Digital Forecast Technologies for Sustainable Agriculture: Optimization of Fungicidal Treatments of Potato for the Far East Region

M A Kuznetsova¹, O I Iakusheva¹, A N Rogozhin¹, K V Borovsky¹, N V Statsyuk¹
¹Department of Potato & Vegetable Diseases, All-Russian Research Institute of Phytopathology, Institute str., vl. 5, Bolshie Vyazemy, 143050, Russia

E-mail: mari.kuznetsova@gmail.com

Abstract. Far East represents the zone of risk farming that limits the productivity of potato significantly suffering from the late blight epiphytoties. Modern digital technologies can help farmers to overcome this problem. Using the VNIIFBlight Decision Support System (DSS) and archived data (2004–2018) from eight weather stations of the Khabarovsk Territory, we zoned this region in relation to potential potato yield losses associated with the late blight outbreak risk and calculated average frequencies of seasons with high, moderate, and low risks for each observation point. For each season and point, DSS determined dates of possible reinfection and the optimal dates of fungicidal treatments providing efficient protection. Comparison of the DSS-recommended scheme with the routine approach (regular treatments every 8 days) showed that DSS provided 1.9, 2.2, and 5× reduction of the number of treatments for seasons with potential yield losses >20, 10–20, and <10%, respectively. To provide farmers with the access to information required for decision-making, a “Geosystem” GIS was developed as a part of the meteorological service of the Infometeoservice company (http://infometeos.com/Map/Data). The GIS works in a real-time mode indicating the risk of the late blight outbreak at the points of interest that is important for the final decision concerning crop protection activities.

1. Introduction
The Far Eastern Federal District (FEFD) is the largest federal district in Russia. The area of this region is 6216000 km² that makes 36% of the territory of the country; at the same time, 80% of its territory is covered with the permafrost, and only 2% is suitable for agriculture [1]. Moreover, the most part of the region is characterized by a low soil fertility and negative effect of the monsoon climate that complicates the development of a local agriculture.

A significant size of the region, various relief, and presence of seashore in its eastern part determine a wide range of climatic conditions across its territory. The northern territories represent rather areas of risk farming due to severe temperature conditions, so the most part (77%) of agricultural lands are situated in the southern part of the district (Primorsky Territory, Khabarovsk Territory, Amur region, and Jewish autonomous region) [1]. At the same time, the mentioned territories are under the influence of monsoons; high air humidity and temperature regime provide favorable conditions for the development of fungal plant pathogens [2].
Since Russian Far East represents an important geopolitical region of the Asia Pacific, the development of sustainable agriculture and provision of food safety in this region are of special importance. A successful development of the agrarian industry requires the use of modern technologies providing the growth in the yield and quality of main agricultural crops.

Like in many parts of the world, potato is an important food crop of the region. Potato consumption per capita varies in different FEFD regions from 72 (Magadan region) to 195 (Sakhalin island) kg; the average value reaches ~125 kg per capita that exceeds the standard value (95 kg per capita) [3, 4]. The total area under potato fields in the region stably makes 92-95 thousand hectares, from which only 17-18 thousand hectares are located on the northern territories [4, 5]. The most part of potato is grown on small private plots; nevertheless, potato production provides a significant part of incomes of agricultural companies [5].

The average yield of potato in the northern and southern territories within 2008-2014 made 11.8 and 14 ton/ha, respectively [6]. These values are significantly lower than those obtained in the leading potato-producing regions of Europe and may be explained by high climatic and epiphytotic risks. High humidity often provokes the development of potato late blight, the most dangerous disease of this crop caused by Phytophthora infestans and able to destroy up to 100% of yield in the absence of any protective measures. According to the data of our long-term observations, the FEFD territory is characterized by a high risk of late blight outbreaks and the corresponding significant yield losses.

The main way to control this disease is application of fungicides. The common (routine) approach to the chemical control of the late blight is based on regular (each 7‒10 days) treatments of plants with fungicides during a vegetation season. However, this approach is rather expensive, provides a significant pesticide load on the environment, and may result in the appearance of fungicide-resistant strains of the pathogen, which suppression will require higher dosages of fungicides in the future. At the same time, there is an alternative approach based on the use of digital technologies and geoinformation systems and intended to determine a site-specific risk of infection outbreaks and to make a corresponding optimization of pesticide use to minimize the costs of protective treatment without increase in yield losses. Such precision agriculture technologies are usually realized as weather-based decision support systems (DSS). Analyzing meteorological data, such DSS determine weather conditions favorable for the infection development and make recommendations concerning the necessity of a fungicidal treatment at the given moment.

Earlier we developed a DSS “VNIIFBlight” and showed its efficiency in relation to the forecasting of possible late blight outbreaks and yield losses; the average difference between the real and calculated yield losses did not exceed 5% [7]. Using this DSS and the long-term weather data of the North Caucasus and Baltic regions, we determined zones with different level of forecasted yield losses within these regions and calculated a potential reduction of the number of effective fungicidal sprayings, as well as the corresponding costs of such treatments [8, 9]; depending on the zone, such reduction may reach >3 times. The purpose of this study was the evaluation of the efficiency of such approach in relation to the optimization of fungicide treatments of potato in the FEFD climatic conditions using the Khabarovsk Territory as a model region characterized by a large size and different climatic conditions across its territory.

2. Materials and methods
The climatic zoning of the region in relation to potential yield losses was carried out using the earlier developed mathematical simulator describing the dependence of potato yield losses on meteorological conditions of a vegetation season [7]. The calculations was carried out for the case of potato cultivars susceptible to the late blight using archives of weather data for the last 15 years (2004–2018) obtained from eight weather stations located in different parts of the region (Fig. 1). The process was performed using available QGIS software package, which included an interpolation method based on the inverse distance weighting (IDW). The archive weather data were downloaded from www.r5.ru; we also used weather information from the website of the All-Russian Research Institute of Hydrometeorological Information – World Data Center. Potential potato yield losses were determined separately for each
year included into the study. The calculated average annual yield losses were used for the map construction, and the frequencies of each of three variants of losses (<10%, 10–20%, >20%) for each weather station were also determined.

The main way to reduce the number of fungicide applications is based on the prediction of the dates favorable for the re-infection of potato with the late blight and the fungicidal treatment of plants exactly before these dangerous periods. Possible re-infection dates were calculated using the VNIIFBlight DSS (http://www.kartofel.org/vniif.fitoftora/index_ru.html). The program was also used to determine the recommended dates of fungicide applications and the corresponding number of required treatments per each season; the limiting condition was that the average duration of the protective effect of a fungicide treatment makes seven days.

Figure 1. Locations of weather stations used in the study.

Figure 2. Map of the predicted average potato yield losses caused by late blight outbreaks (Khabarovsk Territory). Yield losses <10%, 10–20%, and >20% are indicated with green, yellow, and red colours, respectively.

3. Results and discussion
The performed retrospective analysis of data from the weather stations included into the study and the earlier determined quantitative connection between meteorological data and disease severity allowed us to construct a region map divided into three zones in accordance with the predicted average yield losses caused by the late blight (Fig. 2). According to the obtained results, zones with high (>20%) and moderate (10–20%) yield losses take almost equal areas in the region, i.e., potato late blight represents an economically significant disease for the region. The territories with a high risk of yield losses are
located mainly in the northern part of the region and include the Okhotsky district (excepting its northern part, which climatic conditions are unsuitable for potato growing), Ayano-Maisky and Tuguro-Chumikansky districts, and some territories of the Poliny Osipenko and Verkhnebureinsky districts. In addition, a separate “red” zone was also revealed in the south-eastern part of the region (Vanino, Sovetskaya Gavan, and Nanaisk districts). Low risk of disease-caused yield losses was observed for the area around Khabarovsk, as well as a very small part of the Nikolaevsky district. All other territory of the region is characterized by moderate predicted yield losses.

The constructed map based on long-term weather data, can be used by potato growers of the region to assess a possible risk if the late blight outbreaks. At the same time, seasons with high or low late blight severity occur within each of the above-mentioned zones. The frequency of seasons with different levels of yield losses, as well as the average yield losses calculated for each of weather station locations, are shown in Table 1.

Table 1. Calculated frequency of seasons with different levels of potato yield losses caused by the late blight in different parts of the Khabarovsk Territory (2004–2018).

| District                  | Weather station location | Averaged potential yield losses, % | Average frequency of seasons with potential yield losses level: | <10 % | 10–20 % | >20 % |
|---------------------------|--------------------------|-----------------------------------|------------------------------------------------------------|-------|---------|-------|
| Okhotsky                  | Okhotsk                  | 29.6                              |                                                      | 0.0   | 30.8    | 69.2  |
| Ayano-Maisky              | Staritsa (Ayan)          | 33.2                              |                                                      | 0.0   | 7.7     | 92.3  |
| Tuguro-Chumikansky        | Bolshoy Santar           | 27.4                              |                                                      | 7.7   | 15.4    | 76.9  |
| Tuguro-Chumikansky        | Kaunas (Dzhana)          | 21.4                              |                                                      | 30.8  | 7.7     | 61.5  |
| Poliny Osipenko           | Poliny Osipenko          | 13.1                              |                                                      | 61.5  | 7.7     | 30.8  |
| Khabarovsk                | Smidovich                | 5.0                               |                                                      | 84.6  | 7.7     | 7.7   |
| Ulchsky                   | Bogorodskoe              | 9.3                               |                                                      | 76.9  | 7.7     | 15.4  |
| Sovetskaya Gavan          | Sovetskaya Gavan         | 20.5                              |                                                      | 23.1  | 15.4    | 61.5  |

The range of the potential yield losses in the Khabarovsk Territory calculated for different years was very wide. For example, in the Okhotsky district the value of this index varied from 15.4% (2009) to 46.3% (2013); in the Ayano-Maltysky district it varied from 17.8% (2011) to 45.2% (2007); Poliny Osipenko district showed variations from 6.1% (2007, 2016, 2017) to 32.4% (2010), etc. In such cases, the total financial losses of potato growers may be also caused by the cost of unnecessary protective treatments performed in seasons unfavorable for the late blight development. The example of such situation is showed in Fig. 3. During the considered period (July 1 – August 20), routine scheme of protective treatments proposes six spraying (blue bars). At the same time, in the course of the season, there were only two periods favorable for the late blight outbreaks (the corresponding days are indicated with red bars). The corresponding DSS recommendations providing an efficient disease control, include only three treatments (green lines) completely covering the dangerous periods.
Figure 3. Example of the DSS recommendations concerning the dates of protective treatments of potato for the period of July–August of 2018 (Amursky district, Khabarovsk Territory).

Therefore, to make a correct decision in relation to the crop protection strategy under conditions of a significant non-uniformity and variability of weather conditions and to avoid unnecessary expenses, they should choose optimal dates of protective treatments. Such choice should be based on the use of DSS systems, which allow potato growers to spray potato when it is really necessary.

To illustrate the efficiency of such approach, we calculated the optimized number of recommended plant treatments per a season for each of the weather station locations using the VNIIFBlight DSS (Table 2). Note that the use of the routine scheme (regular treatments) would require eight treatments per each season.

Table 2. Average number of fungicidal treatments recommended by the VNIIFBlight DSS for the efficient late blight control.

| District            | Weather station location | Number of recommended treatments for the calculated potato yield losses level: |          |
|---------------------|--------------------------|--------------------------------------------------------------------------------|---------|
|                     |                          | <10%                                                                            | 10–20%  | >20%    |
| Okhotsky            | Okhotsk                  | 0.0                                                                             | 4.8     | 5.7     |
| Ayano-Maisky        | Staritsa (Ayan)          | 0.0                                                                             | 5.0     | 5.6     |
| Tuguro-Chumikansky  | Bolshoy Santar           | 2.4                                                                             | 3.0     | 3.5     |
| Tuguro-Chumikansky  | Kaunas (Dzhana)          | 1.9                                                                             | 2.0     | 3.0     |
| Poliny Osipenko     | Poliny Osipenko          | 2.0                                                                             | 4.0     | 4.6     |
| Khabarovsk          | Smidovich                | 2.0                                                                             | 3.0     | 3.9     |
| Ulchsky             | Bogorodskoe              | 2.1                                                                             | 3.0     | 2.5     |
| Sovetskaya Gavan    | Sovetskaya Gavan         | 2.3                                                                             | 4.0     | 4.5     |

The average number of recommended plant treatments virtually calculated by the VNIIFBlight DSS for seasons with three different levels of potential yield losses is shown in Fig. 4. According to the obtained data, DSS-recommended scheme of protective treatments provided a 1.9, 2.2, and 5× reduction of the number of fungicidal treatments for the seasons with the potential yield losses >20, 10–20, and <10%, respectively. Therefore, application of the DSS-based potato protection strategy is quite justified for climatic zones with stably high risks of disease outbreaks.
To provide potato-growers with the access to information required for decision-making, we developed a “Geosystem” GIS intended to determine the dates of protective treatments in a real-time mode and introduced it as a part of the meteorological service of the Infometeoservice company. The access to this system is available at http://infometeos.com/Map/Data. After the loading of the map, a user should choose a “Late blight risks” layer (Fig. 5). The resulting map with show zones of different risks for the late blight outbreaks (red and yellow colors indicate high and moderate risks, respectively; white color indicates no risk), so a user can evaluate the risk at the point of its interest. This information is recommended to be used for the further analysis and decision-making in relation to crop protection activities. The final decision concerning the necessity of protective treatments should be made after a complex analysis of the situation on a field.

4. References

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