

RESEARCH ARTICLE

**Estimating farmers' net change in profit when using insect frass
as an input for *Brassica* crops**

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Supplementary material

1 Detailed expert elicitation methodology

Frass expert elicitation

To estimate by how much pest and disease presence and crop yield is expected to change (research questions 1 and 2), we conducted an expert elicitation with insect frass experts in April 2021. The expert elicitation was conducted in two rounds – individual interviews followed by a group discussion. Two rounds were conducted to first obtain and assemble the individual estimations and then openly discuss the estimations as a group. In this way, all experts' estimations could be considered, and the group could together reason towards a refined range of estimates.

In this study, insect frass experts were defined as researchers conducting and/or supervising experiments on the effects of insect exuviae (molted skins) or frass on crop and soil health at Wageningen University & Research. Eight experts were asked to participate. Seven participated in interviews; a last-minute cancellation made it that six of the seven participated in the group discussion.

Interviews

Prior to conducting the interviews, an interview guide was constructed and pre-tested. Relevant assumptions were developed that the experts should consider throughout the interview. The assumptions specified, among other aspects, a crop rotation and the weather conditions. The crop rotation was necessary to include to capture how the net change in profit may differ from year to year because frass' health promotion effects are expected to improve over time (Torgerson *et al.*, 2021). Therefore, experts' estimations were elicited for the *Brassica* crops over several years – for year 0 (indicating it is used now, in the current year), and then again in

four years and finally after eight years. In addition, experts were asked to assume ideal weather conditions when making their assessments. Box 1 presents all the assumptions.

Box 1 – Assumptions

Consider that a farmer has a crop rotation where he will be planting broccoli and Brussels Sprouts this year which I refer to as year 0, in 4 years and again in 8 years.

Assume:

- (1) it is allowed by legislation to apply insect frass to fields, and it is abundantly available,
- (2) the farmer will add insect frass at the ideal application dose each year (now, in 1 year, in 2 years, etc.),
- (3) consistently ideal weather conditions,
- (4) a 1-hectare plot of land with an annual crop rotation of broccoli and Brussels sprouts (50:50) – potatoes – sugar beets – wheat and
- (5) the soil type is clay.

The questions in the interview guide were formulated to elicit (1) quantitative estimates regarding how much pest and disease presence and crop yield were expected to change and (2) qualitative reasoning for each estimate. Fourteen pests and eleven diseases that are notoriously destructive and common in *Brassica* production were addressed (listed in Appendix A, Table A1) (Agriculture and Horticulture Development Board, 2017).

As the interviews took place during the COVID-19 pandemic, they were conducted virtually using Microsoft Teams. Each interview began with a description of the research, discussing and signing the informed consent and requesting permission to audio record the interview. Thereafter, the assumptions (see Box 1) were presented. The interview was then split into three parts – estimates for pests, diseases and yield. For pests, the experts were asked, “Which of these fourteen insects, if any, do you predict that insect frass will reduce the presence of over time?” Of those identified, the experts were asked to provide quantitative estimates. For example, “By how much percent do you expect insect frass to reduce the presence of *Delia radicum* (or the cabbage root fly) this year? In four years? In eight years?” Three percentages were elicited for each of the three years: the lowest estimate, the mostly likely and the highest estimate. Once the percentages were given, the experts were asked to explain their reasoning. Similar questions were asked regarding the specific diseases in the second part of the interview. For the third and final portion of the interview, experts gave estimations regarding frass’ influence on crop yield for organic and conventional production. As an example, experts were asked, “Do you predict that insect frass will improve crop yield on organic farms over time?” If yes, “By how much percent do you expect insect frass to improve crop yield on organic farms this year? In four years? In eight years?” Afterwards, a qualitative explanation followed.

To analyze the interview data, first, an overview of each interview was created that included the selection of pests and diseases addressed by the expert and the quantitative and qualitative input for all estimations provided regarding pests, diseases and yield. Then a summary of all of the interviews was compiled; the summary (anonymously) presented each experts’ range of quantitative estimates and provided an overview of the qualitative explanations. The summary was utilized in the second round of the expert elicitation.

Group discussion

The second round of the expert elicitation with the frass experts was a group discussion. The purpose of the second round was to discuss and refine the ranges and most likely scenarios collected during the interviews. Prior to the group discussion, the summary of the interview results was distributed to all of the participants. It was communicated that the discussion would follow along with the summary, so having a brief read through the summary prior to the group discussion was encouraged.

As the group discussion was also conducted during the COVID-19 pandemic, it was hosted virtually using Microsoft Teams. The session took two hours and was audio recorded. Following the structure of the summary, the session consisted of ten discussions – yield (i.e. conventional and organic yield), pests (i.e. flea beetle, thrips, Hemiptera insects, cabbage root fly and Lepidoptera insects) and diseases (i.e. protozoan, bacterial and fungal diseases). Each of the ten discussions consisted of eight minutes deliberating over the estimates and qualitative input, followed by two minutes filling in a questionnaire to elicit their updated estimations. The questionnaires were developed using Qualtrics software version 2021 (an online survey platform) (Qualtrics, 2021); all of the questionnaires followed the same structure. For example, the experts were asked in the questionnaire, “By how much percent do you expect insect frass to reduce the presence of thrips this year?” Experts were asked to provide a best estimation and the lower and upper bounds of the range. Supplementary Figure S1 shows an example questionnaire.

To analyze the group discussion data, the quantitative estimates from the questionnaires were exported from Qualtrics into Excel. For each organic and conventional yield and for each pest and disease, the estimates for the “best estimation” were averaged. Likewise, the estimates

for the lower and upper bounds were also averaged. As not all experts provided estimates for every pest and disease, the number of experts providing estimates for each pest and disease was also documented. The averaged estimations were graphed in Excel as a visual representation of the estimations, which was used during the expert elicitation with crop advisors. The qualitative data collected throughout the discussion were transcribed from the audio recording, summarized, and incorporated in the results of this research (presented in section 3. Results, Economic model, Broccoli).



Assume:

- (1) it is allowed by legislation to apply insect frass to fields, and it is abundantly available,
- (2) the farmer will add insect frass at the ideal application dose each year (now, in 1 year, in 2 years, etc.),
- (3) consistently ideal weather conditions,
- (4) a 1 hectare plot of land with an annual crop rotation of broccoli and Brussels sprouts (50:50) – potatoes – sugar beets – wheat and
- (5) the soil type is clay.

Consider that a farmer has a crop rotation where he will be planting broccoli and Brussels Sprouts this year, in 4 years and again in 8 years.

Using whole numbers, specify the lower and upper bounds of a range and a best estimation in the boxes below.

NOTE: If you do not want to provide an estimation, please write "don't know" or "NA". If you want to estimate 0%, write "0".

By how much percent do you expect insect frass to reduce the presence of Thrips this year?

Lower Bound of Range	<input type="text"/>
Upper Bound of Range	<input type="text"/>
Best Estimation	<input type="text"/>

By how much percent do you expect insect frass to reduce the presence of Thrips in year 4?

Lower Bound of Range	<input type="text"/>
Upper Bound of Range	<input type="text"/>
Best Estimation	<input type="text"/>

By how much percent do you expect insect frass to reduce the presence of Thrips in year 8?

Lower Bound of Range	<input type="text"/>
Upper Bound of Range	<input type="text"/>
Best Estimation	<input type="text"/>

FIGURE S1 Example questionnaire used during the group discussion with insect frass experts.

Expert elicitation with crop advisors

To estimate by how much insecticide and fungicide use and crop yield is expected to change (research questions 2 and 3), we conducted an expert elicitation with crop advisors in April 2022. Experts invited to participate included crop advisors with experience in broccoli and/or Brussels sprouts organic/conventional production in the Netherlands. Five Dutch crop advising companies were contacted, and the contacts of five experts were provided, of which three agreed to participate. The expert elicitation was conducted using individual interviews – one was conducted using Microsoft Teams due to the experts’ time constraints and the other two interviews were conducted in-person.

Prior to conducting the interviews, an interview guide was constructed and pre-tested. The questions in the interview guide were formulated to elicit (1) quantitative estimates regarding how much fungicide and insecticide use and crop yield was expected to change and (2) qualitative reasoning for each estimate. Background information was provided as the experts were not familiar with insect frass, and they were informed of the assumptions (Box 1). The graphs generated from the results of insect frass experts’ group discussion, that showed by how much pest and disease presence and crop yield were expected to change, were also provided.

The estimates for changes in insecticides, fungicides and yield were elicited for conventional and organic broccoli and Brussels sprouts. Supplementary Figure S2 shows an example of how the estimates for insecticides and fungicides were elicited. The active ingredients in the insecticides and fungicides and the quantities applied per hectare were listed (KWIN-AGV, 2018). The expert was asked, “Based on your experience with this kind of crop and all of the information provided, if a farmer were to integrate frass into his crop management, would you advise changing the dose of any of these insecticides?”. For those identified, the expert was then asked, “If a farmer were to integrate frass into his crop management this year, in terms of percentage, how much would you suggest increasing or decreasing [the identified insecticide] by?”. A range was also elicited by asking, “Could you also give a lowest and highest estimate? Plus or minus what percent?”. Finally, the experts were asked to explain the reasoning behind the estimations they provided.

As a reference, a table was provided that detailed which active ingredients were found in which commercially available products and for which pests (or diseases) these products are used against. For example, esfenvaleraat (25) (in Supplementary Figure S2) is the active ingredient in the commercially available insecticides called “Sumi-Alpha 2.5 EC” and “Sumicidin Super”, and of the pests discussed in this research, these products are used against caterpillars such as *Mamestra brassicae*, *Pieris brassicae*, *Pieris rapae* and *Plutella xylostella*. This reference helped the crop advisors to consider the estimations in terms of the (often more familiar) commercially available products. For yield estimations, the advisors were asked, “Can you comment on the anticipated yield changes in conventional Brussels sprouts production as proposed by frass experts? Do you agree or disagree? Why or why not?”.

Insecticides	quantity (l/ha)	year 0		year 4		year 8	
		% reduced	+/- %	% reduced	+/- %	% reduced	+/- %
esfenvaleraat (25)	0.4						
lambda-cyhalothrin (100)	0.15						
spinosad (480)	0.4						
spirotetramat (150)	1						

FIGURE S2 Crop advisor interview – example question.

To analyze the interview data, the quantitative estimates were compiled into Excel where the lowest estimates were averaged, the most likely estimates were averaged, and the highest estimates were averaged. The averaged estimates were used as input for the economic model. The qualitative data (i.e. experts' reasonings) were transcribed from the audio recording, summarized, and incorporated in the results of this research (presented in section 3. Results, Economic model, Brussels sprouts).

References

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