Presentation

Analysis of volunteer density under the influence of cropping practices: a contribution to the modelling of primary inoculum of *Phytophthora infestans* in potato crops

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SUMMARY
In order to improve current potato late blight risk assessment, potato volunteer distribution and densities have been studied in different agricultural environments. Preliminary mathematical approach helped designing sample size for field collecting data; the quadrat method was adopted with variable sample sizes. Large set of data have been collected in two contrasting potato producing regions. Only volunteer densities as influenced by cropping practices (waste piles or volunteers as weeds) and climatic conditions are presented in this report. High densities are found on waste piles whereas volunteer as weeds are dispersed in decreasing densities according the ability of the crop to cover the soil: important density in artichokes, moderate in cereals (wheat, barley) and low in ray-grass. Further implementation of the observed data will help simulate primary inoculum production and optimize predictive quality of current decision support systems, given the fact that any potato volunteer occurrence, even in its lowest expression, is a key factor to the setting of late blight epidemics in the vicinity of a growing potato crop.

KEYWORDS
Phytophthora infestans, *Solanum tuberosum*, modelling, potato volunteer, primary inoculum, cropping practices.

INTRODUCTION
In most parts of Europe where potatoes are grown extensively, volunteer potato plants may grow from left-over and over-wintering tubers; they are becoming a major concern for crop management and

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they should be considered as weeds. They are in fact the result of a combination of different factors such as unsuitable harvesting machinery, harvest of too small sized tubers, that are maintained in the soil with sprouting ability thanks to mild winter temperatures or to following crops that do not fully cover the soil so to prevent potatoes from further development etc…, short rotation and climate change amplifying the situation (Cooke *et al.*, 2011). It is clear that excess of volunteers jeopardizes the phytosanitary status in any potato growing area by acting as a reservoir or an uncontrolled host for most pests and diseases of the potato, including late blight (LB).
In the development of Decision Support Systems, namely DSSs, that are aimed to integrate all factors which might contribute to an optimal control of potato late blight, the calibration of epidemiological models for the actual beginning of the LB epidemics, ie the primary source(s) of inoculum, is becoming a real challenge.
After more than a decade of development of potato late blight DSSs (MilPV and Mileos®) across French potato producing areas, the necessary improvement of the LB risk assessment relies upon a more accurate knowledge of primary source(s) of inoculum and its potential regional variability.
As in many European climatic conducive environments where potato is grown, the very initial source of inoculum to the epidemics of late blight is still subject to hypothesis: latent infested seeds, randomly dispersed and uncontrolled infested volunteers or aggregated on waste piles, soil-borne oospores: the respective share of these different potential sources of inoculum still has to be demonstrated. Up to date, there is no evidence for oospore formation under French cropping conditions, thus this study concentrates on volunteers as major primary sources of *P. infestans*.

This paper reports on the preliminary investigations and data collections that have been carried out in 2010 and 2011. The aim of the study is to build up a sub-model based on observed volunteer data in very contrasting potato growing areas as i) North-western Brittany for early potato crops and seed producing areas and ii) the Central Northern part of France where large acreages are devoted to fresh market and processing potato productions. After describing the different cropping practices in the two different environments and designing a preliminary sampling strategy, field surveys for potato volunteers have been carried out. Data analysis is presented and first steps to further integration of the data into sub-models will be investigated.

MATERIALS AND METHODS

Determination of the number of quadrats to be observed prior to assessing volunteer density with a given accuracy level

In order to determine the best strategy for getting references on volunteer density under different cropping conditions (open field or waste pile) with an acceptable level of confidence and for a limited labor cost, a preliminary simulation test has to be carried out. The quadrat method (count of individuals per area of 1 square meter) is chosen to estimate the potato volunteer density and the number of replicates, ie size of the observed area, has to be determined by simulation. Fields with a given volunteer density were simulated, assuming that potato volunteer stems were spatially and randomly distributed. By simulation, such fields were sampled several times, from 1 to n quadrats (n being the maximum number of blocks equal to the total area of the field). This set of data is repeated for volunteer densities, di, ranging from 0.1 to 5 and for 300 simulated experiments. The number of quadrats to be observed was identified according the estimated average (field or pile) volunteer density associated to the required level of accuracy.

Description of sampled units: geographical unit and cropping practice, choice of variables

Two different potato producing areas were selected for volunteer data collection. They reflect two of the most prevalent cropping practices related to diverse climatic conditions.

In the Brittany region

This part of the country has an oceanic climate in most coastal areas, favourable to early crop productions, occasionally with plastic covers. Winters are mild (a few days per year with negative temperatures) and average temperatures and relative humidity are moderate all year round. Volunteer sampling occurred in May 2010 and May 2011, in two different agricultural environments and approximately ten fields were surveyed each year, in each location.

In the coastal areas, early potato production is prevalent. All fields had early potato crops in the preceding year; half of them were cultivated with artichoke (near Paimpol) at the time of sampling, the others were not yet cultivated (near Saint Pol de Léon) at the time of sampling (bare soil). The most important trait in this cropping practice is the very short rotation for the potato with intercrops, as artichoke or cauliflower, which last for complete soil cover.

Further inlands as Brest and Landivisiau, fields were dedicated –the preceding year- to the production of certified potato seeds. The technical rules for such production require a rotation of minimum four years between potato crops (three years without potatoes). When sampled, the fields were covered respectively with winter wheat (18 fields), maize (7), barley (5) and ray-grass (3).

In the Picardy and Nord Pas-de-Calais regions

This part of the country has a more continental climate with harsh and cold winters and warm summers, suitable for maincrop potato production. All types of potato production are present: fresh consumption, processing (French fries and starch) and certified seed. Fields have a large size (average size: 10 ha). Scattered waste piles have been sampled in May 2011, and 34 piles in total were fully observed.

Volunteer density assessment and measured variables

For each field (or waste pile) to be sampled and, in order to assess the volunteer density, the chosen number of the randomly distributed quadrat counts (1 m^2) was validated according the above-mentioned method. In each quadrat, the number of emerged stems from volunteer plants was recorded. Field and pile sizes were assessed and recorded. Cropping practices (cultivar, type of rotation and intercropping crops, soil type, harvesting techniques etc…) of the farmers were recorded (data not shown in this report). At the time of sampling, the phytosanitary status of the volunteer plants was recorded, namely for the presence of blighted volunteers.

RESULTS AND DISCUSSION

Determination of the number of quadrats to be observed prior to assessing volunteer density in a given environment

As a result of the simulation (Fig. 1), two sets of graphs are available for decision making. For a given volunteer density ranging from 0.5 to 5, the coefficient of variation of the assessed density (y axis) is varying according the number of replicates (x axis) contributing to the information. For practical reasons and feasibility when the expected volunteer density averages were 5 (or more) stems per square meter, then 20 replicated counts, distributed at random in a given area, provide an acceptable coefficient of variation of 10 %; more replicates would not improve the accuracy (Graph A1, Fig. 1). This number of replicates was applied for volunteer density assessment on waste piles.

Whereas, when the expected volunteer densities are 3 or below 3 per square meter, the number of replicates allowing an acceptable coefficient of variation less than 20 %, is 40 as it can be deduced from the graphs (Fig. 1). Thus, in open fields, 40 replicates were assessed when volunteer density was three or less per square meter, and 30 replicates when density was five or more. In both cases, the size of replicated quadrat assessment was a fair compromise between accuracy and required time to score each field and waste pile.

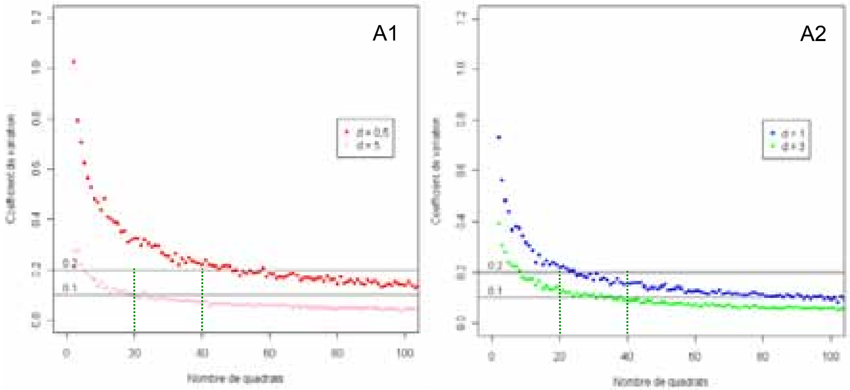

Figure 1 Simulated graphs for sample size according volunteer densities.
If $0{,}1 \leq d < 0{,}5$ then for $nb = 40$ $cv \approx 40$ % — if $1{,}0 \leq d < 3{,}0$ then for $nb = 30$ $cv \approx 15$ %
if $0{,}5 \leq d < 1{,}0$ then for $nb = 40$ $cv \approx 20$ % — if $d \geq 3$ then for $nb = 20$ $cv \approx 10$ %
d : volunteer density (m^{-2}) nb : number of sampled quadrats cv : coef. of variation on the assessed volunteer density

Assessment of potato volunteer density in different agroecological environments

In the Brittany region

In all sampled fields and in both years, potato volunteers were present. Highest densities (ca 6 stems per m²) were recorded in the coastal areas where early potatoes alternate with artichoke productions (Fig 2). Cropping practices linked to this specialized production are highly favourable to the development of any tubers left in the soil: stem cuttings are planted one meter apart leaving uncovered soil where potatoes can easily grow. There is no chemical weed control only mechanical. In the inland sampled fields, mostly in the certified seed areas, cereal crops as barley or ray-grasses are more efficient for limiting volunteer growth (Fig 3). On average, the volunteer densities are contained below 2 stems per m². In winter wheat and maize, volunteer density is intermediate, with a mean of three stems per square meter (Fig 3). Lower density of volunteers was noticed in fields near Brest and Landivisiau, but field areas were greater, compared to those of St Pol and Paimpol (Fig. 2). LB epidemics occurred later in the season in 2010 and 2011, and only one blighted plant was recorded in May 2011, in a wheat field, near Landivisiau.

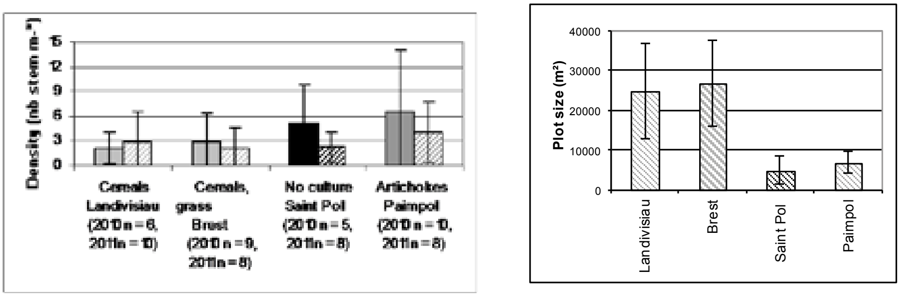

Figure 2 Left: Volunteer potato density (number of stems per m²) in fields (Brittany) as a function of sampling year and location; plain columns: density assessed in 2010 (from May 25th to 28th) and shaded columns: density assessed in 2011 (May 16th to 19th). Right: Average field area at the four different locations.

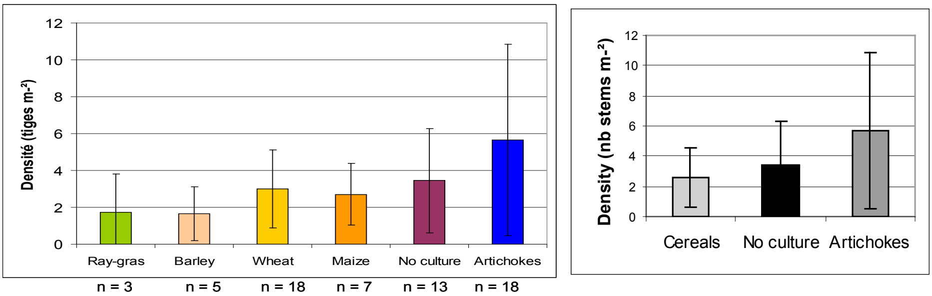

Figure 3 Left: Volunteer density in fields (Brittany) as a function of the following crop (average density, 2010 and 2011). Right: Volunteer density in fields where cereal crops (wheat, barley and maize) and artichokes are grown and fields that are left uncultivated at the time of sampling (May).

In the Picardy and Nord Pas-de-Calais regions

Large ware and processing production areas were studied in these two Northern Regions, Picardy (near Amiens) and Nord Pas-de-Calais (near Lille and Dunkerque). Waste piles are a common cultural practice among potato producing growers. However, they tend to be found in very isolated corners; nevertheless, there are always found in the middle of potato growing areas and could play an important role as primary *P. infestans* source. Thanks to local extension technicians, a set of 34 piles was identified for both regions and scored in 2011. After the sampling period, these piles were actively controlled as it is mandatory requested.

For each pile, the projected area was assessed (Fig 4, right). The largest mean size is observed in Nord Pas de Calais (175 m²), some piles exceeding 750 m² found in the vicinity of packing industries. According the visual estimation of volunteer densities (above 10 stems per m²), only 20 quadrats per pile were scored in order to assess the actual density with an expected 10 % level of accuracy. At the time of sampling, tubers on the piles were actively emerging and all stages of development were present. Only one pile (in Nord Pas de Calais) was found to be blight infested, this as a result of a very warm but dry spring. However, most piles were infested by large and actively evolving populations of Colorado beetles (*Leptinotarsa decemlineata*). In both regions, average volunteer densities were very high, above 90 stems per m² and irrespective of the projected area.

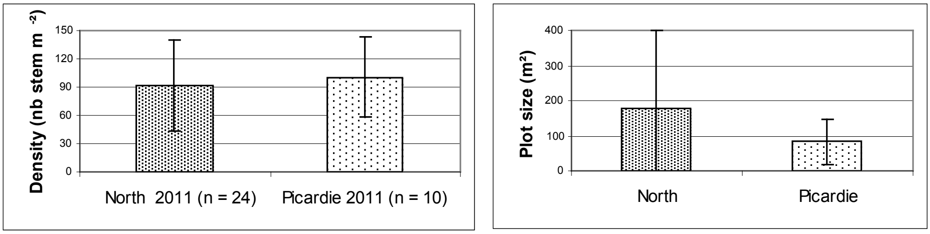

Figure 4 Left: Volunteer densities on waste piles (number of stems per m²), in Nord Pas-de-Calais and Picardy regions, assessed from May 2nd to 5th, 2011. Right: Mean pile projected area at the two locations.

CONCLUSION AND PERSPECTIVES

This paper reports on preliminary analysis on a large collection of field data with the objective to assess, with optimal accuracy, the primary sources of *P. infestans* in agricultural areas where potato crops are prevalent. Volunteers were found in all fields of Brittany where potatoes were grown on the previous year, but density varies according to year, crop and fields for the same crop. They are less abundant in dense crops (grass, barley, wheat) and in maize which is treated with herbicides, hormones than in artichokes.

Prior to data collecting, a mathematical tool had to be designed in order to help deciding sample size as a function of potato volunteer density. The concept of quadrat counting associated with differential levels of replicates proved to be useful for optimal spatial sampling associated with labour and time constraint.

The field data are original because they represent a large variation between regions and within regions, from one field to the other. Traditional cropping practices do influence the source of *P. infestans* primary inoculum. Waste potato piles are more prevalent in the Northern parts and they potentially represent a large source of primary inoculum. They are however spatially distributed in an aggregated manner. On the contrary, dispersed volunteer plants are randomly distributed in the field where a potato crop was grown the year before, they are more prevalent in the oceanic part of Brittany and the nature of the succeeding crop influences the volunteer density, grasses as opposed to artichokes, for example.

This set of data will enable the authors to validate a dynamic model which is currently under construction, to simulate the incidence of volunteer density as a function of potato cultivar, climate and cropping practices. This model, coupled with an epidemiological model, will help design integrated management strategies of potato late blight into the conceptual framework of the SIPPOM model, i.e simulator for integrated pathogen population management, (Lô-Pelzer *et al.*, 2010a and 2010b; Rakotonindraina *et al.*, 2010 and 2012).
Ultimately, this volunteer density simulator could help design control strategies for other pests and diseases of the potato, namely Colorado beetles, quarantine cyst nematodes or soil-borne pathogens, for which epidemics are closely related to volunteer dynamics.

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