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Reduction of Environmental Pollution with Pesticides: *in silico* Evaluation of the Efficiency of the Agrodozor Online Resource

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ABSTRACT

Plant pathogens may cause significant yield losses, threatening global food safety. A common approach for crop protection includes regular and frequent pesticide treatments independently of the weather and disease development level, which often results in excessive contamination of the environment and extra costs due to unnecessary use of pesticides. The use of modern digital technologies, such as computerized decision support systems (DSS) allows farmers to reduce the number of required treatments depending on the weather data and characteristics of the cultivars and pesticides used. To demonstrate advantages of the use of the Agrodozor DSS developed by the authors of this study, in silico evaluation of the efficiency of this online resource has been carried out for the Baltic region (Estonia, Latvia, Lithuania, Poland, and Kaliningrad region of Russia) in relation to the potato late blight and its control by fungicides. Using archived data (2005-2018) from 22 weather stations located at the studied region, the climatic zoning in relation to potential potato yield losses caused by the late blight has been performed followed by the optimization of the fungicide treatment schemes. Weather conditions favorable for the disease development (>20% of potential yield losses) were frequent in the Kaliningrad region, Latvia, and Lithuania (71.6, 50.0, and 50.8% of the analyzed seasons, respectively), whereas Estonia and Poland showed mainly unfavorable conditions (59.0 and 60.3%, respectively). Compared to the routine approach, the Agrodozor DSS provided a 1.3–3.2× reduction of the number and costs of fungicidal treatments and 1.2–5.8× reduction of their total toxicity that indicated its high efficiency and practical potential.

Keywords: *environmental contamination, pesticide load reduction, decision support systems, yield losses, toxicity index, potato late blight.*

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INTRODUCTION

Countries of the Baltic region traditionally consume a large amount of potato; for example, the average potato consumption in Estonia, Latvia, and Lithuania, which in 2000-2013 was equal to 80, 117, and 111 kg per capita per year, respectively, exceeds the same indices for other EU countries [1]. Late blight caused by *Phytophthora infestans* is the most destructive re-emerging disease of potato resulting in significant yield and storage losses of this crop; on a global scale, yearly financial losses associated with this disease are calculated at more than $3 billion [2]. Under favorable weather conditions, each infection cycle may occur within 4–7 days. The main way to control this disease is the use of fungicides; the annual costs for their application worldwide reach $1 billion [3].

Weather conditions of the Northern and Eastern Europe promote sexual reproduction of the pathogen resulting in a formation of oospores able to overwinter and cause earlier outbreaks of the disease, which, in turn, require more frequent fungicide treatments [4, 5]. For example, the number of such treatments in Estonia is 4-7 per season, sometimes increasing up to 11 [6]. Moreover, during the early outbreaks of the disease, protective sprayings may be applied even more frequently than every 5 days [7]. In the case of large potato-producing companies growing potato for the processing industry, the routine scheme of treatment is mainly used, which considers regular (each 7–10 days) fungicidal sprayings during the vegetation season independently of the disease appearance and severity [8]. The application of this scheme often results in excessive contamination of the soil and groundwater with fungicides and negative effects on human health [2]. Moreover, the use of this scheme in the seasons with weak disease development causes some financial losses due to the unnecessary applications of fungicides. In addition, regular use of fungicides provides a selection pressure that often results in the appearance and rapid expansion of fungicide-resistant genotypes in a pathogen population [9]. Due to less fungicide sensitivity of a pathogen, farmers often increase the dosages of applied fungicide to overcome the disease that causes additional contamination of the environment and the further development of more resistant strains. Thus, this strategy results in a large pesticide load on the environment, so consumers demonstrate a lot of concerns about food quality and environmental safety, focusing their attention on agricultural pesticides as possible toxicants [10].

The frequency and dating of fungicidal applications can be optimized using so-called decision support systems (DSS). Based on weather data and characteristics of potato cultivars and fungicides, such computer programs are able to calculate the dates of possible infection outbreaks and the corresponding dates of fungicidal treatments required to prevent disease development [11, 12]. Earlier the authors of this study developed a DSS named "Agrodozor" (http://agrodozor.ru) able to determine the optimal dates of fungicide applications during the season, as well as to choose fungicides, which are the most appropriate for the given weather conditions. The efficiency of this DSS was confirmed by long-term field experiments in the Moscow region demonstrated that its use provided the same level of suppression of the late blight development, as the use of the routine system [13]. The purpose of this study was an attempt to optimize *in silico* application of fungicides for protection of mid-early potato cultivars in the countries of the Baltic region using the Agrodozor DSS and retrospective weather data.

MATERIALS AND METHODS

The climatic zoning of the studied region including Estonia, Latvia, Lithuania, Poland, and Russia (Kaliningrad region) was performed using the earlier developed mathematic simulator, describing the dependence of potato yield losses on meteorological conditions of a vegetation season [13]. The simulator provides a calculation of potential yield losses for mid-early potato cultivars susceptible to the late blight and grown in the absence of sprinkling irrigation and is based on the following equations:

$$\omega_1 = 0.8 \cdot (2.37 + 0.48a + 67b) \text{ if } a > 8,$$
$$\omega_2 = 0.8 \cdot (0.95a + 0.02) \text{ if } a \leq 8,$$

where ω is potato yield losses caused by the late blight (%), a is the number of 5-day intervals with conditions, favorable for the re-infection of plants, determined for a period between the shoot appearance and top wilting, and b is the percentage of such periods during the period between the canopy closure and bud formation in relation to the total number of such periods during the whole season. The favourability of a 5-day interval for plant re-infection with the pathogen depended on the temperature and precipitation data and was determined by a system of equations described in [13].

The calculations were carried out using archival weather data for the past 14 years (2005-2018) recorded at 22 weather stations located across the studied region. The zoning was based on the averaged values of potential potato yield losses (%) calculated for 14 years for each point of weather data collection and was performed using a QGIS software package and IDW interpolation algorithm.

For each season, the optimal data of fungicidal treatments were calculated *in silico* using the "Agrodozor" DSS and taking into account that each next treatment is carried out at least 10 days after the previous one. Additionally, the system recommended the optimal fungicide for each recommended date of treatment. The assortment of fungicides used in this study included three types differing in their action: translaminar Curzate R (C), systemic Ridomil Gold MC (R), and contact Bravo (B). Translaminar fungicides are usually applied at the beginning of the vegetation season (shoot appearance until canopy closure); systemic fungicides are used at the next stages (canopy closure until flowering); while contact fungicides are used at the second half of the season (flowering stage until harvesting). The obtained data were compared with those calculated for the routine scheme of treatment, which included 6 treatments per season, each applied 10 days after the previous one using the following sequence: C–C–R–R–B–B. The example of such calculation of recommended dates for protective treatments is shown in Fig. 1. During the considered period, two periods of possible re-infection occurred (Jun 28–Jul 3 and Jul 29). Thus, the Agrodozor service recommended only two fungicidal treatments (Jun 27 and Jul 28). At the same time, the use of routine scheme would require seven treatments, four of which would be unnecessary (Jun 15, Jul 9, Jul 17, and Aug 2).

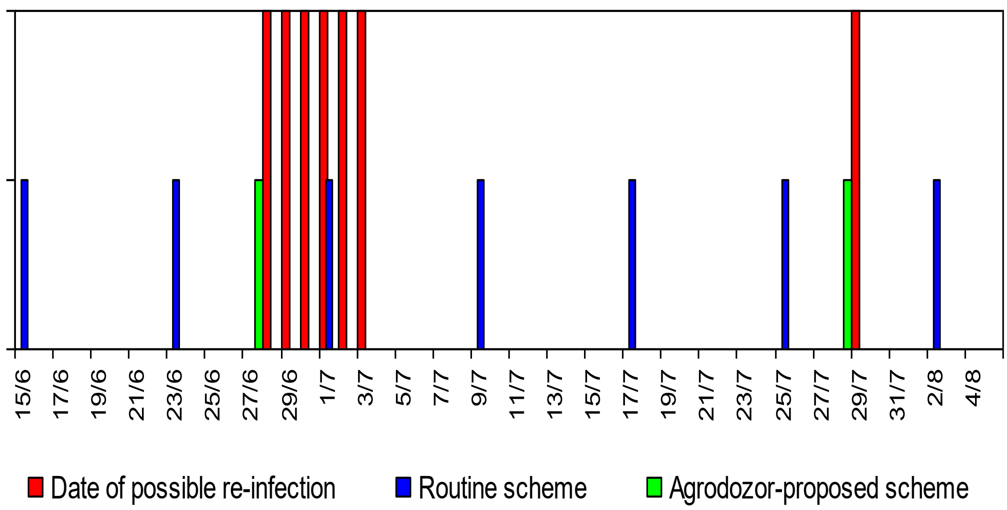

Fig. 1. Example of the calculated recommended dates for protective treatments of potato performed for the period of June-August of 2015 (Pärnu weather station, Estonia).

Toxicity indices of the active substances of the chosen fungicides were determined using the following equation [10]:

$$MATF = 0.5 \cdot AM + CM + ECO + 1.5 \cdot BiolPM,$$

where MATF is a multi-attribute toxicity factor, AM is the acute mammal toxicity index, CM in a chronic mammal toxicity index, ECO is an ecological toxicity index (sum of avian, aquatic and small invertebrate subindex values), and BiolPM is a bio-intensive integrated pest management index. The MATF values calculated for a single treatment of potato with Curzate R, Ridomil Gold MC, or Bravo fungicides are equal to 80, 302, and 82, respectively.

RESULTS AND DISCUSSION

The performed zoning resulted in the construction of a region map divided into three zones differing in the volume of potential yield losses related to the late blight appearance and development (Fig. 2). The lowest (<20%) risk of late blight-caused yield losses was shown for Estonia and the most part of Poland excepting two western and two north-eastern regions. The last one borders with the Kaliningrad region of Russia, which is the most favorable for disease development.

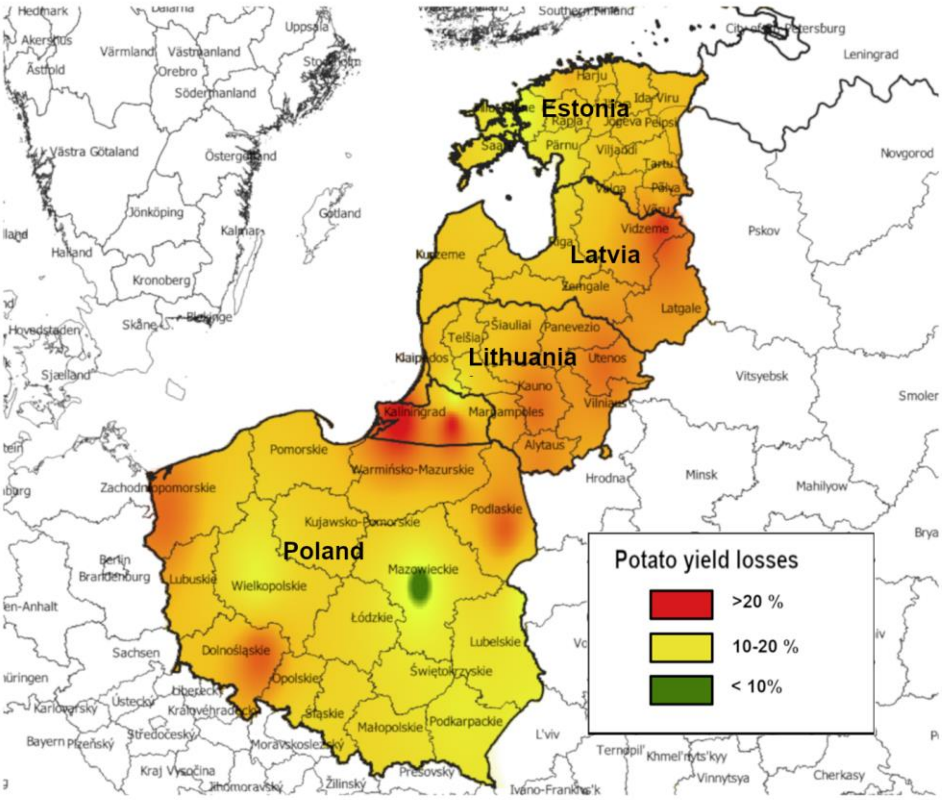

Fig. 2. Zoning of the Baltic region according to the potential harmfulness of the late blight.

Weather conditions favorable for the late blight development (>20% of yield losses) were more frequent in the Kaliningrad region, Latvia, and Lithuania (77.8, 50.0, and 50.8%, respectively), whereas the territories of Estonia and Poland showed mainly unfavorable conditions (59.0 and 60.3% of the analyzed seasons, respectively; Table 1).

Table 1. The average frequency of seasons with different potential potato yield losses in the Baltic region (2005-2018) calculated by the VNIIFBlight simulator.

Country	Average frequency of seasons with potential yield losses			Averaged potential yield losses (%)
	<10%	10–20%	>20%	
Poland	60.3	6.4	33.3	13.0
Estonia	59.0	11.5	29.5	13.9
Latvia	38.5	11.5	50.0	21.0
Lithuania	29.2	20.0	50.8	20.4
Russia (Kaliningrad region)	21.4	7.0	71.6	26.3

The optimized number of recommended plant treatments, average costs of protective treatments, and the averaged multi-attribute toxicity factor of such treatments calculated by the "Agrodozor" DSS, as well as the similar data for the routine scheme of treatment are shown in Table 2. The obtained data showed that compared to the routine protection scheme, the use of the "Agrodozor" DSS provided a 1.3–3.2× reduction of the number and costs of fungicidal treatments and 1.2–5.8× reduction of their total toxicity.

Table 2. Comparison of two protective treatment schemes for the late blight control.

Index	Schemes of protective treatments	
	Agrodozor recommended the scheme for seasons with potential yield losses:	Routine scheme

	<10%	10-20%	>20%	
Estonia				
Average number of treatments per season	1.9	3.5	4.0	6
Average cost of protective treatments, €/ha*	98.3	181.1	207	310.5
Averaged multi-attribute toxicity factor	159	503	666	928
Lithuania				
Average number of treatments per season	1.9	3.1	3.9	6
Average cost of protective treatments, €/ha	98.3	160.4	201.8	310.5
Averaged multi-attribute toxicity factor	159	446	649	928
Latvia				
Average number of treatments per season	2.3	3.3	4.6	6
Average cost of protective treatments, €/ha	119.0	170.8	238.0	310.5
Averaged multi-attribute toxicity factor	192	475	766	928
Poland				
Average number of treatments per season	2.0	3.4	4.0	6
Average cost of protective treatments, €/ha	103.5	176.0	207	310.5
Averaged multi-attribute toxicity factor	167	490	666	928
Russia (Kaliningrad region)				
Average number of treatments per season	3.0	3.2	4.7	6
Average cost of protective treatments, €/ha	155.3	165.6	243.2	310
Averaged multi-attribute toxicity factor	431	460	782	928

*The cost of a single treatment with Curzate R, Ridomil Gold MC, and Bravo fungicides is 20.2, 27, and 21.3 €/ha, respectively.

DSSs provide the user a possibility to integrate available information on the pathogen, host cultivar, fungicide characteristics, and the influence of observed and forecast weather on the development and severity of the disease required to make decisions in relation to the disease control. Such systems can deliver site-specific recommendations to the users by telephone, fax, e-mail, SMS, as well as on websites and via the Internet (in the form of online services). Since the 1990s, a number of computer-based DSS solutions have been developed in many countries to help farmers to manage various crop diseases, such as the late blight, cereal leaf rusts, downy mildew of grape, etc. [14–16]. In Europe, several DSSs for the late blight control have been developed based on various disease forecasting systems and models [17]. Now certain European countries, such as the Netherlands, report that more than 30% of potato growers use recommendations of commercial DSS to assist with their late blight management [17]. Results of the long-term use of various DSS show they improve disease suppression, reduce crop losses, and often decrease the volumes of chemicals used for protective treatments.

The VNIIFBlight simulator earlier developed by the authors of this study showed good results in relation to the disease control and reduction of fungicide treatments [18]. The further improvement of this DSS with the extended number of factors included in the decision support algorithm resulted in the development of the web-based Agrodozor service capable to make point-specific recommendations in a real-time mode [19]. Potential yield losses calculated by this DSS showed a good correlation with the real values obtained for the corresponding points of observations. The average deviation was only 4.5% [13]. In this study, we showed the potential benefits of Agrodozor DSS use by potato producers of the Baltic region. This interactive system helps a user to achieve the maximum efficiency of their crop protection strategy by enabling well-informed decisions. The benefit of using this DSS is a reliable disease control while enabling the reduction of fungicide treatments under conditions that are unfavorable for the late blight development. The accuracy of the recommendations of this system is limited by the availability of accurate and representative weather data. In addition, the forecast information should correspond to the actual meteorological conditions observed at the point of its use.

CONCLUSION

An adequate late blight control on potato requires multiple applications of fungicides. The *in silico* use of the developed zoning model and the "Agrodozor" DSS for the Baltic region demonstrated its potential benefits in relation to the reduction of the volume of fungicidal treatments and the corresponding cost savings and minimization of a pesticide load on the environment.

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