POLITECNICO
MILANO 1863

SCUOLA DI INGEGNERIA INDUSTRIALE
E DELL'INFORMAZIONE

Executive Summary of the Thesis

A Data Analysis of Tomato Late Blight Treatment Records of the Emilia-Romagna region (Italy) for Studying the Current Fight Practices and Measuring their Environmental Impact

Laurea Magistrale in Computer Science and Engineering - Ingegneria Informatica

Author: Alessandro Maserati

Advisor: Prof. Matteo Matteucci

Co-advisor: Riccardo Bertoglio

Academic year: 2021-2022

---

1. Introduction

Industrial tomato cultivation in the region of Emilia-Romagna represents a fundamental economic sector for the Italian food industry. Indeed, Italy is the first industrial tomato European producer and the second worldwide. In particular, the province of Piacenza holds the productivity record among the northern regions, with more than 10 thousand cultivated hectares every year.

To prevent the appearance of plant diseases, the Emilia-Romagna region has built a forecasting and warning system, that aims to optimize the effectiveness of phytosanitary treatments, for the benefit of environmental sustainability and agricultural productions. This system uses forecasting models that, elaborating meteorological data, predict the development of plant diseases and phytophagous. These models are updated and validated periodically and their forecasts, together with general agricultural advice, are provided to farmers through weekly integrated and biological production phytosanitary bulletins. This information is usually integrated with the expertise of agronomic technicians and crops phytosanitary state periodic monitoring.

Tomato late blight represents one of the main potential causes of industrial tomato crop losses in the region. This fungal disease, caused by the oomycete *Phytophthora infestans*, affects solanaceous plants and can have disruptive consequences on all organs of the plants, eventually leading to the complete loss of production. The development of this disease is favoured by damp weather with temperatures around 20°C, while dry weather conditions with temperatures over 30°C can totally halt its spread.

To predict the occurrences of tomato late blight, the region combines the use of two climate-based forecasting models validated in the '90s: the *IPI (Infection Potential Index)* model [2] and the *MISP (Main Infection and Sporulation Periods)* model [1]. The IPI model (a *negative prognosis* one) is used in the earlier period of the season, as it identifies a date before which the infection is unlikely to start on the crop. It is therefore used to warn for the first fungicide application. Instead, the MISP model identifies days with weather conditions favourable to the disease infection after the IPI alert, recommending the subsequent phytosanitary treatments. Both models mathematically elaborate the same meteorological parameters, i.e., air temperature, relative humidity and rainfall amounts.

In this work, we analyse the defensive strategies related to the phytosanitary management of tomato late blight, that are currently applied by industrial tomato growers in the province of Piacenza. Specifically, we focus on how the mathematical models' predictions used in the region are followed by farmers. Finally, we quantify the waste in terms of phytosanitary products sprayed in excess, compared to the model outputs recommendations, and its associated environmental impact.

2. Datasets

In this work, we used two main datasets, both supplied by *Image Line*, an Italian tech company specialized in digital solutions for agriculture, developing management software that helps farmers who use it to record their field operations.

The first dataset contains information about the phytosanitary treatments applied by 81 distinct agricultural holdings to their industrial tomato crops (from integrated production only) in the province of Piacenza and neighbouring areas. The total number of production units (fields) present in the dataset is 1261, distributed almost uniformly among three different years: 2018, 2019 and 2020. Each record consists of a single phytosanitary product application. It includes information about the treated production unit (geographic coordinates, total area, transplant date) and the phytosanitary treatment itself (application date, used product, sprayed area, active substances composition, dosage, type of action and targets). For our subsequent analysis, we consider not only the treatments specifically declared against tomato late blight (91% of the resulting subset), but also treatments whose active substances can have effect against this disease.

The second dataset consists of hourly meteorological records of years 2018, 2019 and 2020 from weather stations of the study area. These records geographically cover the entire area of the province of Piacenza where production units included in the first dataset are located. In this way, it is possible to precisely link each specific production unit to a meteorological record. The average distance between the coordinates of each field and the coordinates of its linked weather record is less than 100 meters. The main weather parameters stored in this dataset are hourly air temperature (°C), hourly relative air humidity (%) and hourly amount of rainfall precipitations (mm).

Geographic coordinates of production units have been manually inserted in the dataset, taken from cadastral data available to Image Line. Since not every farm shared this information, for production unit for which we don't have specific coordinates, as linked meteorological record, we make use of a generic one related to the field's municipality.

3. Phytosanitary treatments analysis

Firstly, we analyse the phytosanitary treatments dataset, to give an overview of tomato late blight management in the study area, trying to understand the impact of meteorological trend and highlighting differences in terms of year of reference and epoch of crops transplantation. Furthermore, we investigate how tomato growers complies with some of the regulations and technical recommendations underlined in the weekly phytosanitary bulletins.

In terms of average number of unique phytosanitary operations sprayed on production units, year 2018 shows an average of 8.04 operations, year 2019 shows an average of 6.65 and year 2020 an average of 8.33. The lower average of the year 2019 is explained by two meteorological facts. The month of May was one of the rainiest of the last century, while the months of June and August were very dry, with hot temperatures. The IPI model alert was reported during a rainy period that made impossible to intervene with treatments since the beginning of June. So, the initial difficulty to enter the fields combined with a later summer period not favourable to late blight disease, has generally reduced the number of completed operations during that year.

Differentiating by epoch of transplantation, generally, crops transplanted lately (after May 20th) receives more treatments than medium ones (transplanted between April 25th and May 20th) and early ones (transplanted before April 25th). This is explained by the dryness that usually characterise the study area from July to the mid-

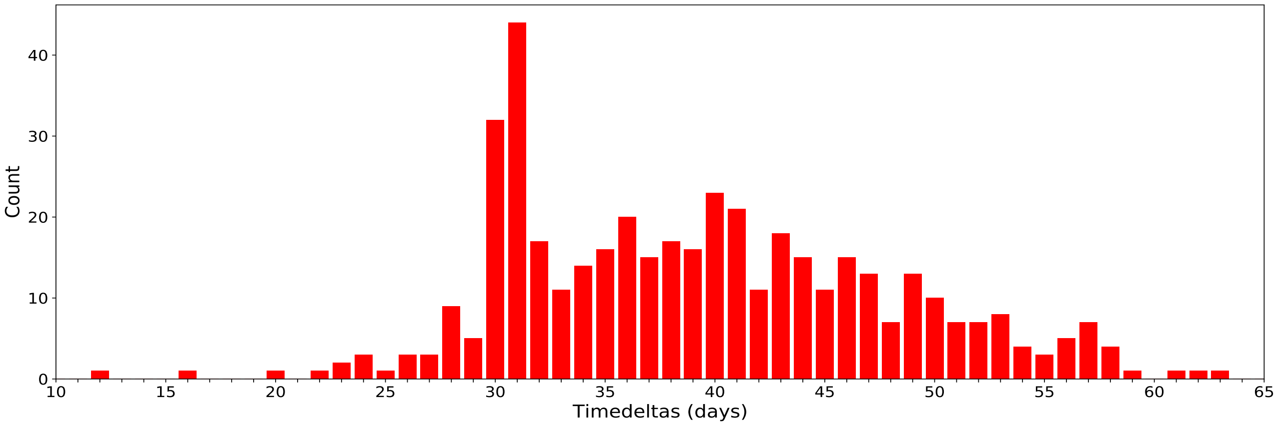

Figure 1: Count of production units of year 2019 by their timedelta (days) between transplantation and first anti-late blight phytosanitary operation

dle of August. So, crops that are not harvested during that period, usually experience the storm phenomena and lower temperatures of late August and September, and therefore need to be protected with more phytosanitary treatments.

A particular anomaly that must be pointed out is related to the temporal distance between the transplant date and the date of the first carried out phytosanitary treatment. Analysing this distribution, it can be noticed that a relatively high percentage (from 15% to 20% every year) of production units are sprayed with the first treatment exactly after a month from the transplantation. Figure 1 highlights this anomaly for production units of 2019. This suggests that some tomato growers apply fungicide sprays following the traditional calendar-based pest schedule. This type of pest management consists of a traditional method of preventive defence of plants, planned with periodic treatments regardless of the course of the infestations and the actual risk of their appearance, starting from the age of susceptibility of the seedling.

Regarding the existing regulations governing the maximum amounts of active substances that can be sprayed on crops, the Commission Implementing Regulation (EU) 2018/1981 requires that no more than 28 kg of cupric active substances should be applied per hectare every 7 years. This implies that, on average, the amount of cupric active substances applied on each single tomato crop should lie around 4 kg/ha per year. We compute the copper derivatives quantities sprayed on each production unit in the dataset. The yearly average values are 5.75 kg/ha for 2018, 4.8 kg/ha for 2019 and 5.8 kg/ha for 2020 and the percentages of production units where the yearly average of 4 kg/ha is met are quite low (25% in 2018, 46% in 2019 and 38% in 2020).

A technical recommendation that is often pointed out in the weekly phytosanitary bulletins is related to the combined use of purely covering products (that just avoid the penetration of the disease in the plant organism, usually cupric substances) and endotherapic products (that inhibit the development of the disease once that the infection has already occurred). In particular, to limit the waste, farmers are advised not to add cupric covering products to endotherapic treatments that already contains a percentage of cupric active substances. We compute the percentages of this kind of discouraged operations with respect to the total number of endotherapic operations already containing cupric active substances: 36.8% in 2018, 19.4% in 2019 and 8.5% in 2020. Even if these percentages are consistent, the trend is clearly decreasing, suggesting that environmentally unfriendly practices are gradually disappearing.

4. Analysis of IPI and MISP adoption

To analyse how IPI and MISP models are followed by farmers fighting against tomato late blight, we compute the outputs of these models for each specific production unit in our dataset exploiting the precise meteorological records at our disposal. Then, we compare the outputs of the models with the operations registered in the treatment dataset.

Regarding the IPI model (that identifies the first theoretical date of infection of the crop), the great majority of production unit are sprayed after our computed alert: 71% in 2018, 76% in 2019 and 69% in 2020. Inspecting the production units where the model recommendation is not respected, we can notice that most of them were transplanted lately in the season. Indeed, farmers tend to spray their late crops waiting not for the IPI alert (which probably will happen in late summer), to avoid the risk of possible late blight infection arising from the proximity to tomato crops that have been in the field for longer.

The temporal difference between the computed IPI alert and the date of first treatment depends also on how much time has elapsed between the transplantation and the alert itself. Distinguishing between production units with a very early IPI alert (between 0 and 15 days from transplantation), with a medium IPI alert (between 16 and 30 days from transplantation) and with late IPI alert (after 30 days from transplantation), it can be noticed that the model recommendation is considered at different extent. Production units with early IPI are usually sprayed several days after the model alert because the crop is not enough phenologically developed to receive a chemical product. On the other side, production units with late IPI date are treated before IPI threshold crossing, as farmers do not wait it because of phytosanitary safety. Medium IPI category is instead the one that respect mostly the indicated IPI date, with production units that are sprayed closer to the actual IPI recommendation. Figure 2 shows this behaviour for the year 2019: production units with early IPI date are sprayed about one month after the alert, while those with late IPI date are usually sprayed before it.

Instead, the MISP model outputs (dates of potential infection after the first one) are almost not considered. Farmers usually spray periodically their tomato crops, in order to keep them protected whenever a rainy event occurs (or it is expected), rendering almost useless the utilisation of such a model. In fact, the percentages of phytosanitary treatments carried out around a MISP alert date in 2018, 2019 and 2020 are 50%, 55% and 39%, while the other sprayed treatments are not explained by the model's outputs.

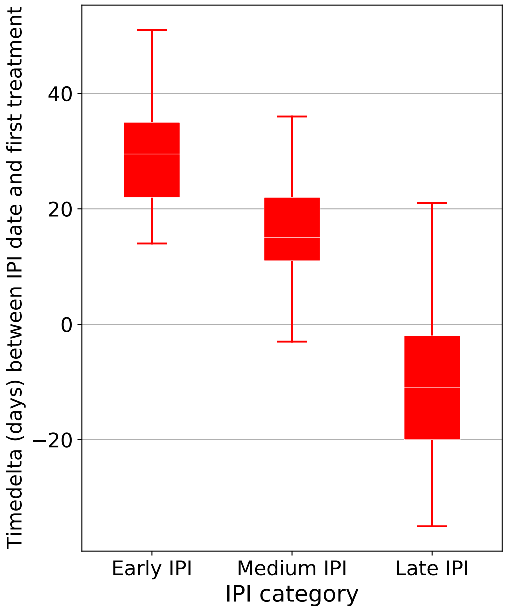

Figure 2: Timedeltas (days) between our computed IPI date and first anti-late blight phytosanitary operation distinguishing by IPI category, considering production units of year 2019.

5. Measures of the environmental impact

To quantify the environmental impact of the fight against tomato late blight disease in the study area, we compute the quantity of phytosanitary products and active substances that could be saved following the suggestion of our computation of IPI and MISP outputs. For this analysis, we consider only phytosanitary treatments sprayed on production units for which we have the precise geographic location. To classify each phytosanitary treatment as necessary or unnecessary according to the models, we decide to define two criteria: one for the IPI model and one for the MISP model.

The IPI criterion classifies only treatments applied before our computed IPI alert, it flags as unnecessary:

1. all those treatments sprayed before one week from the alert;
2. all those treatments, sprayed within a week before the alert, that are followed by another treatment during the first week after the alert.

The relaxed-MISP criterion, so called because it considers as infection-triggering also minor rainy events, as the suggestions of the phytosanitary

Year	Cupric unnecessary quantity	Cupric percentage reduction	Non-cupric unnecessary quantity	Non-cupric percentage reduction
2018	1.94 kg/ha	33%	1.71 kg/ha	40%
2019	1.9 kg/ha	40%	1.73 kg/ha	41%
2020	2.56 kg/ha	44%	2.5 kg/ha	43%

Table 1: Average unnecessary sprayed quantities per hectare and related percentage reduction with respect to the total, distinguishing by type of substances (cupric and non-cupric).

bulletins do, flags as necessary the treatments that satisfy at least one of the following criteria:

1. were sprayed within a week (before and after) from a MISP alert;
2. were sprayed within 5 days (before and after) a day with at least 4 hours of rain;
3. were the first treatment of the season for their production unit.

In total, according to the relaxed-MISP criterion 32% (2018), 38% (2019) and 41% (2020) of the phytosanitary treatments applied after our computed IPI alert are considered unnecessary.

Table 1 illustrates the total average of unnecessary quantities of active substances sprayed per hectare, distinguishing by cupric substances and non-cupric substances, according to the combination of the two criteria. This distinction is made because they have a different impact on the soil and the crop; usually, cupric products are environmentally more impacting. Furthermore, Table 1 shows the percentage reductions in the use of both types of substances that would have been obtained if only the necessary treatments had been sprayed.

To better understand the environmental impact caused by unnecessary treatments according to the tomato late blight prediction models, we use an indicator adopted by EU States to monitor the reductions in terms of pests placed on the market every calendar year. The *Harmonized Risk Indicator* (HRI1) [3] computes this environmental risk classifying the authorised active substances into four groups, each of which is assigned a weight that increases with the environmental danger associated with their use. We adapt this indicator, applying it to the load of active substances (kg) sprayed per unit area (ha). Then, for each year, we evaluate the percentage reduction in terms of environmental risk, considering only the necessary treatments according to the IPI and MISP criteria illustrated before. The mathematical formula that computes the adapted HRI1 related to a phytosanitary treatment is:

$$AdaptedHRI1 = \frac{\sum_i qt_i \cdot risk\_weight_i}{treated\_area}, \quad (1)$$

where i represents each active substance present in the treatment, qt_i its relative quantity (kg) and $treated\_area$ the area (ha) of the production unit.

Table 2 shows the adapted HRI1 total values (adding all HRI1 treatments values sprayed each year) and the environmental risk percentage reduction that would have been obtained if only the necessary treatments had been sprayed.

6. Conclusions

The results of the analysis about tomato late blight phytosanitary management in the study area show that the quantities of excessively sprayed phytosanitary products are significantly high. The traditional fight practice, namely the calendar-based schedule which plans periodical treatments on the crops to keep them constantly protected, is still applied. Indeed, if the IPI model suggestions are widely considered, the same can not be said for the MISP ones.

The relevant number of initiatives taken by the European Union, aimed at reducing the use of pesticides to improve agricultural eco-sustainability and consumers' health, must inspire also all the Italian agricultural sectors.

This analysis is therefore useful to map both positive and negative behaviours of industrial tomato growers in the province of Piacenza. It can also be the starting point of a discussion involving the main actors of this agricultural

Year	Adapted HRI1 (all treatments)	Adapted HRI1 (necessary treatments only)	Percentage reduction
2018	219	142	35%
2019	113	67	41%
2020	140	78	44%

Table 2: Adapted HRI1 values considering all sprayed treatments, only necessary treatments and deriving environmental risk percentage reductions.

sector (producers, agronomic technicians, policy makers etc.), with the objective of improving the management of tomato late blight disease in the region, trying to take a step forward in the direction taken at international level.

However, we want to underline that our analysis has some technical limits. Firstly, we base our model's computation on historical meteorological data (almost 100% accurate), while IPI and MISP outputs on which farmers rely are computed using weather forecasts, that are not totally trustworthy. Secondly, we do not have data about the phytosanitary state of each analysed production unit (e.g., if a crop showed disease symptoms), so our classification on the need of each treatment is only partially reliable. Furthermore, the IPI output present in the bulletins is computed at provincial level and it is made to start at the beginning of transplantation phase, while our computation starts from the precise transplant date of each production unit. Thus, a mismatch between the actual practices and our models' suggestions is understandable. Lastly, we are aware that tomato growers cannot risk letting the infection start, given the severity of this disease and the difficulties in programming urgent phytosanitary operations.

Although the still applied traditional fight practices are questionable, it is important to point out that there are also signs of improvement, suggesting that the environmentally unfriendly practices are disappearing. For instance, tomato growers are increasingly turning their phytosanitary products choices towards environmentally healthier ones, based on the risk classification made by the EU for the HRI1 computation. Another discouraged practice progressively vanishing is that relating to the combination of endotherapic products partially containing cupric substances with purely cupric covering ones.

The development of new Machine Learning models, able to improve the current mathematical models' predictions related to tomato late blight occurrences in the study area, could be useful to optimize the programming of phytosanitary treatments. Such models should consider more meteorological parameters, data related to the crop cultivar (and its disease resistance) and to its phenological state. But to implement such a model, appearances of tomato late blight in tomato crops or in untreated test fields (fields with no phytosanitary treatments) must be digitally registered by farmers and technicians, together with their precise geographical reference and associated level of intensity (they serve in fact as targets of the model).

References

[1] K. Q. Cao, M. Rucksthul, and H. R. Forrer. Crucial weather conditions for Phytophthora infestans : A reliable tool for improved control of potato late blight? *E. Bouma and H. Schepers (eds.), PAV-Special Report*, (1):85–90, January 1997.

[2] P. Cavanni, I. Ponti, and M. Marinelli. A forecasting model for late blight of tomato. *Informatore fitopatologico*, 40:17–25, 1990.

[3] Eurostat. *Methodology for calculating harmonised risk indicators for pesticides under Directive 2009/128/EC*, 2019.