicting infection conditions than in the other two models (Ullrich-Schrodter and Blitecast models). The application of the 8 - 12 spraying pre-warning system which is routinely done by the manufacturer has been reduced to 4 applications. Hansen et al. (2002), it was reported that the use of early warning systems reduced the use of fungicide by 8-62 % compared to routine practices. With the data obtained in the study, epidemiological conditions of potato subclinical disease were determined and Winstel early warning system which is suitable for the region conditions and biotechnical methods which may be an alternative to chemical control were used. Early warning systems are very important to ensure effective and economic control in the disease management program. In this way, chemical control was applied at the right time and the desired success was achieved in the control against diseases and unnecessary disinfection was prevented during the period of infection.

CONCLUSIONS

With the help of the information obtained in this study, the conditions of epidemic formation of PLB in the region were determined and the use of biotechnical methods which would be an alternative to chemical control by Winstel early warning system which is suitable for the region conditions was provided by the local farmers. Considering the high sporulation capacity of *P. infestans* and the ability to germinate in a short period, the precondition for success in combating the disease is to determine the relationships between host, pathogen and environmental conditions in the best way. Management strategies for PLB include two main approaches; fungicide applications and host resistance. Moreover, the use of certificated and disease-free tubers for planting and cultural control measurements can greatly reduce the early initiation of disease symptoms. Early warning systems are very important to ensure that an effective and economic control program is implemented. In this way, chemical control was applied at the right time to achieve the desired success in combating the disease and unnecessary spraying during the period when infection conditions were not prevented. This study is important in terms of showing that biotechnological solutions can be provided to the disease. As a result, with the early warning studies, the project prepared the ground for the initiation of the biotechnical control with the PLB in Çukurova, which is the most important production area of early grown potato cultivation. Although the approach used to predict the initiation of PLB development is diverse but most of them have been demonstrated to adequately forecast the initial appearance of the disease as well as timely fungicide application.

A large number of late blight forecasting models exist and are currently used in many potato production areas throughout the world and give satisfactory information. DSSs increase the efficacy of control strategies without increasing risk and can also be used to justify fungicide inputs and as a source of advice in situations where the number of sprays or product choice is limited by legislation. The application of forecasting model for late blight of potato reduces the frequency of fungicides application up to 50 % as compared with conventional, calendar-based program.

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Statement of Conflict of Interest

Authors have declared no conflict of interest.

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