FINAL PROJECT REPORT
Canola Agronomic Research Program (CARP)

The Final Report should fully describe the work completed for the year and note the personnel involved. It should also note any deviations from the original plan and next and/or corrective steps as may be required if deviations are noted. The report should also provide an update on the status of the Project including forecasted date of completion. A complete statement of expenses should be included. In the event major changes are anticipated within the budget supporting notes along with a proposed budget should also be included. The report should also capture a complete summary of activity for the year.

Project Title: **Development of a Harmonized Clubroot Map**

Research Team Information

Lead Researcher:		
Name	***Institution***	***Project Role***
Stephen Strelkov	University of Alberta	Lead
Research Team Members (add rows as required)		
Name	***Institution***	***Project Role***
Barbara Ziesman	Saskatchewan Ministry of Agriculture	Team Member
Dane Froese	Manitoba Agriculture	Team Member
Sheau-Fang Hwang	University of Alberta	Team Member
Mike Harding	Alberta Agriculture and Forestry	Team Member

Project Start Date: **April 1, 2018** **Project Completion Date:** **March 31, 2020**

Reporting Period: **April 1, 2018** **to March 31, 2020**

CARP Project Number: **CARP 2018.20**

Instructions: This Final Project Report shall be completed and submitted on or about March 31st of the fiscal year that the agreement is in effect (upon completion of the project). The Lead Researcher of the project in question shall complete and submit the report on behalf of his/her complete research team.

This Report is a means by which to provide a detailed account upon completion of the project.. Final project financial reporting should be provided at this time.

The following template is provided to assist you in completing this task. Please forward the completed document electronically to the CCC contact listed below.

In addition to the Final Project Report, a one page Research Abstract including rationale, objective, methodology, summary and conclusions (with a summary graph/table or supporting image for the project), acknowledgement and references is due upon completion. The Research Abstract is intended for use in publications such as the *Canola Digest* and the CCC Research Hub and is intended to support messaging to all audiences.

Please include the funding acknowledgements outlined in your research agreement in all deliverables (publications, presentations, etc.) from this project.

This research is part of the Canola Agronomic Research Program (CARP Grant 2018.10) with project funding provided by Alberta Canola, the Manitoba Canola Growers (MCGA) and the Saskatchewan Canola Development Commission (SaskCanola).

1. Date of Completion:

March 31, 2020

2. Status of Activity: (please check one)

_____ Ahead of Schedule _____ On Schedule _____ Behind Schedule __X__ Completed

Comment: The work was completed in March 2020.

3. Completed actions, deliverables and results; any major issues or variance between planned and actual activities.

Changes in the research team:

There were no changes in the Research Team since submission of the 2018-2019 Annual Report. The contributions to this work by students and other highly qualified personnel, particularly Dr. Yoann Aigu (Post-Doctoral Fellow with Dr. Strelkov), are gratefully acknowledged.

Progress and completed actions:

The project had three main objectives: 1) examine the feasibility of a harmonized clubroot map, 2) determine what such a map will look like, and 3) communicate findings and recommendations to stakeholders including the Clubroot Steering Committee. Despite some of the challenges associated with obtaining clubroot distribution and geo coordinate data from Manitoba and Saskatchewan, the project met its objectives. The results of this work are summarized below.

1) Examine the feasibility of a harmonized clubroot map

Clubroot maps can serve as important tools for grower education, the selection of effective disease management strategies, and assessing disease risk in specific regions. The availability of maps that represent the clubroot situation in a uniform manner across the provinces will help in communicating the need for proactive approaches to clubroot management, and may be of particular importance in highlighting the value of preventative actions before the disease becomes prevalent in a region. Ultimately, a harmonized clubroot map will better reflect the nature of this disease as a biological entity that is not constrained by political borders.

Maps across the provinces. Since this project began, the Saskatchewan Ministry of Agriculture has generated its first clubroot distribution maps, complementing the maps already produced by Alberta and Manitoba. Each province has its rationale for presenting the data in a particular way, and there are significant differences in how the occurrence and distribution of clubroot are shown (Fig. 1). Up to and including 2018, the Alberta

clubroot map depicted the occurrence of the disease as the total number of infested fields per county or municipality. Saskatchewan adopted a similar approach, yet also incorporated some differences in the color scheme used to denote different infestation levels. Furthermore, the Saskatchewan map indicates districts where the clubroot pathogen has been detected in the absence of disease, information that is not displayed on the Alberta map given the prevalence of clubroot in that province. The Manitoba map is perhaps the most distinct, showing whether visual symptoms have been identified in a municipality and the highest *P. brassicae* resting spore concentration measured in the fields tested. Comparison of these maps, particularly by growers or non-specialists, can be confusing in light of the differences in the type of data and color schemes depicted.

Limitations and datatypes. To facilitate comparisons and avoid confusion, it is important to develop a harmonized clubroot map. As a first step, we had to select the type of data used to generate the map. These data had to be representative of clubroot distribution, yet not be prohibitively expensive, labor-intensive or time-consuming to collect. This becomes an increasingly important consideration as the extent and intensity of the epidemic grows. Given the much more entrenched nature of the clubroot outbreak in Alberta relative to Saskatchewan and Manitoba, at present the situation in the former largely dictates what would be feasible for an inter-provincial map. This does not mean, however, that additional data collected in Manitoba or Saskatchewan (or in specific regions of Alberta) cannot be added to certain variants of the map (see discussion below). In this context, the number of confirmed clubroot infestations (fields) represents a good basic datatype or unit for use in the generation of harmonized maps. In fact, clubroot infested fields are a particularly reliable type of data, since an infestation can be confirmed by different people or organizations without the need for highly specialized knowledge or equipment. An additional advantage is that data on the number of field infestations have been collected from the beginning (or close to the beginning) of the outbreak in most regions. As such, there is no technical limitation to the generation of a harmonized map if we use the same type of data across regions. The main limitation becomes the inability of different parties to share data on the occurrence of clubroot, since there can be regulatory or other concerns with distributing this type of information. Indeed, this was a factor in the current project: in the first year (2018-19), data on surveillance and detection of clubroot in Saskatchewan and Manitoba were provided to the PI by the collaborators, but had to be redacted from the Annual Report. In the second year (2019-20), it was not possible to obtain any field-specific data from Saskatchewan or Manitoba, and hence most maps had to be developed based on data from Alberta. Late in the project, however, data were received from Saskatchewan on clubroot distribution at the rural municipality level, allowing us to generate some additional (preliminary) maps.

2) Determine what a harmonized clubroot map may look like

Data on the occurrence of clubroot in Alberta were obtained from surveys led by the University of Alberta in collaboration with Alberta Agriculture and Forestry and individual counties and municipal districts. Since field-specific data from the other provinces had to be redacted from the 2018-19 Annual Report and could not be obtained in 2019-2020, the maps presented in this report are based mainly on the information from Alberta. Nonetheless, limited data (down to the rural municipality level) were obtained for Saskatchewan late in the project, enabling us to generate some preliminary interprovincial maps. The maps in this report can serve as templates for other provinces, particularly as clubroot becomes more prevalent in those regions and grower sensitivity about this disease declines.

Depicting the data. There are two main ways of presenting the data to illustrate clubroot distribution most accurately. The first is by indicating the total number of clubroot-infested fields per county or municipality within one province (Fig. 1, 2) or across more than one province (Fig. 3). This method provides a clear and rapid overview of clubroot distribution over a wide geographical area, along with some measure of the intensity of the outbreak in particular regions. The second way to present the data is by showing infested fields as individual points on a map, corresponding either to the specific fields or to the townships in which they occur (Fig. 4). By seeing where clubroot infestations are actually located, users can gain a better

understanding of specific areas where the disease is a problem, as well as knowledge of the disease distribution within an area. Maps showing individual points can also be customized, for example by using different colors to denote different pathotypes (not shown). However, in regions where clubroot is not prevalent, there may be privacy concerns associated with showing the approximate location of field infestations.

Color schemes and gradients. There are different approaches to depicting the total number of infestations within districts. For example, in the maps generated from Alberta up to and including 2018 (Fig. 1), there were distinct color categories representing different numbers of confirmed infestations: 0 (green), 1-9 fields (yellow), 10-49 fields (blue) and ≥ 50 fields (red). As this project progressed, it became clear that some counties and municipal districts were not keen on these broad categories, since they served to exacerbate the artificial effects of political borders, but this time at a county rather than provincial level. As such, we developed a map that shows infestation level as a continuum, from very light yellow to red (Fig. 2), so that a difference of one or two infested fields does not result in the movement of a county into a different color category. Indeed, based on the feedback we received, county and industry personnel and growers liked this new way to show the occurrence of clubroot in the province. For this reason, this was the format used to prepare the 2019 Alberta clubroot distribution map in our annual disease survey report (Strelkov et al. 2020). A preliminary Alberta-Saskatchewan interprovincial map was also generated using this color scheme and is shown in Fig. 3. Another possible variation of this version of the map involves using the same color continuum (from very light yellow to red) but instead of the number of clubroot cases, indicating the number of infested acres as a proportion of total cultivated acres in a county. We evaluated this approach and it resulted in a map (not shown) very similar to the one shown in Fig. 2. However, this process involves more extrapolation, since the exact number of infested acres is not available; this means that the number of cases needs to be multiplied by 160 (i.e., taking a quarter section as the base unit) to arrive at an estimate of the affected acres.

Static vs. dynamic maps. Based on our experience with the Alberta data, we explored two additional ways to present the clubroot map, specific to the communication format used. The first is a static format (Figs. 2, 3 and 4) best suited to communication via factsheets, handouts, journals, and industry newspapers and magazines. We developed these maps using the ggplot2 package in R software. While providing a good overview of the situation at a particular point in time, this type of map can show only one type of data per map, and does not allow inclusion of supplemental information (such as the GPS coordinates of a field, or the number of cultivated fields in a county).

The second type of format is a dynamic or animated version of the static maps, which is better suited for slide presentations and similar types of interactions (Supplementary Figs. S1, S2 and S3). We developed these maps with the ggplot2 and gganimate packages in R software. Animated maps are very useful in showing a sequence of changes over time (including the spread and intensification of the outbreak), and can serve as important teaching and education tools. As with the static maps, however, extra or supplemental information cannot be included on the animated maps.

Interactive maps. A last option is an interactive map adapted to communication on a website. We developed an interactive clubroot map using the Leaflet package in R software. This map allows the user to zoom in and out, select the type of data they wish to see, and get more information regarding the county or field they are pointing at with their cursor. While extremely valuable and informative, an interactive map may contain sensitive information that cannot be made public. As such, this format may be better suited for restricted use by specific stakeholders as a research or management tool. Indeed, we are now using an interactive clubroot map as a research tool within the Plant Pathology Lab, University of Alberta, allowing us to better visualize and utilize the large amount of information stored in our clubroot database. For the purposes of this report, a screen capture is included in Supplementary Fig. S4 to illustrate what such a map looks like. An in-person demonstration is planned at the next meeting of the Clubroot Steering Committee, to illustrate the functionality of the interactive map.

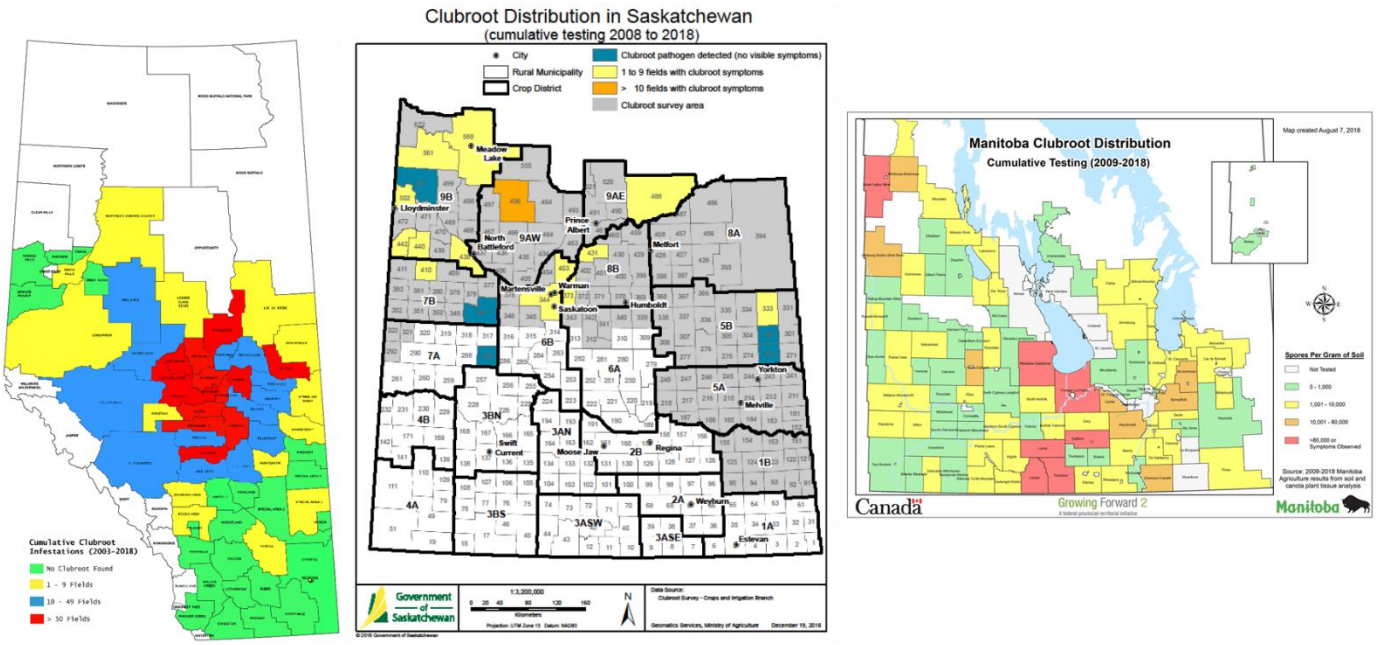

Fig. 1. Clubroot distribution maps generated for Alberta (University of Alberta/Alberta Agriculture and Forestry), Saskatchewan (Saskatchewan Ministry of Agriculture) and Manitoba (Manitoba Agriculture) for 2018. The way that data are presented on the Alberta map was changed significantly in 2019 (see Fig. 2) based on the results of this project.

Fig. 2. The occurrence of clubroot in Alberta in 2019. Note that on this map, the cumulative number of infestations per county or municipality is indicated using a continuous color gradient from light yellow to red, rather than by distinct color categories (compare with Fig. 1). Gray denotes districts with no confirmed infestations.

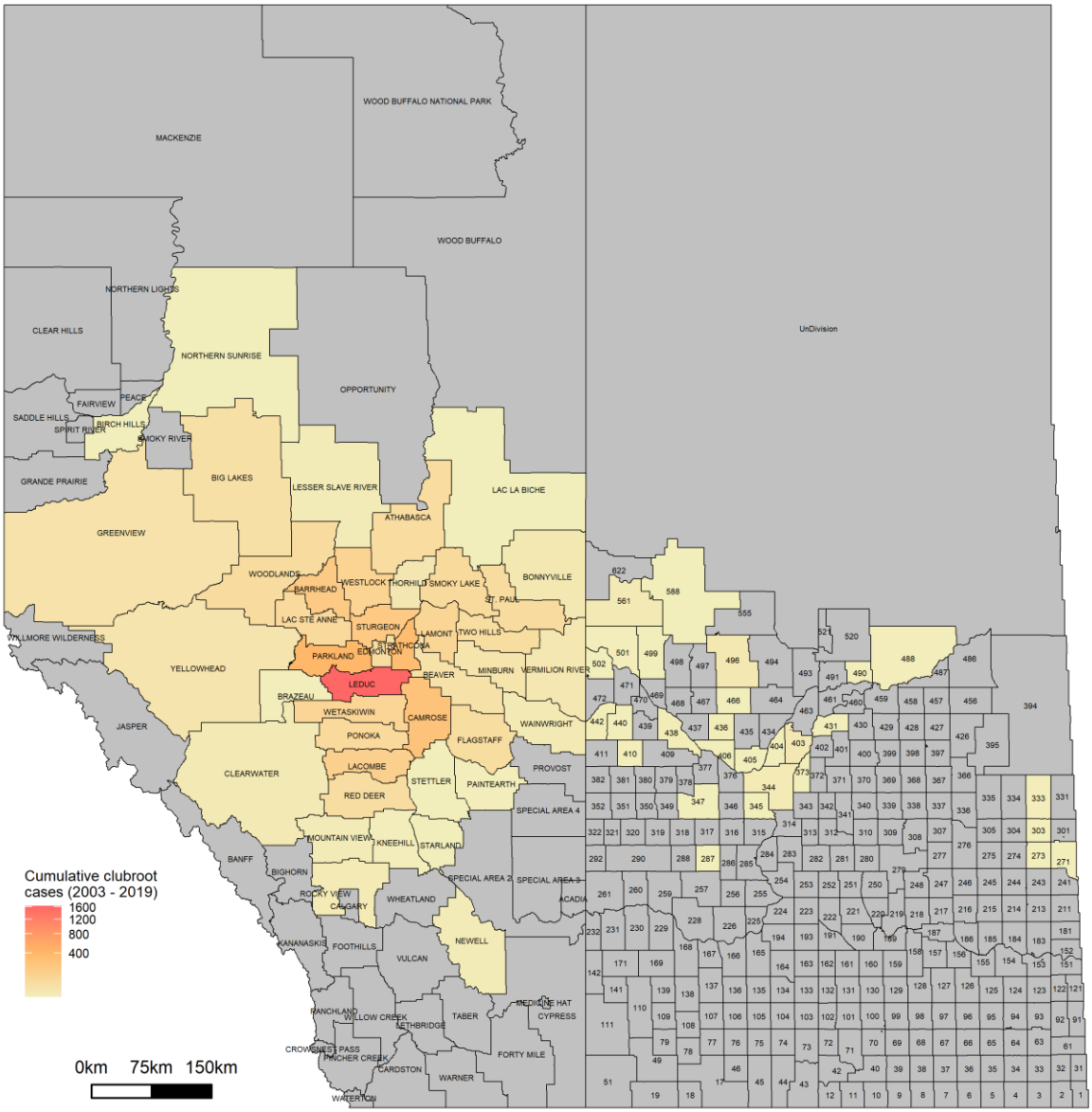

Fig. 3. The occurrence of clubroot in Alberta and Saskatchewan in 2019. The cumulative number of infestations per county or municipality is indicated using a continuous color gradient from light yellow to red, rather than by distinct color categories (compare with Fig. 1). Gray denotes districts with no confirmed infestations. **[Note: Barbara Ziesman, Saskatchewan Ministry of Agriculture, requested (31 March 2020) that Figure 3 and Supplementary Fig. S2 not be made public until she receives approval from her ministry].**

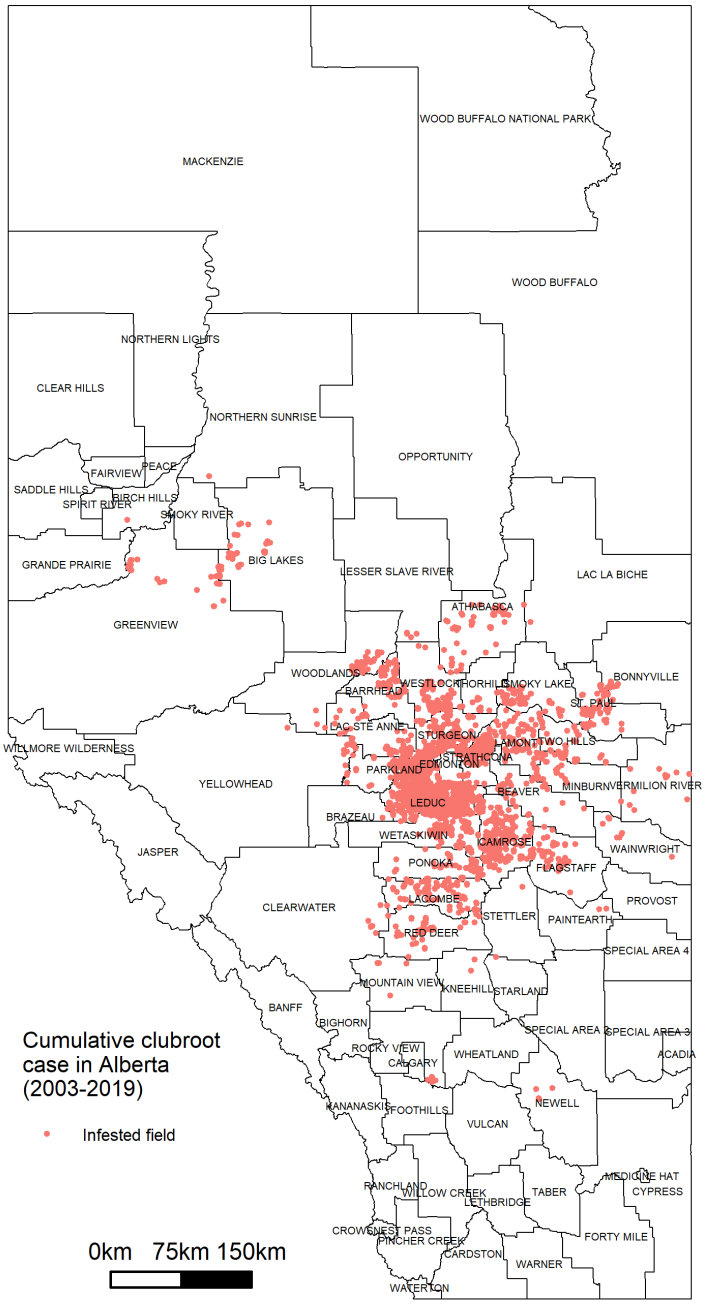

Fig. 4. The occurrence of clubroot in Alberta in 2019. The locations of fields where symptoms of clubroot have been identified on canola are shown as red points.

3) Communication of findings and recommendations

Communication of findings. The research team has been actively sharing our findings, and incorporating the new maps into presentations and other dissemination, communication and linkage activities. Below is a list of some of these activities:

Presentations

(1) Strelkov, S.E. 2019. Development of a harmonized clubroot map. Clubroot Steering Committee Meeting, April 25, 2019, Edmonton, AB. *[Summary of the progress after the conclusion of the first year of the project]*

(2) Harding, M.W., Strelkov, S.E., and Orchard, D. 2019. Clubroot: a disease of concern for Alberta's canola industry. JEDI Ag Forum, Wetaskiwin, AB, November 21, 2019. *[New map design based on this project was included in the presentation]*

(3) Strelkov, S.E., Hwang, S.F., Manolii, V.P., Hollman, K., Aigu, Y., and Harding, M.W. 2019. The status of clubroot on the Prairies. Canola Industry Meeting & Innovation Day, Dec. 4, 2019, Saskatoon, SK. *[Included versions of the new static and dynamic maps generated from this project]*

(4) Strelkov, S.E., Hwang, S.F., Manolii, V.P., Hollman, K., Aigu, Y., and Harding, M.W. 2020. Clubroot update. Western Canadian Canola/Rapeseed Recommending Committee Pathology Sub-Committee Meeting, Feb. 3, 2020, Saskatoon, SK. *[Participated remotely – included versions of the new static and dynamic maps generated from this project]*

(5) Strelkov, S.E., Hwang, S.F., Manolii, V.P., Hollman, K., Aigu, Y., and Harding, M.W.2020. Clubroot of canola: A challenge across the Prairies. Crop Connect Conference, Feb. 12-13, 2020, Winnipeg, Manitoba. *[Included versions of the new static and dynamic maps generated from this project]*

(6) Note: static and dynamic maps (GIFs) were also distributed to the Canola Council of Canada agronomists, Agricultural Fieldmen, and other collaborators for use in their own presentations to industry and grower groups

Contributions to the *Canadian Plant Disease Survey*

(7) Strelkov, S.E., Manolii, V.P., Harding, M.W., Daniels, G.C., Nuffer, P., Aigu, Y., and Hwang, S.F. 2020. The occurrence and spread of clubroot on canola in Alberta in 2019. Can. Plant Dis. Surv., 100: (In Press). *[Incorporated the new style of map (see Fig. 2) to illustrate clubroot distribution in Alberta]*

Popular press and websites

(8) The PI was recently interviewed for a story that will run in *Top Crop Manager* regarding a harmonized clubroot map for the Prairies

(9) A version of the map in Fig. 2 was recently provided to Taryn Dickson, Canola Council of Canada, for posting on clubroot.ca

Recommendations. The availability of harmonized clubroot maps that present similar information in a similar manner will be important for proactive disease management and widespread understanding of the nature of the outbreak. These could be combined with map variants that include additional information of particular interest in different regions (for example, variants that show pathotype distribution or the presence of pathogen DNA could be developed and used to complement the main clubroot distribution maps). With respect to a harmonized map, we can make a number of broad recommendations:

(1) Use of a color-continuum rather than discrete color categories to indicate levels of infestation may provide a more realistic reflection of the intensity and distribution of clubroot in different regions; this would help reduce 'artificial' differences between counties or municipalities (for example, one county

with 9 cases shown in yellow, but the neighboring county with 10 cases shown in blue)

(2) The colors selected for the maps should be consistent across provinces. While this may seem like a straightforward recommendation, different jurisdictions may have internal preferences or reasons for selecting specific color schemes. Ideally, even if different information or colors are shown on the maps for each province, a consistent scheme could be agreed upon for the generation of an interprovincial map

(3) As a minimum, a harmonized map should show the distribution and relative levels of clubroot infestation across the provinces; additional information (e.g., pathogen DNA, pathotype, or other features) could also be included on map variants generated from the main map as needed or when the information becomes available

(4) A map showing field infestations as individual points, which is biologically very relevant and provides greater information regarding clubroot distribution patterns, should be considered in the future when the sensitivity regarding sharing clubroot information declines

(5) Animated maps (GIFs) are important educational tools and clearly illustrate the progress of the clubroot epidemic over time; these should be prepared and incorporated into communication activities whenever possible

(6) Interactive maps have great potential as clubroot management and research tools, but may not be suitable for public release given privacy or other confidentiality-related considerations

Despite the potential benefits of harmonized clubroot maps, the sensitivity related to this disease and its distribution may make their adoption difficult in the near future. This was highlighted in the current study by the difficulty in obtaining data from some provinces. Nevertheless, the maps developed as part of this project can serve as a foundation or template for illustrating clubroot distribution and severity in western Canada.

4. Significant Accomplishments

This project resulted in significant improvements to the available clubroot maps, particularly with respect to the generation of animated maps highlighting the progress of the epidemic over the years (Figs. S1, S2 and S3). The project also enabled the development of a new style of clubroot distribution map (Figs. 2 and 3) that we are now using for Alberta, where the disease is most entrenched. These maps, along with the recommendations above, will serve as a template for improving education and communication related to the occurrence and spread of clubroot on canola.

5. Research and Action Plans

While the project is now complete, a presentation highlighting the results and recommendations stemming from this work is planned for the next meeting of the Clubroot Steering Committee. In addition, as an offshoot of the research, we are working on a shinny application for the interactive map that will allow one more interactive element (selection of year).

6. Final Project Budget and Financial Reporting
A final project financial report will be forwarded to the funders in April, as soon all of the expenditures have posted for March 2020. Finally, the Research Services Office (University of Alberta) will prepare the official Statement of Award and Expenditures in mid- to late-April.

Please forward an electronic copy of this completed document to:

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