Arable farmers' innovation decision process towards using by-products of insect production

Kirstin Foolen-Torgerson

Propositions

1. Group discussions increase the relevance of descriptive social norms as predictors of farmers' intentions to trial insect frass.
   (this thesis)

2. Insect frass is only economically viable as a crop and soil health promoter if it reduces crop loss.
   (this thesis)

3. Western research-based recommendations for raising children has fostered unnatural parenting behavior and ultimately childhood depression.

4. Publication bias in social science research is propelled by permitted publishing of deficient methodological procedures in scientific journals.

5. Only regulated hunting can provide a sustainable source of meat.

6. Personal financial management education should be mandatory and recurring throughout secondary school.

Propositions belonging to the thesis, entitled

Arable farmers' innovation decision process towards using by-products of insect production

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Thesis

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Table of Contents

CHAPTER 1

General Introduction

The growing human population and increasing wealth of the low-income group has resulted in an increased demand for food (Bodirsky et al., 2015; Cohen, 2003). The rising demand is met by increased food production and consequently a surge of residual biomass. As an alternative to waste generation and accumulation, a circular economy recognizes and capitalizes on the value of waste. By recycling by-products as useful inputs, a circular economy aids in minimizing the use of limited resources (Geissdoerfer et al., 2020). Agriculture has been identified as an industry where resources are avoidably leaking throughout the supply chain (Dagevos & de Lauwere, 2021). There are opportunities for the by-products of one form of production to be recycled as valuable inputs for another. The urgency to move towards circular agriculture has likewise been supported by policy makers (Rijksoverheid, 2019).

Insects provide an attractive opportunity to contribute to both circular agriculture and the growing global food demand. For example, insects can transform residual biomass into high-quality protein at ten times the efficiency of cattle (Chia et al., 2019; FAO, 2013; van Huis, 2013). In addition, the by-products of insect production – the insect manure, shed exoskeletons and unconsumed feed, collectively known as frass (Barragán-Fonseca et al., 2022) – can be repurposed as a crop and soil health promoter for use on arable farms.

Frass is expected to promote crop and soil health in two ways. First, as frass is decomposed in the soil, nutrients are released (Lovett & Ruesink, 1995; Poveda, 2021). By making nutrients more available, frass supplements the nutritional needs of the crops and soil (Chavez & Uchanski, 2021; Kebli & Sinaj, 2017; Quilliam et al., 2020; Temple et al., 2013; Vickerson et al., 2017). Improved growth allows the plant to be better able to allocate its resources to improve its natural defenses against below- and above-ground herbivores (Pangesti et al., 2013).

The second health promoting function stems from the chitin found in the exoskeletons within frass. Chitin can stimulate plant responses like triggering the expression of defense-related genes (Parada et al., 2018), and as the chitin is decomposed, the activity and growth of chitin-degrading bacteria and fungi is increased (Debode et al., 2016; Wieczorek et al., 2019). For this, the bacteria produce chitinases that can impede the development of pathogens (Cretoiu et al., 2013) and root herbivores (Veliz et al., 2017).

Chitin also stimulates the activity of beneficial soil microbes known as Plant Growth Promoting Rhizobacteria (PGPR) (Hol et al., 2013; Pieterse et al., 2014). For example, when added to the soil, the exoskeletons of mealworms increased the colonization of the PGPR *Bacilli* by more than fifteen percent after seven weeks (Bai, 2015). PGPR are microbes that live symbiotically directly around a plant's roots. In return for utilizing the nutritious secretions from the plants' roots, PGPR can induce the plant's systemic resistance to below- and aboveground pathogens and herbivores, can be pathogenic to pests and can impede the growth of harmful microbes (Francesca et al., 2015; Gadhave et al., 2016; Gadhave & Gange, 2016; Kupferschmied et al., 2013; Lugtenberg & Kamilova, 2009; Pangesti et al., 2013;

Pineda et al., 2010; Sharma et al., 2013). For a more in-depth explanation of the expected crop and soil health promoting mechanisms of frass, we refer to Barragán-Fonseca et al. (2022). Overall, such properties suggest that frass can be a valuable and recycled input for arable farms.

Drivers of and barriers inhibiting farmers' adoption of innovations

For insect frass to successfully penetrate the market, it must be an attractive crop and soil health promoter for farmers. To determine how attractive frass is, first the farmers must become aware of frass and then be intrigued enough to engage in subsequent information collection (Pannell et al., 2006). With enough information about frass' characteristics, the farmer can form a perception of it; if their perceptions of frass are positive enough, farmers' may opt to trial frass on their farms (Pannell et al., 2006; Rogers, 2003). In addition to their perceptions of the innovation, farmers' eventual decisions to adopt an innovation have also been shown to depend on economic and non-economic factors. Some economic factors include the expected profitability of the innovation and associated financial risks (Borges et al., 2019). Non-economic factors include the farms' context, farm and household characteristics, risk attitudes and cultural, cognitive, social and dispositional factors (Borges et al., 2019; Dessart et al., 2019; Pannell et al., 2006).

The context in which information regarding frass is communicated can also influence the success of its diffusion. As Rogers (2003) states, "When they share common meanings, a mutual subcultural language, and are alike in personal and social characteristics, the communication of ideas is likely to have greater effects in terms of knowledge gain, attitude formation and change, and overt behavior change." A group of farmers share the common goal to continue farming by, among others, optimizing and continuously improving crop and soil health. Such a group of like-minded farmers would be expected to process information regarding frass differently than a farmer who receives and processes the information alone. In a review conducted by Borges et al. (2019), they found that farmers' attendance at training sessions and membership in farmer groups were two of the variables that had a significant effect on farmers' adoption. Thus, it is important to consider the context in which farmers encounter innovation-related information as it plays a role in how the information is mentally processed and in how opinions are formed (Glover et al., 2019; Katz, 1961; Rogers, 2003; Werner et al., 2008).

Notably, countless barriers could potentially impede frass' diffusion. For example, in a European study investigating the uptake of soil carbon management practices, Ingram et al. (2014) found that farmers doubted the advice because they believed that scientists themselves did not yet fully understand soil carbon dynamics. In addition, farmers argued that there was also a lack of evidence regarding the cost effectiveness and potential yield for implementing such management practices in the long run. Likewise, the information source where farmers learn about frass and the lack of evidence could be viewed skeptically.

Another barrier to frass' diffusion may be that, if the perceived short-term profit when using frass is negative, it may play a role in dissuading its use regardless of the long-term strategic value of using frass to promote crop and soil health. In research conducted by Mandryk (2016) regarding farm level adaptations to climate change in the Netherlands, farmers accounted for organic matter when making strategic decisions, but for practical decisions, economic maximization was the focus. Farming production decisions are often short-term focused due to factors such as weather, policy, market developments, own debt, tenure and family status (Ingram et al., 2014). Adopting an innovation like insect frass requires a long-term vision. It promotes crop and soil health over time; the physical and economic effects are not expected to be substantially immediate.

Problem statement

Arable farmers are among those tasked with producing enough food to feed the growing human population and doing so within the limits (e.g., environmental-oriented policies) set by the government. This balancing act requires informed and strategic management decisions by farmers regarding their crops and soil. Thoughtful soil management determines its long-term productivity and biodiversity capacity (USDA-NRCS, 2019), and thoughtful crop management is critical to combat harmful pests and diseases - the culprits responsible for the biggest crop losses (Oerke, 2006). Additionally, to be able to continue farming, the farmer has to manage inputs in a way that can best secure income. Reliable and sustainable innovations in crop and soil health promotion are needed for farmers' financial security and the long-term preservation of agricultural land. Farmers' concurrence to use sustainable and circular inputs is crucial for the future of food production.

In addition, the insect sector is growing as rearing insects gains traction as a form of mini-livestock production. Such traction is evident by European insect producers' expectations of increasing investments from over €350 million in 2018 to over €2 billion by 2025 (International Platform of Insects for Food & Feed, 2019). With more insect production occurring, more frass will be generated. Thus, finding outlets for frass is becoming urgent; identifying the most value-creating outlets would be ideal.

Given the increasing restrictions faced by arable farmers, the increasing generation of by-products from insect production, and the societal and governmental push towards sustainable and circular agriculture, insect frass as a crop and soil health promoter is a relevant and timely case for research. Furthermore, very little is known from the farmers' viewpoint regarding why they would or would not be interested in using insect frass nor is there information available regarding the valuation of insect frass to gauge if it is even economically feasible for farmers to use. By exploring farmers' decision-making processes towards the use of frass, potential drivers and barriers of frass' dissemination as a crop and soil health promoter on Dutch arable farms can be identified.

Objective and research questions

The objective of this research was to investigate factors that influence arable farmers' intentions to trial insect frass. Four research questions were addressed to achieve this objective:

1. What is known regarding the characteristics and application of insect frass as a crop and soil health promoter?
2. What is the expected net change in profit of using insect frass as a crop and soil health promoter on conventional and organic arable farms?
3. What is the decision-making process farmers implement regarding the selection of crop and soil health promoting products, and how does it differ between farmers who discuss their first impressions of frass with farming peers and farmers who do not?
4. What drives farmers' intentions to trial insect frass, and how do group discussions affect the drivers of farmers' intentions to trial insect frass?

Conceptual framework

Three theoretical frameworks are applied in this research: the model of Innovation-Decision Process (IDP), the Means-End Chain (MEC) and the Theory of Planned Behavior (TPB). Figure 1.1 provides a conceptual framework that corresponds with the chapters in this thesis.

The theoretical backbone of this thesis is the IDP. The IDP is a five-stage process described by the diffusion of innovations theory – a theory that stems from technology adoption and communication research. The first stage is the knowledge stage. According to Rogers (2003), there are three types of knowledge individuals acquire to learn about an innovation – knowledge that the innovation exists (awareness knowledge), knowledge of how to use the innovation (how-to knowledge), and knowledge of how the innovation works (principles knowledge).

Equipped with knowledge, one progresses to the second stage – the persuasion stage – where impressions of the innovation are formed based on the individual's perceptions of its attributes. According to the theory, an innovation is evaluated based on five attributes: the extent to which the innovation is perceived to be better than comparable products (relative advantage), is consistent with one's existing values, needs and past experience (compatibility), is difficult to use or understand (complexity), produces results that are noticeable by others (observability) and can be experimented with (trialability). In this research, frass is not widely available to trial, nor is its effectiveness detectable in an observable sense; the focus is therefore on the relative advantage, compatibility and complexity of frass, as shown in Figure 1.1.

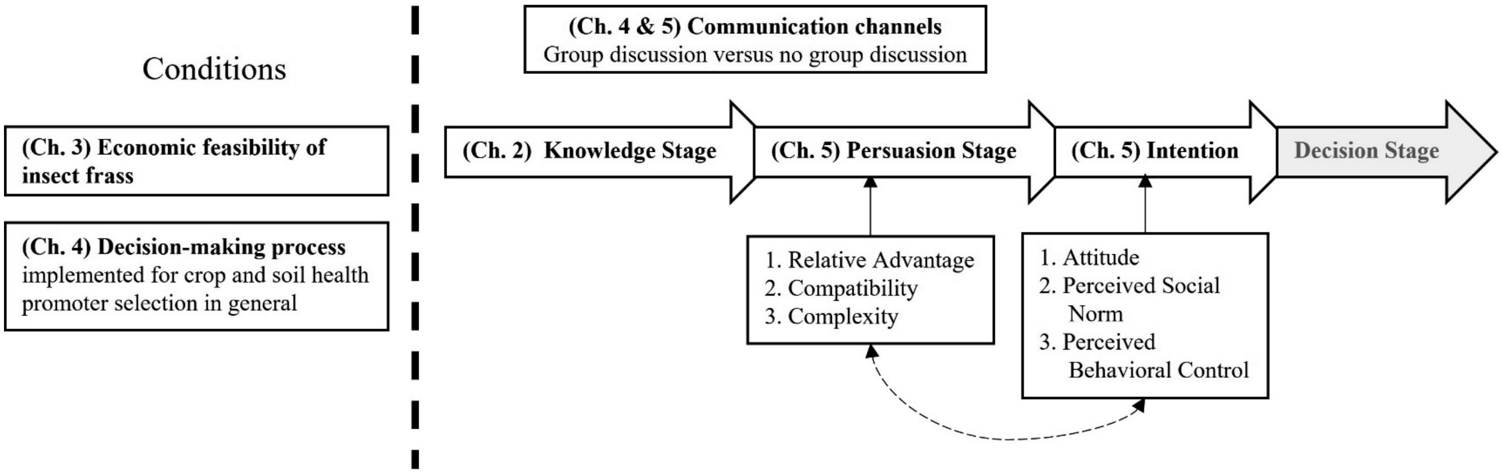

Figure 1.1 - Conceptual framework

The Innovation-Decision Process from Rogers (2003) provides the basic structure for this research regarding farmers' perspectives towards insect frass. More specifically, the first two stages (knowledge and persuasion) and the influence of group discussions are explored in detail. The Means-End Chain theory (applied in Chapter 4) and the Theory of Planned Behavior (applied in Chapter 5) provide complementary and insightful perspectives to the exploration of farmers' innovation-decision process.

Based on the perceived characteristics, in the decision stage, the individual decides whether to adopt or reject the innovation (Rogers, 2003). However, given that frass cannot be applied yet as a crop and soil health promoter on arable farms, the decision stage cannot be reached. Using a forward-thinking exercise where farmers imagine applying frass on their farm can further develop their impressions (Rogers, 2003). This mental exercise can dictate the individual's intentions to trial the innovation (Pannell et al., 2006). 'Intention' is a construct also familiar to the Theory of Planned Behavior (TPB). The TPB, from social psychology, posits that one's intention to perform a given behavior depends on three factors: one's disposition in favor or against the behavior (attitude), the perceived social pressure associated with the behavior (perceived social norms) and the extent of control and ability over performing the behavior (perceived behavioral control) (Fishbein & Ajzen, 2010).

The TPB and IDP are frameworks that provide complementary lenses on the decision-making process. With the two lenses, it is possible to investigate how intentions to trial frass are influenced by farmers' perceptions of frass' characteristics and farmers' attitudes, perceived social norms and perceived control of using frass on their farms. Missing from this investigation is an understanding of the personal goals driving the decision to trial frass. The third theory applied in this research – Means-End Chain (MEC) theory – offers insights into what product attributes are important and why. MEC theory was originally based on personal construct psychology (Kelly, 1955) and was further developed by Gutman (1982) and Reynolds and Olson (2001). The theory links together means to ends with three factors: the product's characteristics (attributes), the expected outcomes from using the product (consequences) and one's personal goals (values). Attributes are sought to achieve various consequences; consequences ultimately play a role in upholding values. Having elicited the qualitative justifications, a map is constructed to provide a visual representation of the decision-making process. The MEC approach is suitable only for decisions that have already been made. As previously mentioned, the decision stage is not yet reachable in the case of adopting frass as a crop and soil health promoter. MEC theory was therefore applied to provide insight in the decision-making process farmers implemented when selecting their currently used crop protection products. The assumption is that when farmers would consider trialing insect frass, they would apply the decision-making process identified in the MEC study.

As described by the TPB, perceived social norms influence one's intention to perform a behavior (Fishbein & Ajzen, 2010). Similarly, the review conducted by Borges et al. (2019) determined that farmers' attendance at training sessions and membership in farmer groups influenced their adoption. According to the IDP, interpersonal channels play an important role in the persuasion stage. This is because individuals may have doubts or uncertainties regarding the innovation; therefore, social reinforcement is sought to ascertain that their impressions are similar to their peers' (Rogers, 2003). Group discussions can therefore provide a platform where participants can learn what the group's impression towards a given behavior is, and obtain social reinforcement for their decisions (Cialdini, 2001; Lewin, 1952).

The context in which farmers encounter innovation-related information can have an impact on how the information is mentally processed and on how opinions are formed, which ultimately influence the decision-making process (Glover et al., 2019; Katz, 1961; Rogers, 2003; Werner et al., 2008).

Thesis outline

This thesis consists of six chapters: the general introduction (Chapter 1), four research chapters (Chapters 2-5) and a general discussion (Chapter 6). Chapters 2 and 3 provide a description of frass as a crop and soil health promoter. Chapters 4 and 5 detail farmers' decision-making process and explore the effects of group discussions on the decision-making process.

Chapter 2 addresses the first research question by describing frass in accordance with the three types of knowledge as overviewed in the IDP (Rogers, 2003). An expert elicitation using semi-structured interviews and a Delphi study were conducted. This was an essential first step as there is a great deal of technical and laboratory research emerging, but the translation of these findings for practical application is scarce. The summarized findings of Chapter 2 were used in Chapters 4 and 5 to describe insect frass to farmers. Note that the term "insect waste streams" (or "IWS") was used in Chapter 2 instead of "insect frass".

Chapter 3 addresses the second research question by describing frass in terms of its expected economic contribution as a crop and soil health promoter. A series of expert elicitations with insect frass experts and crop advisors were conducted. The elicitations resulted in the expected changes in costs and revenues associated with the crop production if frass were to be applied as a crop and soil health promoter. The estimations provided by the experts were integrated into a financial model known as a partial budget. The partial budget was used to determine the expected net change in profit of using insect frass on conventional and organic arable farms. As this thesis was conducted simultaneously with field and lab experiments testing frass' effectiveness as a crop and soil health promoter, Chapter 3 was the last of the four studies conducted; it therefore capitalized on what the experts learned over the four years of experiments. Notably, farmers only received an overview of the results from Chapter 2; they did not receive an overview of the economic analysis of Chapter 3.

Chapter 4 addresses the third research question by providing insights on farmers' decision-making using the MEC theory. Forty-six farmers participated in the research. All farmers first watched an informational video about frass (derived from the findings of Chapter 2). Then twenty-three farmers participated in a group discussion where their first impressions of insect frass were shared; the other twenty-three farmers did not. Days later, each farmer was interviewed. The interviews conducted are known as laddering interviews. Laddering interviews begin with a determined set of product attributes that make similar products distinguishable (e.g., color or size). For each attribute, a series of repeated questioning occurs by asking, "Why is that important to you?". In doing so, a map of logical reasoning is generated, known as a hierarchal value map (HVM). The results show how the aggregated HVMs of those who participated in group discussions differed from the HVMs of those who did not.

Chapter 5 addresses the fourth research question by providing insights on farmers' intentions to trial insect frass via two lenses: the TPB and perceptions from the IDP. The farmers that participated in the research of Chapter 4 were the same farmers that participated in Chapter 5. In addition to the data collection process described for Chapter 4, the farmers also completed two questionnaires. The first was completed directly after watching the informational video (and before any group discussions took place), and the second was completed after the interviews. Questionnaires from two time points were used to compare the drivers of intentions right after becoming aware of an innovation with the drivers of intentions that persisted days later. Linear regression was run to determine how group discussions are associated with farmers' intentions to use frass.

Chapter 6 provides a general discussion that begins with a synthesis of the results across the research chapters. Following the synthesis of results, implications for business and policy are described along with a reflection on the materials and methods. Finally, ideas for future research are proposed, and the main conclusions are stated.

CHAPTER 2

Towards circular agriculture – exploring insect waste streams as a crop and soil health promoter

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Abstract

Insects have tremendous potential for utilizing the waste generated from other agricultural sectors to produce high value protein. The by-product of insect production, insect waste streams, can be recycled and repurposed for promoting the health of crops and soil as the chitin, present in the molted skins, acts as a substrate for beneficial microbes that aid in plant protection. However, because insect waste streams are currently in the research and development phase, little information regarding its potential as a crop and soil health promoter is available. To address this information gap, this research explores experts' knowledge of the characteristics and application of insect waste streams as a crop and soil health promoter. To conduct this research, a two-step expert elicitation approach was used consisting of semi-structured interviews followed by a Delphi study. Interviews were conducted with six experts. Topics arising from the interviews that produced conflicting expert opinions were tested in the Delphi study. Fourteen experts participated in the Delphi study in an attempt to reach an agreement on these topics. The results of this research indicate that insect waste streams could be produced as a granulate-type compost, seed coating, or impregnated into a biodegradable seedling cup. To use insect waste streams, farmers should apply it next to the roots of each plant during the time of planting. Experts were unable to reach an agreement on some topics (e.g., dosage recommendations and expected yield changes). A brief discussion of insect waste streams' legal context is also provided. The results of this research contribute the first description of insect waste streams as a crop and soil health promoter. Such results serve as a tool to potentially aid in its uptake thus progressing towards circular agriculture.

Keywords

expert elicitation, Delphi study, knowledge, innovation decision process

2.1 Introduction

The growing global human population and increasing wealth of those in the low-income group are creating a rising demand for protein consumption (Bodirsky et al., 2015; Steinfeld et al., 2006; Thornton, 2010). At the same time, recycling the by-products of one agricultural system for use in another (circular agriculture) and the quest for more sustainable food production and consumption are becoming higher priorities for policy makers (Rijksoverheid, 2019). Insects provide an attractive opportunity to contribute to both the aims of circular agriculture and the growing global protein demand (Chia et al., 2019; van Huis, 2013). Thus, insect production is gaining traction as a form of mini-livestock production. Such traction is evident by European insect producers' expectations of increasing investments from over €350 million in 2018 to over €2 billion by 2025 (International Platform of Insects for Food & Feed, 2019). The production of insects as a protein source has several advantages. First of all, insect production has demonstrated lower emissions of greenhouse gases and ammonia compared to conventional livestock production (Oonincx et al., 2010). Also, some insects are able to utilize the waste of other agricultural sectors and convert it into high value protein – a type of bioconversion (Council on Animal Affairs (RDA), 2018; FAO, 2013). Insect production thus aligns with the United Nations' twelfth sustainable development goal for ensuring sustainable consumption and production patterns (United Nations, 2018) and contributes to circular agriculture.

Though insect production may utilize the waste of other sectors, the potential added value of its own generated by-product (i.e. insect manure or insect frass, molted exoskeleton, and undigested feed) has been investigated primarily as a potential fertilizer application (Bortolini et al., 2020; Dulaurent et al., 2020; Houben et al., 2020; Poveda et al., 2019). However, there is increasing research attention to insect by-products having even greater potential as a crop and soil health promoter (Debode et al., 2016; Kebli & Sinaj, 2017; Quilliam et al., 2020; Temple et al., 2013; Vickerson et al., 2017). For example, research conducted by Bai (2015) showed that when the waste generated during insect production or insect waste streams (IWS) are integrated into the soil, Bacilli colonization increases by more than fifteen percent after seven weeks. Many Bacilli species are known to induce systemic plant resistance within its aboveground tissues and biological control against soil-borne pathogens and below- and aboveground insect pests (Francesca et al., 2015; Gadhave et al., 2016; Gadhave & Gange, 2016; Lugtenberg & Kamilova, 2009; Sharma et al., 2013). Thus, IWS can be used to promote the health of crops and soil of arable farms, thereby also reducing the need for chemically-based plant protection products (PPP) such as chemical pesticides. Using IWS as an input for arable farms closes the loop of the insect production sector, making it a circular form of agricultural production.

For IWS to successfully penetrate the market, it must be an attractive crop and soil health promoter for farmers. One way to forecast IWS' attractiveness amongst farmers is by understanding the decision-making process farmers will undergo prior to making an adoption or rejection decision. The process is referred to as the innovation decision process (IDP). The IDP is 'the process through which an individual (or other decision-making unit) passes from gaining initial knowledge of an innovation, to forming an attitude towards the innovation, to making a decision to adopt or reject, to implementation of the new idea, and to confirmation of this decision' (Rogers, 2003).

Previous research has applied the IDP to farmers' uptake of various agricultural innovations. For example, Goldberger et al. (2013) explored farmers' adoption decisions for biodegradable plastic mulches in the USA. Special attention was given to determining the perceptions farmers have and the barriers they face. Jenkins et al. (2018) investigated farmers' adoption decisions for orange-fleshed sweet potatoes in Mozambique. Mbosso et al. (2015) investigated the factors that influence farmers' attitudes towards a kernel extracting machine in Cameroon.

Unlike the previous research on adoption of innovations, it is currently not feasible to investigate farmers' adoption decisions, perceptions or attitudes regarding IWS. This is because IWS are neither readily available nor understood by farmers. In fact, there is currently very limited information regarding IWS as a crop and soil health promoter (apart from e.g., Debode et al. (2016); Kebli and Sinaj (2017)). Especially limited is information that is tailored for briefing farmers. To address this information gap, this research generates IWS information to specifically address the first stage (the knowledge stage) of the five-stage IDP. According to Rogers (2003) 'Knowledge occurs when an individual (or other decision-making unit) is exposed to an innovation's existence and gains an understanding of how it functions.' Rogers specifies that there are three types of knowledge individuals acquire to learn about an innovation (see Table 2.1).

Table 2.1 - Knowledge types defined by Rogers

Awareness-knowledge	'Information that an innovation exists'. The information should also describe what the innovation is (Rogers, 2003).
How-to knowledge	'Information necessary to use an innovation properly' (Rogers, 2003).
Principles-knowledge	'Information dealing with the functioning principles underlying how an innovation works' (Rogers, 2003).

Awareness, how-to, and principles knowledge regarding IWS as a crop and soil health promoter is limited. The objective of this research is to investigate experts' knowledge of the characteristics and application of IWS as a crop and soil health promoter. Fulfilling this objective will be useful to (1) assemble a practical and descriptive overview of IWS as a crop and soil health promoter, which can serve as a tool to inform farmers and stakeholders (e.g., consumers and policy makers) and (2) if perceived favorably by farmers, may aid in the uptake of IWS thus progressing towards circular agriculture.

One of the world-leading nations in insect production is the Netherlands, which holds two of the world's largest production facilities and is a driver of developing innovative productionupscaling technologies (Council on Animal Affairs (RDA), 2018). This research therefore focuses specifically on the application of IWS on Dutch arable farms.

2.2 Materials and Methods

Experts with knowledge of IWS and its potential application on Dutch arable farms participated in this research. To elicit experts' knowledge regarding the application of IWS as a crop and soil health promoter on arable farms, a two step-approach was used (see Figure 2.1). First, interviews were conducted to gain insight into the range and diversity of experts' opinions regarding various IWS topics. In many cases, experts shared similar opinions. For a few topics, however, some of the opinions were conflicting. To see whether experts could reach an agreement on these topics, a second step was conducted. In the second step, experts anonymously exchanged thoughts and feedback in an expert consultation method commonly known as a Delphi study.

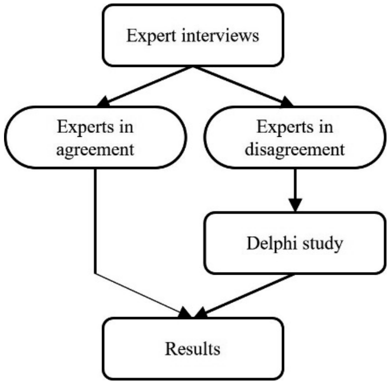


Figure 2.1 - Methodological process

2.2.1 Expert interviews

The questions in the interview guide were formulated according to Rogers (2003) to generate awareness-, how-to, and principles-knowledge. Table 2.2 presents some examples of how each type of knowledge was elicited. A full list can be obtained from the corresponding author upon request.

Table 2.2 - Example knowledge elicitation questions

Awareness-knowledge	What is the physical appearance of the product when it is purchased?
How-to knowledge	What steps do farmers need to take to use the product?
Principles-knowledge	How is the health of the arable crops and soil promoted when using the product?

An extension was made specifically to the definition of awareness knowledge to better align it with the arable farming context. Awareness knowledge was previously defined as information that describes what the innovation is. In the farming context, arguably, the physical appearance of a health promoting innovation is not as important as the expected consequences of using the product. These consequences contribute to the awareness-knowledge of IWS. Thus, to capture expected consequences regarding IWS' performance, studies that investigated attitudes and perceptions of biocontrol agents (Moser et al., 2008) and insects in (food and) feed (Verbeke et al., 2015) were used as input for the interview guide. One example question that derived from this addition was, 'What are the risks [benefits] for the environment when arable crops and soil are treated with the product?'.

Additional questions were included by the researcher to directly address context specific considerations that are relevant for the feasibility of IWS. For example, the following question was included, 'How are the current regulations inhibiting the use of the product as a crop and soil health promoter?'. This question is important to answer as legislation in the Netherlands' farming sector becomes increasingly less predictable and farmers try to maintain suitable margins to run their businesses.

Five participants pretested the interview guide following the cognitive interview approach as described by Willis (2005). Participants of the cognitive interviews were selected using convenience sampling based on their experience in crop and soil protection. Improvements were made to the interview guide based on the participants' feedback.

In the current study, an IWS expert was defined as someone who was either (1) conducting research using IWS, (2) familiar with the preliminary research of IWS and was able to conceptualize its application for Dutch arable farmers, or (3) able to conceptualize the regulatory context that could develop in response to IWS. Six IWS experts participated in one-hour, face-to-face interviews, which took place between May and June 2019. These six participating experts did not overlap with the five who pretested the interview guide.

The interviews were analyzed using content analysis (Gray, 2004). First, opinions were organized into subcategories within each interview question. Then subcategories were created as various topics emerged. For example, the question 'What steps do farmers take to use the product?' resulted in subcategories including: how often it is applied and how it is stored. Subcategories were evaluated based on how many participants discussed them and how diverse the opinions were in each. Only the subcategories that contained conflicting expert opinions were tested in the Delphi study.

2.2.2 Delphi study

A Delphi study was conducted to clarify the conflicting findings in the expert interviews. A Delphi study is a structured group communication process in which data are collected from experts in several subsequent rounds with the aim of facilitating the experts to come to an agreement on a particular topic (Dalkey & Helmer, 1963; Linstone & Turoff, 1975). A Delphi study consists of at least two rounds of data collection. In the first-round experts give their anonymous and independent opinion on various aspects of the topic of interest, usually by means of a survey. Results are summarized by the study moderator and fed back to the experts. Based on this feedback experts are able to reconsider and change their opinion in the next round of surveys.

Experts invited to participate in the Delphi study included the six experts who participated in the expert interviews and those who they proposed as suitable experts at the end of the interviews. In total, fifteen experts participated in the first round of the Delphi study. Participating experts came from sectors including: academia, governmental agencies, insect and seed producers, and agricultural product developers. Their expertise included among others: microbiomes, microbial and terrestrial ecology, entomology, economics, insect rearing, soil, plants, seeds, and policy.

For the first round of the Delphi study, a survey was developed which included thirteen statements about IWS based on the conflicting opinions from the expert interviews. The survey was pre-tested by three researchers (not part of the fifteen experts who participated in the Delphi study) from Wageningen University who gave feedback on its design and the formulation of the statements. In the improved version of the survey, experts were asked to rate to what extent they agreed with the statements. Ratings were made on a scale from 1 (strongly disagree) to 7 (strongly agree). A 'don't know' option was present for experts who wanted to opt out of rating any of the statements. In addition to rating each statement, experts were encouraged to explain their ratings.

The survey developed for the second round of the Delphi study was similar to the first round. Experts were asked to rate the same statements on the same scale. However, this time each statement was provided with a summary of the results from the previous round. This summary consisted of three parts: (1) the expert's own rating of the statement in the previous round, (2) a histogram, showing the distribution of the ratings across the seven points of the scale, and (3) the explanations experts gave for their ratings (anonymized). That way, each expert was able to read the summary and decide whether to modify his/her own rating. Figure 2.2 shows an example summary of the feedback for one of the statements. Note that the explanations given by experts are not pictured in Figure 2.2, which were presented in the actual surveys just after the histogram.

The survey for the third (and final) round followed the same set-up and procedure as the second round. Five statements were not presented again because a sufficient level of agreement was achieved for two statements and because ratings remained virtually unchanged (plateaued) for three statements.

All surveys were developed using the online survey platform Qualtrics (Qualtrics, 2015). Rounds 1, 2 and 3 took place between September and October 2019. Round 1 surveys were administered during an individual face-to-face meeting. Because the number of experts was small enough, visiting each expert in the first round was ideal to encourage their participation in subsequent rounds. Each meeting was scheduled for forty-five minutes. The surveys for rounds 2 and 3 were sent to participants via email.

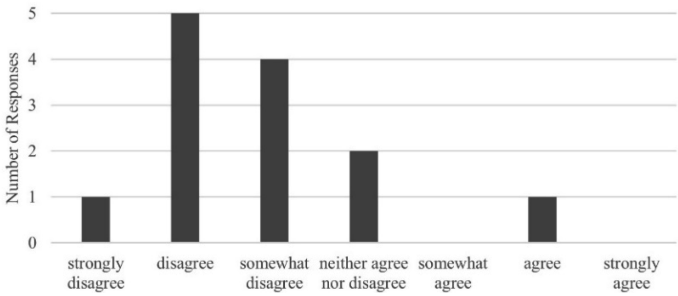
To estimate the level of agreement among experts on each statement, the Strict Agreement (SA) Index (Meijering et al., 2013) was calculated using the statistical data-analysis program R (R Core Team, 2019). The SA expresses the number of agreeing expert pairs as a proportion of the total number of possible expert pairs. In the current study, two experts were regarded as being in agreement when they rated a statement using the same point or adjacent points on the scale. For example, on the scale of 1 (strongly disagree) to 7 (strongly agree), rating pairs of 1-1 and 1-2 were both regarded as being in agreement. An exception was made

In Round 2, you stated to what extent you agree or disagree with the following statement about insect waste streams (IWS):

IWS will fully replace artificial fertilizers.

You gave the following answer: **neither agree nor disagree**.

The graph below shows the answers given by all participating experts.



The table below shows the explanations experts gave for their answers.

Figure 2.2 - Example quantitative feedback

with regards to the mid-point of the scale (4) as it was labelled in the survey as 'neither agree nor disagree'. Arguably, neither ratings of 3 (somewhat disagree) nor 5 (somewhat agree) are in agreeance with 4. Thus, in the calculation of the SA, the following pairs of ratings were regarded as being in agreement: 1-1, 1-2, 2-2, 2-3, 3-3, 4-4, 5-5, 5-6, 6-6, 6-7, 7-7. For each statement, the SA was calculated by dividing the number of agreeing expert pairs by the total number of possible expert pairs. In theory the SA can take on values between 0 (none of the experts agree with each other) and 1 (all experts agree with each other). In the current study an SA greater than 0.7 was regarded as a sufficient level of agreement among experts as it indicates that 70% of all expert pairs agreed on the rating of a statement.

Explanations provided by experts in the final rounds underwent a content analysis. This was performed by summarizing the explanations making similar arguments, to reduce the feedback. Explanations that were different from any other explanation were summarized and captured in the results. Any explanation that was deemed unclear by the first author was excluded from the results.

2.3. Results

2.3.1 Interview results

Table 2.3 shows experts' opinions regarding the awareness knowledge (i.e., physical appearance, anticipated consequences, and policy) of IWS that farmers require. Opinions mentioned by three or more experts were included in Table 2.3.

Table 2.3 – Experts' opinions regarding awareness knowledge of IWS (number of experts that expressed the opinion)

Physical appearance of IWS	The combined form of these components will be sold as a dry granulate (also described as a highly concentrated compost), a seed coating, or an IWS-impregnated biodegradable cup that contains seedlings. (6)
	IWS are made of the molted skins (exuviae), manure and undigested feed of insects. (3)
Environmental consequences	Indirect benefits of IWS are the reduction of biocides and thus no build up and negative effects of harmful chemicals in the soil. (3)
	IWS are expected to reduce the amount of chemical residues on crops by reducing the need for spraying. (5)
Marketing consequences	IWS are expected to qualify for organic certification. (4)
	Using IWS poses no foreseeable marketing risks. (3)
	Using IWS poses no foreseeable exporting risks for the end product. (4)
Consumer health consequences	Experts were able to come up with diverse though highly unlikely risks to consumer health. (6)
Farm production consequences	Improved yields and reduced plant loss are expected, especially on soils that are not very productive. (6)
	IWS is less weather sensitive compared to biocides or artificial fertilizers. (4)
	IWS supplements but will not replace organic fertilizers. (4)
	IWS increase organic matter build up in the soil. (4)
	IWS function as a natural fertilizer by providing nutrients to the soil. (4)
	IWS induce a plants' systemic resistance by functioning as a biocontrol against pathogenic soil borne organisms, harmful fungus, and natural enemy insects. (4)
	There are no economic incentives used to promote the use of IWS. (3)
	An overapplication of IWS can be harmful to plants. For instance, it could result in nitrogen leaching. (4)
Farmer health consequences	IWS could improve the health of farmers that currently spray their crops, as using IWS should be low risk itself and would reduce farmers' exposure to higher risk products. (5)
	There are no direct health benefits for farmers. (4)
	As insect material is often not found in highly concentrated forms like IWS, it may cause reactions for farmers with allergies to insects. (5)
External forces supporting IWS use	Minister supports circular, sustainable agriculture. (3)
	There is a societal trend towards supporting increased circularity and decreased use of synthetic biocides. (5)
	Farmers face problems of neonics being taken out of the market. (3)
IWS regulations	EU is attempting to implement new legislation on registering biostimulant-type products, which IWS would be subject to if positioned as a biostimulant product. (3)
Existing evidence of IWS effectiveness	Initial research on shrimp chitin showed promising health effects of chitin. (3)

According to the experts, IWS could be sold in various forms (i.e., dry granulate, seed coating, and biodegradable seedling cup). Expected benefits of using IWS include the reduced use of harmful chemicals, thus reduced residues on crops and improved yields on unproductive soils. IWS are expected to be more rain resistant, provide organic matter and nutrients to soil, and provide protection for young plants. Some anticipated risks of using IWS include the misuse (e.g., over application) of IWS which can harm production and possible allergic reactions by farmers with insect allergies. Effects on consumer health have not been researched. Until proven otherwise, there could be a risk to consumers.

Table 2.4 shows experts' opinions regarding the how-to knowledge of IWS farmers require. Opinions mentioned by two or more experts were included in the table.

Table 2.4 – Experts' opinions regarding how-to knowledge of IWS (number of experts that expressed the opinion)

Purchasing IWS	No prior investments are required to use IWS. (3)
	IWS should be purchased approximately 1x per year. (3)
	Experts speculated over various sales channels farmers could source IWS from. (3)
Using IWS	IWS should be applied during or shortly after sowing or planting. (3)
	Insect waste streams should not be spread over all the field but rather only precisely around the root systems of the plants. (2)
	No additional labor requirements are needed to use IWS. (5)
	IWS are to be kept in a dry and relatively cold place, as other plant protection products are normally stored. (5)
	Shelf life of IWS is long and comparable to other PPPs. (3)
Mindset	IWS will require a mindset change for some farmers to implement them. Instead of seeing pests and spraying, farmers must have faith that the plant is mobilizing defenses and he/she should not spray. (2)

Experts expected that IWS need to be purchased annually. No other investments need to be made to make use of IWS as the various forms of IWS products are expected to be compatible with existing machinery. IWS should be applied precisely around the roots of seedlings or seeds at the time of planting. No additional labor for applying IWS is expected. Storage requirements and shelf life are expected to be comparable to existing product alternatives.

Table 2.5 shows experts' opinions regarding the principles knowledge of IWS farmers require. Opinions mentioned by two or more experts were included in the table.

Table 2.5 – Experts' opinions regarding principles knowledge of IWS (number of experts that expressed the opinion)

How IWS promote crop/soil health	Insect skin contains chitin which demonstrates health promoting effects. (5)
	IWS provide substrates for the soil microbiome. Fungi and beneficial microbes in the soil promote the nutrient uptake, resistance, and health of the plant. (4)
	Long-term, IWS improve soil health by altering and creating favorable soil-dwelling microbial populations that emit usable compounds for plants to uptake. (3)
	Rather than killing everything with chemicals, IWS creates an equilibrium using a more natural and diverse effect on pathogens than chemical products. (2)
	IWS would have difficulty creating resistance in pathogens, as IWS is a more complex product than chemical products. (5)

Experts indicated that chitin within the molted insect skins acts as a substrate for specific soil-dwelling microbes. The presence of these microbes creates a favorable environment for the plant, as they promote the plant's nutrient uptake and resistance against pests and diseases. This process thus promotes the health of crops and soil.

Table 2.6 presents the topics where mismatches were identified amongst expert opinions on the awareness, how-to knowledge, and principles knowledge. An example of identified conflicting opinions can be illustrated using the topic: 'expected effect of IWS in end quality/aesthetics of the end (e.g., vegetable) product'. Some experts gave opinions that IWS would reduce the end product quality and others expected no change.

Table 2.6 - Topics regarding IWS on which experts had conflicting opinions

		Delphi statement reference nr.
Awareness-knowledge	Expected effect of IWS in end quality/aesthetics of the end (e.g., vegetable) product	1
	Expected cost of IWS compared to currently available products	2, 3, 4, 5
	Expected availability of IWS by 2020	6
	Extent which IWS replaces the use of artificial fertilizer	7
	Extent which IWS replaces the use of chemical sprays and seed coatings	8. 9
How-to knowledge	Expected dosage of IWS per plant (or hectare)	N/A
	Intensiveness of monitoring arable crops and soil treated with IWS	10, 11
Principles-knowledge	Expected effect of IWS on soil microbial biodiversity	12

Based on the topics in Table 2.6, statements were translated and presented to experts in a Delphi study to find out to what extent they were able to reach an agreement. The numbers in the right most column of Table 2.6 link the identified conflicting topics to the translated Delphi statements (presented in Table 2.7). For example, the first conflicting topic in Table 2.6 was translated into Delphi statement 1 in Table 2.7.

2.3.2 Delphi study results

Fourteen of the fifteen invited experts participated in all three Delphi rounds. Table 2.7 shows summary statistics for each Delphi round – number of ratings, median, SA, and the distribution of ratings. The number of ratings can be less than the total number of participating experts because the 'don't know' option was available to utilize for any question.

The topic – *expected dosage of IWS per plant (or hectare)* – was removed after the first round due to the large amount of non-response and variation in the few provided answers. Experts were asked to provide an approximate value as kg/hectare. Only four of fifteen experts responded, and the values ranged from 40 to 5,000 kg/hectare.

Table 2.7 - Summary statistics for all Delphi study rounds

	Nr. of ratings			Median			SA Index			Distribution of ratings in final round	
Statement: Compared to current crop protection practices, ...	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**Disagree (rated 1, 2, or 3)**	**Agree (rated 5, 6, or 7)**
1. ... when sold in supermarkets, crops (e.g., broccoli) treated using IWS will have reduced aesthetics (physical appearance).	12	14	14	2	2	2	0.47	0.53	0.51	11	1
2. ... in the short-term, IWS will result in higher production costs.	13	13	13	4	4	4	0.30	0.33	0.40	1	5
3. ... in the long-term, IWS will result in higher production costs.	11	13	N/A	4	4	N/A	0.49	0.72	N/A	2	0
4. ... in the short-term, IWS will result in higher yield.	13	13	13	4	4	4	0.31	0.28	0.27	5	5
5. ... in the long-term, IWS will result in higher yield.	12	13	N/A	4.5	4	N/A	0.32	0.33	N/A	1	6
6. Assuming (1) IWS are approved by law to sell as a crop and soil health promoter and (2) there is a large demand for IWS from high-value crop (e.g., broccoli) farmers in the Netherlands, there will be enough IWS supply in 2025 to satisfy the demand of farmers.	10	10	8	5	5	4.5	0.42	0.40	0.38	1	6
7. IWS will fully replace artificial fertilizer.	13	13	14	3	3	2	0.39	0.54	0.54	10	0
8. IWS will fully replace chemical crop protection sprays (e.g., pesticides).	14	13	N/A	2	2	N/A	0.62	0.85	N/A	12	0
9. IWS will fully replace chemical seed coatings.	13	13	13	2	2	2	0.55	0.62	0.59	11	0
10. ... in conventional farming, farmers will spend more time monitoring crops and soil treated with IWS.	14	14	14	5	5.5	5.5	0.36	0.53	0.48	2	10
11. ... in conventional farming, farmers must obtain additional knowledge and skills for monitoring crops and soil treated with IWS.	15	14	N/A	5	5	N/A	0.50	0.48	N/A	3	10
12. IWS will increase the microbial diversity within soil.	15	14	N/A	6	6	N/A	0.51	0.51	N/A	1	11

Two of the twelve statements reached the desired SA Index threshold of 0.7. The first was ‘IWS will fully replace chemical crop protection sprays (e.g., pesticides)’. This statement reached an SA Index of 0.85 with a median rating of 2 or ‘disagree’. The second statement was ‘Compared to current crop protection practices, in the long-term, IWS will result in higher production costs’. This statement reached an SA Index of 0.72 with a median rating of 4 or ‘neither agree nor disagree’. Both statements fall under awareness knowledge.

The remaining ten statements tested in the Delphi study did not reach the 0.7 threshold. Two reasons that occurred frequently in the feedback of experts throughout the Delphi rounds could explain this outcome. The first recurring argument was that IWS functions only as a fertilizer. In other words, some experts did not agree with or were not familiar with the idea of IWS being used as a crop and soil health promoter. As an example, one expert stated, ‘In some answers, people made a connection with pesticides, but that is not the question. IWS is a fertilizer and will be used in that way...’ Opposing this argument, an expert stated, ‘IWS is more than a fertilizer, it is expected to also promote soil microbiota and consequently crop protection.’ The second recurring argument was that there is currently too little information and not enough concrete results to draw conclusions.

The following three sections provide an overview of the feedback experts exchanged in the final round of the Delphi study and is presented based on the respective knowledge type.

2.3.3 Expert feedback on awareness-knowledge statements

Regarding statement 1, residues on the final product would not be expected because IWS should be applied at an early stage (e.g., during planting), thus it would not be present when harvested. Granted, crops treated with IWS should be compared with organic crops, which ‘are usually less perfect.’ The aesthetics could also be affected in cases of overdosing or due to more insect damage as IWS’ efficacy may be lower than conventional PPP. However, in combination with PPP use, such effects would not be anticipated.

In response to statements 2 and 3, higher short-term costs are expected for farmers due to (1) selling IWS to a niche market and asking higher prices, (2) the lack of IWS available for the market, and (3) more initial monitoring. However, these higher costs are expected to reduce in the long-term as more product is made available and less monitoring is required.

In the long run, IWS could be reasonably priced, but it is dependent on many unpredictable factors including: IWS registration costs, cost of producing and processing IWS, the amount and price of reduced inputs (e.g., pesticides), R&D’s trials, and supply and demand. Though some indicated that they did not expect higher costs of production for farmers.

In statements 4 and 5, lower short-term yields were expected. As IWS is new, farmers need to spend time learning how to work with it, resulting in potentially lower crop yields. Also, optimal and balanced fertilization practice combined with chemical control is ‘unbeatable’ by IWS, which is 'unknown, variable, [and has] uncharacterized composition.' IWS' lower yielding effects could be comparable to the bio-farming yields.

Contrary to the aforementioned arguments, the combination of certain unique micro-elements, soil microbial diversity, and improved soil life should result in more stable and (slightly) increasing crop yields over the long-term. Notably, the motivation for using IWS should not be to increase yield but to farm more sustainably, as using current conventional crop protection is not sustainable.

Regarding statement 6, IWS availability will be dependent on: the growth of the insect production sector, how much IWS is needed to apply to be effective, what sort of IWS product is being considered (seed coat versus compost), and the value of crops it is intended to be used on. The insect production sector is expected to grow. Thus, the supply and uptake by farmers is also be expected to grow. Granted this may be true for high value crops such as vegetables, but for crops like maize, potato, wheat, and sugar beet, there will be insufficient supply.

In response to statements 7, 8, and 9, IWS will not fully replace seed coatings, sprays and artificial fertilizers. IWS is amongst a combination of a diverse range of organic farming practices that reduce the use of pesticides and artificial fertilizer. However, fully replacing fertilizers or PPPs was not considered realistic. Specifically regarding the replacement of seed coatings and sprays, IWS only targets a specific group of chitin-degrading microbes. Although this is an important contribution, more protection and solutions are needed against nematodes, insects, and bacteria. IWS alone are not going to be as effective (or direct) as current chemical treatments; it is comparably unstable and unpredictable. In extreme problems and as a last resort, chemical crop protection will still be needed to treat specific pests quickly. Specifically, regarding fertilizer replacement, IWS could in general provide for a nutrient base and therefore reduce the use of artificial fertilizers. However, farmers will also have to use artificial fertilizers to add specific trace elements to create an optimal soil-nutrients balance as the nutrient content of IWS is neither balanced nor optimal for full replacement of artificial fertilizers.

2.3.4 Expert feedback on how-to knowledge statements

Regarding statements 10 and 11, IWS will require more monitoring, at least in the short-run because (1) it is a new product, (2) its effects are expected to be more variable and thus it is more difficult to judge if it is effectively suppressing pests and diseases compared to chemical treatments and (3) when part of an integrated pest management approach, it will automatically mean more monitoring than conventional farming. Farmers need extra training in (1) recognizing pest problems in an early stage, (2) understanding soil microbial and soil chemical processes, and (3) accounting for the (non-uniform) nutritional value and less predictable effects (e.g., nutrient release time) of IWS. Opposing these arguments, IWS 'should work according to the recommendations based on research.' Therefore, no additional knowledge or skills would be necessary for farmers.

2.3.5 Experts feedback on principles knowledge statements

In response to statement 12, IWS will increase soil microbial diversity because of the addition of different sources of food for microbes. In other words, increasing the variety of organic matter in the soil increases microbial diversity. Several experts stressed that they have seen increased soil-microbial diversity in their own research on IWS. However, the longevity of the biodiversity changes should be further investigated. Indirectly, using IWS will reduce the use of pesticides which will 'result in a stimulation of soil microbiota'. In opposition to the aforementioned position, the microbial communities will only face temporary shifts in composition, but there will not be a change in the number of species.

2.4 Discussion and Conclusion

This study set out to investigate experts' knowledge of the characteristics and application of IWS as a crop and soil health promoter. In brief, the interviews generated the following IWS knowledge. IWS can potentially be produced as a granulate-type compost, seed coating, or impregnated into a biodegradable seedling cup. Anticipated benefits of using IWS include: the reduced use of harmful chemicals, the addition of organic matter and nutrients to soil, and protection for young plants against pests and disease. The latter two points were similarly concluded by Vickerson et al. (2017) regarding the effects of black soldier fly larvae waste streams on protecting plants from harmful wireworms. Main risks affiliated with using IWS include: the misuse (e.g., over application) of IWS and allergy reactions by farmers allergic to IWS. To use IWS, farmers should apply it next to the roots of each plant during the time of planting. IWS work as a crop and soil health promoter because the chitin, present in the molted skins, acts as a substrate for beneficial microbes. The microbes emit compounds that promote the plant's health by defending it from pathogens and pests.

From the interviews, topics were identified in which experts did not agree. These topics, further investigated using a Delphi study, resulted in one additional awareness knowledge finding – IWS will not fully replace chemical crop protection sprays (e.g., pesticides). Though many of the tested statements in the Delphi study did not reach the sufficient 0.7 SA index level, several of the topics resulted in a clear direction of expectations. Though doubted by a few of the participating experts, the general expectations are that IWS will not reduce the aesthetics of final products sold in supermarkets; IWS will not fully replace artificial fertilizers nor chemical seed coats; farmers will need to spend more time and acquire more knowledge and skills to monitor crops and soil treated with IWS; IWS will increase the microbial diversity within soil. Though one should not conclude that these trends are sufficiently supported by experts, they did result in the support of a great majority.

The results suggest that experts found it easiest to generate principles knowledge; only one topic resulted in some disagreement amongst experts during the interviews, and in the Delphi study, there was a strong trend in the distributions of the statement's ratings. This could be explained in part by either experts conducting their own ongoing research or experts were aware of the results from prior research relating to IWS (Bai, 2015; Debode et al., 2016; Kebli & Sinaj, 2017) and similar materials like shrimp exoskeleton (Benhabiles et al., 2012). Likewise, the results suggest that experts found it more challenging to generate how-to and especially awareness knowledge. Eleven out of the twelve statements tested in the Delphi study were a part of awareness and how-to knowledge. By the end of the Delphi study, five awareness knowledge topics and one how-to knowledge topic showed very little homogeneity in experts' expectations: short and long-term effects on production costs and yields, the availability of IWS by 2025, and the expected dose of IWS per hectare.

All three types of knowledge are important to understand the innovation; however, awareness knowledge has a particularly crucial role. Rogers (2003) indicates that 'awareness knowledge may motivate an individual to seek a second and third type of knowledge.' If the knowledge generated from this research is presented to farmers, the missing IWS awareness knowledge may result in either farmers' lost interest or false assumptions. In either case, farmers may become demotivated to continue acquiring further IWS-knowledge, ultimately affecting their perceptions of and adoption/rejection decisions regarding IWS.

Although most of the statements in the Delphi study resulted in insufficient levels of agreement, this result is also an important finding. Confucius once said, 'When you know a thing, to hold that you know it; and when you do not know a thing, to allow that you do not know it; this is knowledge.' Having a clear overview of what experts agree on and disagree on is crucial to obtaining a full picture of the available knowledge. Ultimately this research successfully accumulated the first insights into experts' knowledge, expectations, and areas of uncertainty regarding IWS.

As briefly mentioned in Section 2.3.2, the SA index levels below the 0.7 threshold could be attributed to the fundamental disagreement about the functionality of IWS; is IWS only a sort of fertilizer or also functioning as a crop and soil health promoter? This could be explained because the participating experts had different types of expertise. Had the researchers screened the experts for this fundamental functionality belief (that IWS promote the health of crops and soil) it is possible that a higher level of agreement would have been achieved. However, for two reasons, the experts were neither screened nor explicitly informed of the crop and soil health promoting expectations of IWS. The first reason was to allow the experts to express their knowledge unconditionally. Second, the target population of IWS experts in the Netherlands is small; there are simply not many experts affiliated with the topic of IWS.

2.4.1 Policy implications

Currently, IWS is available on the market as a 'soil improver' but cannot be sold yet (until further legislative support) as, for instance, a biostimulant. The legislative support for applying IWS in practice is lacking in the Netherlands as well as in the EU. IWS currently falls under the EU manure fertilization regulations. However, alternative registration options would be more suitable. For instance, the EU has a regulation in the pipeline to register biostimulants. Under such registration, IWS can claim to affect plant growth and natural resistance against harmful pests (only) in a general sense. Biostimulant registration would be cheaper, would require less testing, and would be subject to less regulation than biocide registrations. Granted, if registered as a biocide, IWS can claim its effectiveness against specific pathogens or pests, once tested and proven. Registering IWS as either a biostimulant or as a biocide will have enormous consequences on the cost of research and registration, ultimately affecting the price sold to farmers and the feasibility of widespread use in the sector.

Policy makers should recognize the dilemma raised for companies and ultimately farmers by not having a supportive registration process in place that is flexible enough to accommodate biological innovations. Certainly, tests ensuring IWS' effects on food safety, the environment, user's health, etc. must be conducted. However, as society pushes for circularity and sustainability, products embracing such initiatives should be facilitated through the regulatory framework.

2.4.2 Recommendations for future research

A logical next step for future research would be to track farmers' decision-making process through the IDP. Since IWS are not yet diffused into the market, this case provides a unique opportunity to document farmers' progression through the following stages of their IDP. This expert elicitation can thus serve as a basis of information to disperse to farmers to provide them with at least a basic understanding of how IWS can be applied in practice.

A second suggestion for future (and ongoing) research is to investigate the technical grounds for IWS, especially regarding its effectiveness and practical application on Dutch arable farms. The results of such research should eventually provide evidence to the Delphi statements that did not reach a 0.7 SA including: expected short and long-term crop yields, effects on soil microbial diversity, which PPP and fertilizers IWS could potentially substitute, and crop monitoring and dosage recommendations. Once this information is made available, economic feasibility research could estimate farmers' potential production costs and economic benefits when using of IWS.

A third suggestion for future research is a call for further investigations into the knowledge stage of the IDP. This is especially crucial in the agricultural production sector where there is increasingly more demand for more efficient and safer production. Thus, farmers are constantly faced with innovations, just like IWS. The knowledge-generating approach undertaken in this research should be applied to more agricultural innovations and applied to innovations in other sectors.

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CHAPTER 3

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

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Abstract

As circularity in agriculture becomes more urgent, innovative solutions to use the by-products of one production system as inputs for another are needed. One such example is recycling the by-products of insect production (collectively termed frass) for use as a crop and soil health promoter on arable farms. However, an understanding of the profitability of using insect frass is lacking. The objective of this research was to estimate the net change in profit farmers can expect by utilizing insect frass as an additional product in their array of insecticides and fungicides used in *Brassica* production.

Due to lack of data on frass' performance, expert elicitations were conducted with experts experimenting with insect frass and with arable farming crop advisors. An economic model in the form of a partial budget was then constructed to compare a baseline production scenario (a 'normal' and representative year of production) to an alternative scenario (a 'normal' and representative year of production that includes frass as an additional input). Partial budgets were made for four crops (organic and conventional broccoli and Brussels sprouts) and for three different years – this year, in four years, and in eight years to reflect a typical crop rotation. Stochastic variables were integrated into the model to reflect the uncertainty in the estimations provided by the experts.

Based on the results of this research, we estimate the economic consequences of using frass as a crop and soil health promoter, which forecasts its feasibility as a recycled input for use on arable farms. More specifically, we conclude that by the second and third application, frass is expected to increase the arable farmers' profit by 8-19% depending on the type of production system. Notably, the first year frass is implemented can have positive or negative net change in profit as it takes time for the frass to influence the soil microbiome in a way where it becomes most effective. Frass generated the highest increase in net profit in conventional broccoli production and the lowest (though still positive over time) in conventional Brussels sprouts production.

Keywords

circular economy, biopesticide, crop yield, innovation adoption, stochastic simulation, group discussion, interviews

3.1 Introduction

Supply chains are prone to leaking by-products when producing the main product results in the creation and accumulation of waste. To combat this issue, more circular production systems are being implemented that capitalize on the creation of by-products by recycling and repurposing them, which helps to reduce the reliance on limited existing resources (Geissdoerfer et al., 2020). Agriculture is one of the sectors moving towards circularity as opportunities for by-product recycling become more apparent (Dagevos & de Lauwere, 2021).

One example of circularity in agriculture exists between insect producers and arable farmers. Insect production generates several by-products – molted exoskeletons (exuviae), manure and undigested feed (collectively known as frass) – that can be recycled as a crop and soil health promoter for use on arable farms (Barragán-Fonseca et al., 2022). For example, given that frass is composed of organic matter, it can be used to supplement the nutritional needs of the crops and soil (Chavez & Uchanski, 2021; Kebli & Sinaj, 2017; Quilliam et al., 2020; Temple et al., 2013; Vickerson et al., 2017). Additionally, frass also exhibits potential added value as a crop and soil health promoter. Research conducted by Bai (2015) showed that when exuviae are integrated into the soil, Bacilli colonization increases by more than fifteen percent after seven weeks. By stimulating specific beneficial microbial groups (e.g., *Bacillus* or *Pseudomonas* species), frass can interfere with the performance of various herbivores and suppress various diseases (Andreo-Jimenez et al., 2021; Cretoiu et al., 2013; Kupferschmied et al., 2013; Laurentis et al., 2014; Randall et al., 2020). With fewer pests and diseases present, less crop yield loss would occur. Ultimately, frass could potentially reduce the reliance on chemical insecticides and fungicides while improving crop yield. Researchers continue to test the effectiveness of insect frass as a crop and soil health promoter, though more time is needed to determine its full potential (Barragán-Fonseca et al., 2022).

For frass to play a role in circular agriculture, it should be economically justifiable for farmers. There is currently a lack of a comprehensive overview of frass' influence on the pests, diseases and yield for any one crop. Likewise, there is currently no reliable indication of the extent in which frass can reduce the need for chemical crop protection products. These two factors make it challenging to calculate the economic viability of frass. The objective of this research is to estimate the net change in profit that farmers can expect by adding insect frass to their array of crop and soil health promoters used in *Brassica* production. To meet this objective, three underlying research questions are addressed:

When applying insect frass as a crop and soil health promoter compared to not applying frass,

1. by how much is pest and disease presence expected to change?
2. by how much is crop yield expected to change?
3. by how much is fungicide and insecticide use expected to change?

To answer the research questions, we consulted experts. Relying on expert knowledge provides an opportunity to gain insights into insect frass' performance by extrapolating results from the most recent and on-going studies. Expert elicitations help in gaining insights into topics beyond the current knowledge base as the current literature provides an insufficient overview of frass' potential (Morgan, 2014).

The analysis focuses on the use of insect frass in the Netherlands because a great deal of insect production and the development of insects for food and feed occurs in the Netherlands (van Huis, 2013). Additionally, research investigating insect frass' effectiveness against various pests and diseases in *Brassica* crops is taking place in the Netherlands. Capitalizing on the prevalence of insect production and experts' knowledge and experience, we focus our research on frass' economic worth in the context of Dutch *Brassica* production.

We investigate the net change in profit for two *Brassica* crops (broccoli and Brussels sprouts). *Brassica* crops vary greatly in terms of the extent of pesticide use and how long the crops are on the fields. Among the *Brassica* vegetables, broccoli production utilizes very few active crop protection product ingredients, while Brussels sprouts production utilizes many (KWIN-AGV, 2018). Considering these two extremes is therefore useful for projecting insect frass' potential economic effects within *Brassica* production. We consider both conventional and organic production as the allowance for pesticide usage and application schemes differ between the two systems.

3.2 Methods

3.2.1 Research design

The baseline scenario in this research is defined as a 'normal' and representative year of Dutch *Brassica* production. In a normal and representative year of Dutch *Brassica* production, various organic and conventional pesticides are typically utilized. The alternative scenario estimates how the profit of the baseline scenario would change if, in addition to the various organic and conventional pesticides, insect frass was also utilized. As frass is expected to promote the health of crops and soil, it is expected to affect the presence of pests and diseases and therefore influence the quantities of organic and conventional pesticides used on the crop and the crop's overall yield. To estimate frass' influence on pests, diseases, pesticide use and yield, we conducted expert elicitations with two groups of experts.

More specifically, the first expert elicitation was conducted with insect frass experts with the aim of addressing research questions 1 and 2. The results of the first expert elicitation served as input for the second expert elicitation, which was conducted with crop advisors with the aim of addressing research questions 2 and 3. The results from the second expert elicitation served as input for the economic model that calculated the net change in profit the alternative scenario achieves compared to the baseline scenario. Figure 3.1 depicts this three-step research process.

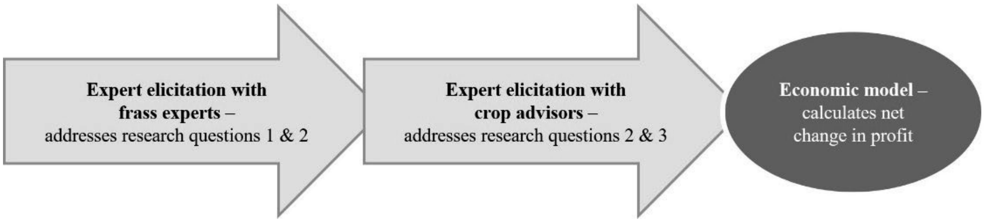

Figure 3.1 – The three-step process implemented to calculate the net change in profit in Brassica production by applying frass

3.2.2 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 in the Netherlands. 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. A scenario was developed to detail relevant assumptions that the experts should consider throughout the interview. The scenario established, 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 the full research scenario.

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).

Box 1 – Research scenario

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.

(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.

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 research scenario (see Box 1) was 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. See Appendix B for 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 3.3.1).

3.2.3 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 research scenario (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. Figure 3.2 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 Figure 3.2) 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?"

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 3.3.2).

		year 0		year 4		year 8	
	Quantity (l/ha)	*% reduced*	*+/- %*	*% reduced*	*+/- %*	*% reduced*	*+/- %*
Esfenvaleraat (25)	0.4						
Lambda-Cyhalothrin (100)	0.15						
Spinosad (480)	0.4						
Spirotetramat (150)	1						

Figure 3.2 - Crop advisor interview - example question

3.2.4 Economic model – a partial budgeting exercise

In this research, we developed an economic model that calculates the expected net change in profit that farmers can expect when comparing the baseline scenario (a 'normal' and representative year of Dutch *Brassica* production where various organic and conventional pesticides are typically utilized) to the alternative scenario (a 'normal' and representative year of Dutch *Brassica* production where, in addition to the various organic and conventional pesticides, insect frass is also utilized). With such a comparison, only the differences between the two scenarios are considered. The analysis is referred to as a partial budget (Kay et al., 2012). The comparison accounts only for the additional or reduced costs and the additional and reduced revenues that arise when comparing the baseline scenario to the alternative scenario.

The alternative scenario requires purchasing insect frass to apply on the field, which is an additional cost. According to the experts, applying frass is expected to result in an increase in crop yield, which translates to additional revenue. Applying insect frass is also expected to reduce the need for applying various insecticides and fungicides, which translates to reduced costs associated with purchasing insecticides and fungicides. To determine the net change in profit, the added costs of buying the insect frass were subtracted from the additional revenue from increased crop yield and the reduced costs of purchasing insecticides and fungicides. Other potential differences in costs or revenues between the baseline and alternative scenarios (e.g., labor for applying the various products and monitoring the crops) or on a farm level (e.g., resilience and yield differences of the other crops in the rotation) were not considered.

In this research, separate partial budgets were made for each year (years 0, 4, and 8) broccoli and Brussels sprouts would be planted in the crop rotation as stated in the research scenario (Box 1). Net change in profit was calculated at three different points in time to capture the differences in profit that were expected over time.

3.2.4.1 Data and model parameterization

To create a baseline scenario for the partial budget model, we used data from the KWIN-AGV (Kwantitatieve Informatie - akkerbouw en vollegrondsgroenteteelt; or qualitative information - arable farming and field vegetable cultivation) which contains Dutch agricultural financial data (KWIN-AGV, 2018). More specifically, KWIN-AGV provides an overview of the expected crop yield and quantities and prices for insecticide and fungicide applications for organic and conventional crops. Table 3.1 provides an overview of the parameters that defined the baseline scenario of this research.

Additional costs

To calculate the additional cost of applying insect frass on one hectare of crops, two variables were considered: the necessary dose and the purchase price of frass. There is no determined dose of insect frass required to achieve the expected health promoting effects. However, in the experiments conducted by the participating frass experts, doses of one, two and five grams of frass per kilogram of soil were tested where one plant occupied one kilogram of soil. These three doses served as scenarios in the analysis and were represented in the model using triangular distributions (see Table 3.2).

Though insect frass is not readily available on the market, there are a few existing exceptions (marketed as “soil improvers” or fertilizers). Prices of frass in the Dutch market as of June 2022 range from €1.20 - €2.85 per kilogram. To capture the range of prices, three scenarios of frass pricing were used in the analysis - €1.00, €2.00 and €3.00 per kilogram of frass. Triangular distributions were used to reflect the three price scenarios in the partial budget (see Table 3.2).

Reduced costs

According to the experts, the alternative scenario is expected to reduce some of the production costs. For instance, as frass is expected to reduce the presence of various pests and diseases, the costs made related to other insecticides and fungicides is expected to decrease. As described in Section 3.2.3, averaged lowest, most likely and highest estimates were determined from the expert elicitation with crop advisors for each change in insecticide and fungicide for each of the three years. More weight was attributed to the most likely estimates. Therefore, a Program Evaluation and Review Technique (PERT) distribution was chosen to represent the range of estimations; PERT distributions are bell-shape d curves that utilize minimum, maximum and most likely estimates (Malcolm et al., 1959). PERT distributions incorporate a weighted mean (μ) which is calculated as follows:

$$\mu = (a+4b+c)/6$$

where a is the minimum, b is the most likely, and c is the maximum.

Table 3.1 – Fixed parameters used in the baseline scenario of the partial budget

	Variable	Measure/Parameter
Broccoli		
	Plants planted per hectare (for conventional and organic production)	38,000
	Conventional yield (plants/hectare)	30,400
	Organic yield (kg/hectare)	7,500
	Insecticides – Dose (in l/hectare unless specified otherwise)	
	Chlorantraniliprole (200)	0.13
	Deltamethrin (25)	0.30 (x 2 applications)
	Indoxacarb (kg/hectare)	0.25
	Fungicides – Dose (l/hectare)	
	Azoxystrobin (200)/Difenoconazool (125)	1.00
Brussels sprouts	Plants planted per hectare (for conventional and organic production)	33,300
	Conventional yield (kg/hectare)	25,000
	Organic yield (kg/hectare)	9,000
	Insecticides – Dose (l/hectare)	
	Spinosad (480)	0.40
	Spirotetramat (150)	1.00
	Lambda-Cyhalothrin (100)	0.15
	Esfenvaleraat (25)	0.40
	Fungicides – Dose (l/hectare)	
	Fluopicolide (63), Propamocarb (524)	0.75
	Azoxystrobin (250)	2.00
	Prothioconazool (480)	1.20
Financial Input	Conventional Broccoli sale price (euro/head)	0.50
	Organic Broccoli sale price (euro/kg)	1.50
	Conventional Brussels sprouts sale price (euro/kg)	0.50
	Organic Brussels sprouts sale price (euro/kg)	0.50
	Conventional Broccoli net profit (euro/hectare)	12,551
	Organic Broccoli net profit (euro/hectare)	6,086
	Conventional Brussels sprouts net profit (euro/hectare)	5,658
	Organic Brussels sprouts net profit (euro/hectare)	10,528
	Price (in euro/l *unless specified otherwise)*	
	Chlorantraniliprole (200)	380.00
	Deltamethrin (25)	36.50
	Spinosad (480)	430.00
	Spirotetramat (150)	130.00
	Indoxacarb (euro/kg)	320.00
	Lambda-Cyhalothrin (100)	123.00
	Esfenvaleraat (25)	34.00
	Fluopicolide (63), Propamocarb (524)	19.50
	Azoxystrobin (250)	43.00
	Prothioconazool (480)	146.00
	Azoxystrobin (200)/Difenoconazool (125)	72.00

NOTE: All parameters are from KWIN-AGV 2018 (sections 6.3.9, 6.3.14, 7.3.4 and 7.3.7).

Table 3.2 – Stochastic parameters used to determine the additional costs of applying insect frass

Parameter	Distribution	Measure/Parameter	Reference
Dose of frass (grams/plant)	triangular	1.0, 2.0, 5.0	Doses used in experiments
Price of frass (€/kg)	triangular	1.0, 2.0, 3.0	Price range found online

Additional revenue

As experts expected that frass will reduce the presence of certain pests and diseases not yet addressed by currently used insecticides and fungicides, additional revenue would be generated from less crop loss. PERT distributions were used to represent the averaged lowest, most likely and highest estimates regarding the expected changes in crop yield elicited from the crop advisors.

Reduced revenue

The alternative scenario was not expected to result in any reduced revenues compared to the baseline scenario. Therefore, no reduced revenues were considered in the partial budget.

3.2.4.2 Software implementation

The partial budget was created in Excel version 2102 (Microsoft Corp., Redmond, WA) along with the commercially available Excel add-in software called Palisade @Risk version 8.2 (Palisade Corp., Ithaca, NY). @Risk was used as it is able to assign each input variable a specified distribution. The net change in profit observed when comparing the baseline scenario to the alternative scenario was calculated by subtracting additional costs (the cost of frass) from the additional revenue (the increased crop yield) and reduced costs (the reductions in insecticide and fungicide use). To calculate the additional costs, the dose and price of frass (scenarios represented by triangular distributions) were multiplied by the number of plants planted per hectare (fixed inputs from KWIN; see Table 3.1). To calculate the additional revenue, the change in crop yield (elicited estimations represented by PERT distributions) was multiplied by the crops' baseline yield per hectare and sales price (fixed inputs from KWIN; see Table 3.1). To calculate the reduced costs, the changes in insecticide and fungicide use (elicited estimations represented by PERT distributions) were multiplied by the price and quantity of the products applied in the baseline scenario (fixed inputs from KWIN; see Table 3.1). Using @Risk, the simulation was conducted with one thousand iterations. Sampling was conducted using the Latin Hypercube method to avoid sampling bias (McKay et al., 1979).

The net change in profit was simulated for each type of crop (organic and conventional broccoli and Brussels sprouts) for each of the three years. In total, the net change in profit and a 90% confidence interval was calculated for each of the twelve scenarios. A positive result indicated that the net change in profit is higher in the alternative scenario than in the baseline scenario; whereas a negative result indicated that the net change in profit is lower in the alternative scenario than in the baseline scenario. Applying frass is therefore only financially interesting for a farmer if the net change in profit is positive.

3.3 Results

3.3.1 Results from the frass experts' elicitation

Figure 3.3 provides a summarized quantitative overview of the changes in pest and disease presence as expected by the experts (see Appendix C for a more detailed overview). In the case of the flea beetles and the (large and small) white butterflies, some of the averaged lowest estimates were below zero, which means that it was on average expected that the presence of these pests may increase by a few percent when frass is applied. Regarding the average most likely estimations, frass is expected to reduce the various pests by 0-15% in the first year, 2-20% in year four and 2-23% in year eight and diseases by 9-18% in the first year, 11-23% in year four and 11-24% in year eight. The estimates provided by the experts were said to be primarily extrapolations from field experience and (lab and field) experiments conducted before April 2021 (when the elicitation with frass experts took place). Experts emphasized that due to the shortage of research regarding the effects of insect frass on pests and diseases, it is too early to confidently provide quantitative estimates regarding frass' performance.

A key consideration during the discussion on pests was regarding which of the plant's phytohormonal pathways the pest induces when it feeds on the plant. When the pest feeds on the plant, the plant responds with induced defense that involves the activation of gene expression. In brief, induced gene expression can initiate a direct defense against the pest by triggering the synthesis of defense-related proteins or secondary plant metabolites. Indirectly, it can modify the blend of volatile organic compounds released by the plant, which attracts natural enemies of the pest (Stam et al., 2014). The consensus was that because the mechanism underlying frass' activity involving the stimulation of plant growth-promoting rhizobacteria requires an active jasmonic acid response, then especially jasmonic acid inducing pests would be affected by frass-mediated resistance (Barragán-Fonseca et al., 2022). Jasmonic acid inducing pests discussed in this research include: flea beetles, thrips, cabbage root flies, and the Lepidopteran caterpillars.

For diseases, a key consideration was whether the disease was soil- or leaf-borne. The consensus was that soil-borne diseases would be more directly affected by the microbial changes stimulated by frass. Leaf-borne diseases would be impacted, though indirectly by induced systemic resistance. Soil-borne diseases discussed in this research include: wirestem, phoma leaf spot and clubroot.

Frass experts were also asked to estimate by how much crop yield is expected to change when applying insect frass as a crop and soil health promoter (compared to not applying frass). Figure 3.4 provides a quantitative summary overview of the expected change in crop yield

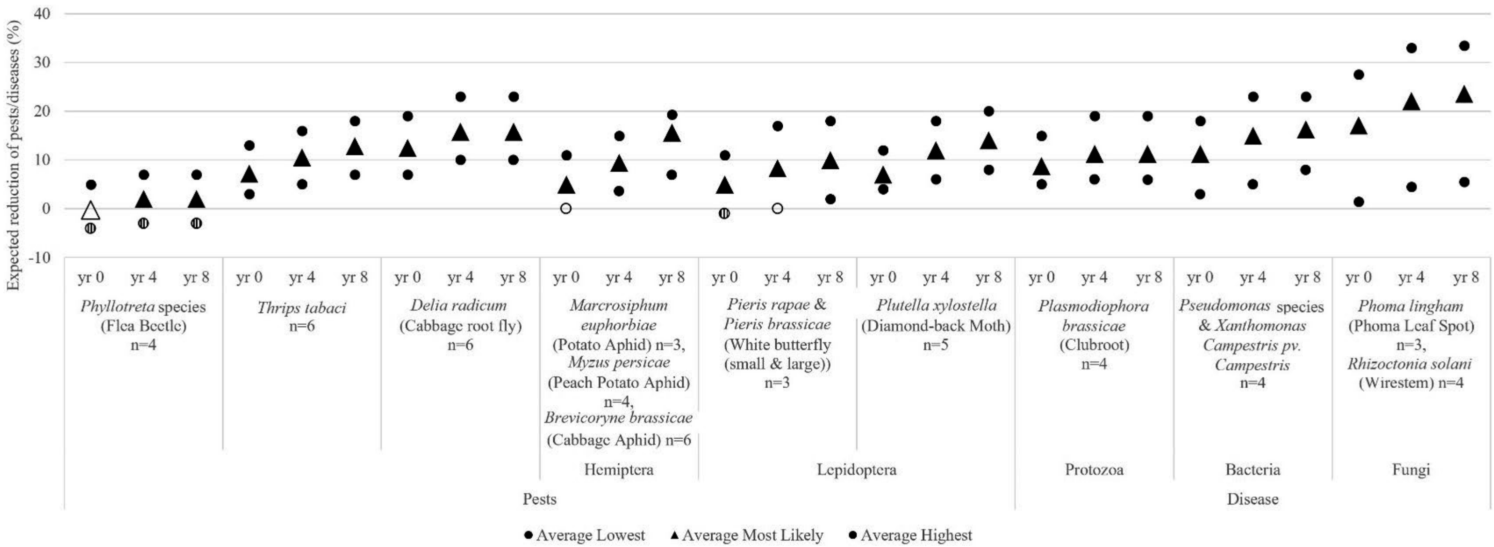

Figure 3.3 – Expected reduction of pests and diseases common in Brassica production when applying insect frass compared to no frass application

Zero percent (transparent fill) indicates that frass is not expected to increase nor decrease the presence of the pest or disease. A negative percentage (vertical line fill) indicates that frass is expected to increase the presence of the pest disease. Circles represent the averaged upper and lower bounds of the estimates; triangles represent the averaged most likely estimates. For each pest and disease, there is an " n=" number provided. This number indicates how many experts were willing to provide an estimation for each particular pest and disease.

Pests and diseases with estimations provided by three or more experts are included in the graph above. The following pests and diseases were omitted from this overview but can be found in Appendix C: Aleyrodes proletella (Cabbage White Fly), Autographa gamma (Silver Y Moth), Mamestra brassicae (Cabbage Moth), Agrotis segetum (Cutworm-Turnip Moth), Evergestis forficalis (Garden Pebble Moth), Mycosphaerella brassicicola (Ringspot), Alternaria brassicae & A. brassicicola (Dark Leaf Spot), Erysiphe cruciferarum (Powdery mildew), Pyrenopeziza brassicae (Light Leaf Spot), Hyaloperonospora brassicae (Downy mildew) and Albugo candida (White blister/rust).

(see Appendix D for a more detailed overview). The frass experts discussed yield in terms of organic versus conventional production and estimated the yield to most likely improve by between 8-13% in either system.

3.3.2 Results from the expert elicitation with crop advisors

The crop advisors discussed yield differences between organic and conventional broccoli and Brussels sprouts production (see Figure 3.4 and Appendix D for a more detailed overview). They posited that frass would improve conventional broccoli yield more than conventional Brussels sprouts. This is because, compared to broccoli, Brussels sprouts is a more challenging crop in terms of its susceptibility to pests and diseases. In addition, crop loss in broccoli can be severe if caterpillars infest and occupy the flowers of the broccoli; their presence deems the broccoli an unconsumable end product, which cannot be sold. If frass can build up the soil's resilience and therefore the plant's natural protection against caterpillars, it can reduce the chance of broccoli loss from caterpillars.

Regarding organic yield, crop advisors expected that Brussels sprouts could experience more improved yields than broccoli. As there are few products allowed to be used in organic Brussels sprouts production, there is a lot of potential gain for frass to reduce the amount of crop loss.

Crop advisors were also asked to estimate by how much insecticide and fungicide use and crop yield is expected to change when applying insect frass as a crop and soil health promoter (compared to not applying frass). Figure 3.5 provides a quantitative summary overview of the expected changes in insecticide and fungicide use (see Appendix E for a more detailed table overview). The use of insecticides and fungicides in organic and conventional broccoli

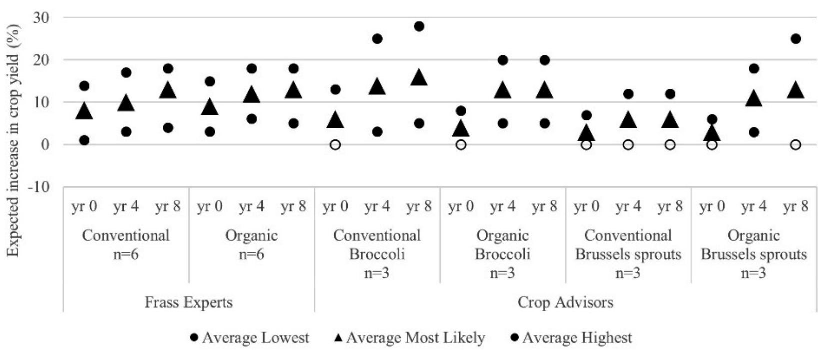

Figure 3.4 – Expected increase in Brassica crop yield when applying insect frass compared to no frass application

Zero percent (transparent fill) indicates that frass is not expected to increase nor decrease crop yield. Circles represent the averaged upper and lower bounds of the estimates; triangles represent the averaged most likely estimates. The "n=" number provided indicates how many experts were willing to provide an estimation for each type of crop yield. Note, all of the participating experts provided estimations for crop yield.

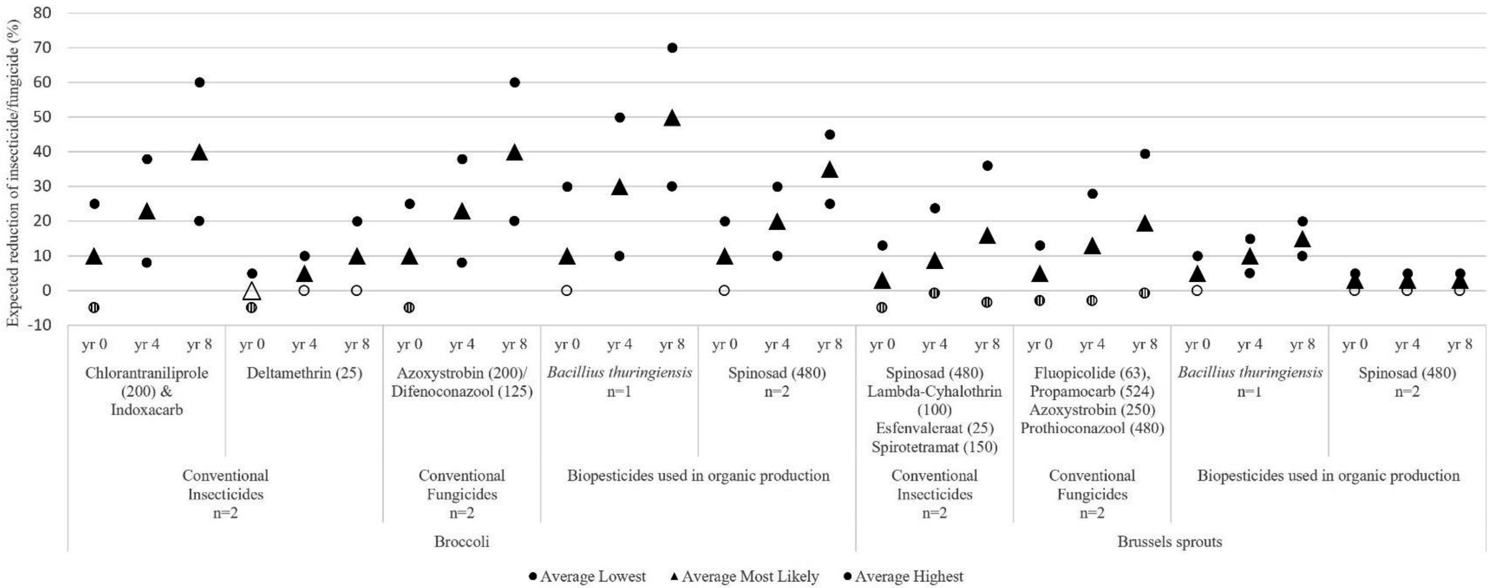

Figure 3.5 - Expected change in insecticide and fungicide applications for Brassica production when applying insect frass compared to no frass application

Zero percent (transparent fill) indicates that frass is not expected to increase nor decrease the quantity of the insecticide or fungicide applied. A negative percentage (vertical line fill) indicates that frass is expected to increase the quantity of the insecticide or fungicide applied. Circles represent the averaged upper and lower bounds of the estimates; triangles represent the averaged most likely estimates. The " n=" number provided indicates how many experts were willing to provide an estimation for each insecticide and fungicide.

production was expected to be reduced more than in Brussels sprouts production (with the exception of Deltamethrin (25) in conventional broccoli production). The crop advisors emphasized, if frass were able to delay the development of pests or diseases, it would have the most potential to reduce the use of pesticides in broccoli than in Brussels sprouts because broccoli spends less time on the field and therefore has less chance of infestation or infection. Therefore, the chance that frass can delay the onset of pests and diseases in broccoli long enough to reduce the need for future pesticide treatments is greater than for Brussels sprouts.

3.3.3 Results from the economic model

Figure 3.6a depicts the net change in profit in conventional and organic broccoli and Brussels sprouts production in years 0, 4 and 8. Figure 3.6b shows the net change in profit divided by the profit obtained in the baseline scenario (provided in Table 3.1). The shaded bars indicate the expected net change in profit per hectare. For each shaded bar, an error bar is also drawn from percentiles 5% and 95% thus indicating the net change in profit with 90% certainty. The length of the error bars is primarily attributed to frass' expected influence on crop yield as was determined in the sensitivity analysis. See Appendix F for a graphical example of the sensitivity analysis.

Figures 3.6a and 3.6b show that the expected net change in profit in the alternative scenario for each form of production is positive, which implies that using insect frass in combination with the various organic and conventional pesticides results in a higher net profit than a normal production system that does not utilize frass. However, considering the confidence intervals, the first year in which frass is used has a chance of returning a negative net profit in three of the four production types. Over time, however, the use of frass is expected to return positive a net change in profit (also at a 90% confidence interval), which is consistent with the expectation that the effects of frass will improve over time.

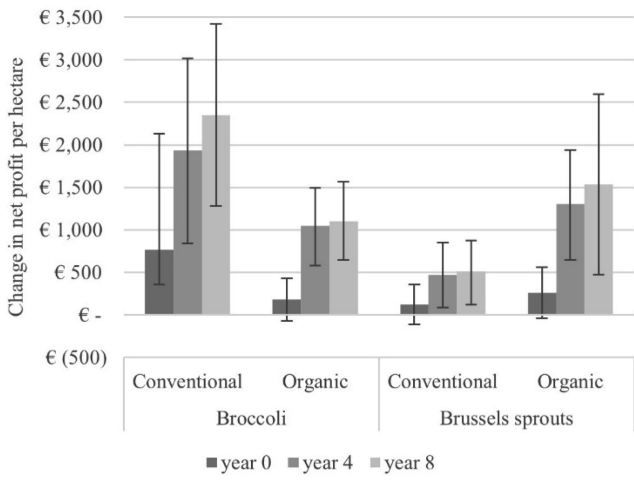

Figure 3.6a – Net change in profit per hectare with frass application compared to no frass application

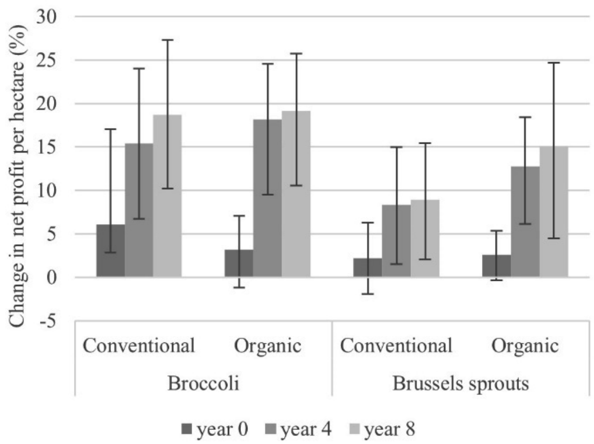

Figure 3.6b – Percent net change in profit per hectare with frass application compared to no frass application
The figures detail the net change in profit and net change in percent profit farmers can expect for each type of production across eight years when applying insect frass compared to when not applying frass. For each shaded bar, an error bar is also drawn from percentiles 5% and 95% thus indicating the net change in profit with 90% certainty. The length of the error bars is primarily attributed to frass' expected influence on crop yield as was determined in the sensitivity analysis. See Appendix F for a graphical example of the sensitivity analysis.

Broccoli

Figure 3.6a shows that the net change in profit when adding frass in conventional broccoli production is about double of that in organic production. Figure 3.6b shows that, in terms of change in percent profit, organic and conventional broccoli production are comparable. Granted, the first year of organic production can return a negative profit based on the 90% confidence interval. The differences between organic and conventional production can be mostly attributed to the difference in crop yield obtained in the baseline scenario. Conventional producers harvest about €15,000 worth of broccoli per hectare; organic producers harvest about €9,000 worth of broccoli per hectare. Therefore, a percent increase in yield has a larger relative impact on profit for conventional production than in organic production. It is useful to note that though frass is expected to influence the amounts of insecticides and fungicides used, financially, the impact of these reductions is minor compared to the financial influence of increasing crop yield.

Brussels sprouts

Figure 3.6a and 3.6b show that, in the first year, the net change in profit in Brussels sprouts is comparable between conventional and organic production. By years 4 and 8, the net change in profit is more than double for organic production (see Figure 3.6a). A few variables explain these trends. Though conventional Brussels sprouts obtains almost three times the crop yield than in organic production, organic producers receive almost four times the sales price per kilogram of sprouts. Notably also, conventional producers have higher costs in insecticides and fungicides than organic producers (KWIN-AGV, 2018). Therefore, though crop advisors expect that yield will increase in year 0 by 3% in both conventional and organic, the net change in profit is slightly higher in organic production.

Worst-case scenario

For a complete overview, we also present the worst-case scenario. The worst-case scenario was calculated by utilizing the following inputs: (1) the highest dose scenario (five grams of frass per plant), (2) the highest price scenario of frass (€3.00 per kg), and (3) the most pessimistic estimates provided by any of the experts.

Depending on the type of production and the year, the worst-case scenario can result in a net profit loss of €-592 to €-485 per hectare (see Table 3.3). At a dose of five grams of frass per plant and at €3.00 per kilogram of frass, the cost of purchasing frass for one hectare of land is €500 for Brussels sprouts and €570 for broccoli. Note, more broccoli is planted per hectare than Brussels sprouts (38,000 versus 33,300 plants), and therefore more kilograms of frass would be applied to one hectare of broccoli than one hectare of Brussels sprouts. Therefore, much of the loss shown in Table 3.3 can be attributed to the purchase price of frass.

Table 3.3 - Worst-case scenario - net change in profit per hectare

	Broccoli		Brussels sprouts	
	Conventional	Organic	Conventional	Organic
year 0	€ -592	€ -570	€ -547	€ -500
year 4	€ -580	€ -555	€ -520	€ -492
year 8	€ -590	€ -526	€ -559	€ -485

3.4 Discussion

Frass is found to have potential as a crop and soil health promoter. For arable farmers to make a switch to using frass instead of more conventional pesticides, it should be financially feasible to make this switch. Via a series of expert elicitations, the objective of this research was to estimate the net change in profit that arable farmers can expect by adding insect frass to their array of crop and soil health promoters in *Brassica* production. By fulfilling the research objective, this research makes the first attempt at quantifying the economic contribution that insect frass could deliver as a crop and soil health promoter. Such estimations are also an important first step for communicating the frass' potential as a circular agricultural input. Innovative solutions for recycling by-products in agriculture are needed for making the sector more circular. Insect frass is one such solution – connecting insect rearing with arable farming.

The results of this research show that insect frass is expected to generate a positive net change in profit for farmers. This finding aligns with that of Tanga et al. (2022), though notably they investigated frass' economic potential as fertilizer, not as a health promoter. Their results show that, in addition to mineral fertilizer, the frass treatment resulted in the highest maize yield and highest economic returns.

More specifically, the results of this research show that, when integrating frass as a crop and soil health promoter, conventional broccoli is expected to return the highest net change in profit. One reason is because the frass could reduce the amount of crop lost to caterpillars; damage resulting from caterpillars on average renders crops unsellable. The frass experts posited that frass will most likely reduce the presence of caterpillars (Lepidoptera) by 5-14% after eight years. Furthermore, the crop advisors estimated that after eight years insecticide use in conventional broccoli would most likely reduce between 0-40%, and the crop yield would most likely improve by 6-16%. Additionally, according to frass experts, frass can delay the onset of (especially soil-borne) diseases most likely by 9-24% after eight years. Crop advisors therefore anticipated that the fungicides used in the broccoli would be reduced between 10-40% after eight years.

The lowest net change in profit when integrating frass as a crop and soil health promoter is expected to be experienced in conventional Brussels sprouts. Its longer time spent on the field makes it more susceptible to pest infestations or diseases. Because frass would be applied at the time of planting (Torgerson et al., 2021), the chance it can reduce the need for late-season pesticide applications in Brussels sprouts is less compared to broccoli. Also, in a 'normal' and representative year, little of the conventional Brussels sprouts crop is lost, especially compared to organic production. Of the 33,300 plants planted per hectare in both systems, organic producers harvest 9,000 kg of sprouts whereas conventional producers harvest 25,000 kg. The higher yields achieved in conventional production can be attributed to the difference in pesticide allowance between the two systems. As there is little room for frass to improve the crop yields in conventional production, crop advisors expect a most likely increase in yield between 3-6% after eight years. Therefore, conventional Brussels sprouts is expected to return the least net change in profit when applying frass compared to not applying frass.

Therefore, the results suggest that frass can potentially be most beneficial when applied in types of production that are on the field for shorter lengths of time and are susceptible to late season pests or diseases that are addressed by frass (i.e., pests that induce jasmonic acid pathways and soil-borne diseases). In addition, the results also suggest that by years four and eight, the net change in profit is estimated to improve by more than 2.5 times in conventional production and by more than 5 times in organic. The improvement over time is mainly due to the functionalities of frass and its influence on the microbial communities in the soil. As farmers' use of chemical pesticides reduces and the populations of natural enemies begin to build-up in the soil, more beneficial effects of frass can be expected. Therefore, it takes time for the soil's environment to become optimal.

The uncertainty of applying frass, especially in the first year, should be considered. With the exception of conventional broccoli, in the first year of applying frass, potentially the net change in profit can be positive or negative. As shown in the sensitivity analysis (presented in Appendix F), the amount of uncertainty behind frass' influence on crop yield accounts for much of the error bar. More research that specifically investigates frass' influence on crop yield would be useful in reducing the uncertainty behind these findings.

For farmers to make a decision regarding whether or not to trial frass, they may rely on various decision tools. For example, for the more risk averse farmers, decisions on using new products may be based on the worst-case scenario – a safety first approach (Kay et al., 2012). The worst-case scenario for using frass could result in a net loss in profit of €500 to €600 per hectare. If the worst-case scenario occurred on the trial plot, the farmer could face a profit loss of between 5% (in conventional broccoli and organic Brussels sprouts) and 10% (in organic broccoli and conventional Brussels sprouts). For this reason, a risk averse farmer, may not be willing to trial insect frass. However, farmers that make decisions based on the option with the highest, most likely outcome would be more likely to trial the frass.

For those that would choose to trial frass, the first year applying it may also require some learning-by-doing experience from the farmer. For instance, frass can only be effective if the farmer bases pesticide applications on what is observed and determined as necessary during monitoring and not based on a strict spraying schedule. It is critical that the farmer is conscious of how frass is expected to perform. For example, knowing which pests and diseases it is expected to deter and knowing what parasitoids it is expected to be able to recruit would be required to monitor the crop effectively. With this awareness, the farmer can possibly eliminate later applications or act in instances when the frass is not performing as expected.

The economic insights provided in this study can help demonstrate frass' potential as a circular agricultural input also for policy development. In November 2021, the EU implemented a policy that standardized frass' processing procedure and permitted its use as an organic fertilizer (European Commission, 2021). This research along with the continual inflow of new evidence regarding frass' effectiveness against various pests and diseases can be used to build a case for insect frass achieving more relevant and specified legislation that permits its use as an input on crop land.

3.4.1 Limitations, practical considerations and future research

This research makes a first attempt at valuing frass as a crop and soil health promoter, which required making numerous decisions. For example, we focused on broccoli and Brussel sprouts, but the effects of frass may be even more valuable in other sectors like tree nurseries or greenhouse vegetables. We also made assumptions in this research that the weather conditions are ideal, and the soil type is clay. Modifying these assumptions would be expected to influence frass' effectiveness. Alternative types of cropping systems, like applying frass in strip cropping, may also influence its effectiveness. Furthermore, future research should explore the effects of frass under alternative assumptions.

Additionally, we did not account for increased or reduced labor needs. As the proposed doses of frass were all less than two hundred kilograms per hectare, such quantities could be applied in the same pass as planting. However, if frass must be applied in a way that does not coincide with the planting equipment and requires an additional application, additional costs related to, for example, labor and fuel should be accounted for. Similarly, if frass eliminates any late season sprays, reduced costs of the same variables should also be accounted for. Though the costs of labor could have a considerable influence on the net change in profit, it was not included as there is not enough information available regarding how frass would be applied and the mechanical implications of its distribution on the field. Once further research has specified how frass should be applied, the respective labor costs should be accounted for.

Reduced costs due to frass reducing the amounts of compost applied were not considered. Compared to spreading manure or composts (>50 tons/hectare), the contribution of frass in the doses considered is relatively small (<0.2 tons/hectare). As such, the organic matter contribution of frass would have a negligible influence on the amount of compost would apply in a 'normal' and representative year.

The costs and revenues associated with utilizing insect frass throughout each year of the crop rotation were not estimated. Though it would be ideal to make such a calculation for an entire crop rotation, there is currently not enough known regarding frass' performance in other crops to do so.

In this research, we discuss insect frass generally. However, frass can vary in terms of the insect species reared or the feed the insects are reared on. Furthermore, some specific components of frass (e.g., the shed skins known as exuviae) show even more promising health promotion effects (Barragán-Fonseca et al., 2022). All of these factors could have an influence on the performance of frass as a crop and soil health promoter. Once there is more understanding of how these components affect frass' performance, an economic feasibility should be conducted to understand their respective financial consequences.

It was assumed in this research that frass would be available in the required quantities. If frass is deemed economically attractive in more forms of production, its availability may come into question. As the insect sector grows, more frass will be generated. However, if the demand for the frass grows faster than the industry can supply, the price of frass may increase and become unfeasible as an input in some forms of production.

Finally, the construction and interpretation of the resulting net changes in profit rely on the estimations elicited from both the frass experts and the crop advisors. Interpretations of the results should therefore be made under the consideration of the limitations faced by the frass experts (e.g., extrapolating their knowledge from field experience and early research trials) and crop advisors (e.g., combining estimations from frass experts with their own experience with comparable products). To confirm the results of this research, on farm trials should be conducted from planting to harvesting that measure pests, diseases, parasitoids and crop yield. Trials that investigate the effects in complete crop rotations over several years would also be required to validate the expected time-related improvements suggested in this research.

3.5 Conclusion

This research relied on experts' knowledge to estimate the net change in profit farmers can expect when using insect frass as a crop and soil health promoter in various types of *Brassica* production. We conclude that frass is expected to be economically justifiable, even attractive over the years, for farmers. While reducing the need for alternative chemical pesticides, frass could contribute to improved soil life and quality. Doing so facilitates balanced, steady and efficient plant growth and contributes to the plant's systemic resistance to pests and diseases. Granted, frass will only perform for farmers that will implement it correctly in a crop monitoring scheme. The way towards sustainable food production in the future will require the abandonment of predetermined spraying regimens and the implementation of monitoring crops and reacting accordingly. In this way, chemical pesticides can be substituted for more sustainable inputs, and in the case of insect frass, they can be substituted for more circular inputs. Thus, insect frass offers a win-win situation for arable farmers, who would be expected to achieve higher profits while using less chemical inputs, and for society as agriculture makes another step towards becoming more circular.

3.6 Acknowledgements

We would like to sincerely thank the following experts who contributed their time and expertise to this study: Derk van Balen, Katherine Barragán-Fonseca, Marcel Dicke, Joop van Loon, Azkia Nurfikari, Max Wantulla, Els van de Zande, as well as the other experts who preferred to remain anonymous. We also walk to thank Prof. Marcel Dicke and Prof. Alfons Oude Lansink for providing feedback on earlier versions of manuscript.

Experts who participated agreed to the research conduct by signing informed consent forms. This work was supported by the Dutch Research Council NWO [grant number ALWGK.2016.010].

Appendix A – Pests, diseases, insecticides and fungicides addressed in this research

Table A1 - Pests and diseases of common in Brassica production

Order	Common name of pest	Scientific name
Lepidoptera	White butterfly – large	*Pieris brassicae*
	White butterfly – small	*Pieris rapae*
	Diamond-back moth	*Plutella xylostella*
	Garden pebble moth	*Evergestis forficalis*
	Cutworm – turnip moth	*Agrotis segetum*
	Cabbage moth	*Mamestra brassicae*
	Silver Y moth	*Autographa gamma*
Diptera	Cabbage root fly	*Delia radicum*
Coleoptera	Flea beetles	*Phyllotreta* species
Hemiptera	Potato aphid	*Macrosiphum euphorbiae*
	Cabbage aphid	*Brevicoryne brassicae*
	Peach-potato aphid	*Myzus persicae*
	Cabbage whitefly	*Aleyrodes proletella*
Thysanoptera	Thrips	*Thrips tabaci*

Kingdom	Common name of disease	Scientific name
Fungi	Wirestem	*Rhizoctonia solani*
	Ringspot	*Mycosphaerella brassicicola*
	Phoma leaf spot/Canker	*Phoma lingham*
	Dark leaf spot	*Alternaria brassicae & Alternaria brassicicola*
	Powdery mildew	*Erysiphe cruciferarum*
	Light leaf spot	*Pyrenopeziza brassicae*
Bacteria	Spear rot	*Pseudomonas* species
	Xanthomonas black rot	*Xanthomonas campestris pv. campestris*
SAR[a]	Downy mildew	*Hyaloperonospora brassicae*
	White blister (white rust)	*Albugo candida*
	Clubroot	*Plasmodiophora brassicae*

[a] *SAR: Stramenopiles, Alveolates, and Rhizaria*

Table A2a – Overview of pests, insecticides and active ingredients

Active chemical ingredient	Chemical insecticides	Pests
Deltamethrin (25)	Desect Spray Luxan Delete Luxan Delete Spray Desect Omni Insect -- Decis Protech Decis Imex-Deltamethrin E.C. 25	*Phyllotreta* species *Brevicoryne brassicae* *Macrosiphum euphorbiae* *Myzus persicae* -- *Autographa gamma* *Pieris brassicae* *Pieris rapae* *Evergestis forficalis*
Chlorantraniliprole (200)	APN chlorantraniliprole 200 SC Coragen Voliam WOPRO Insect-weg	*Mamestra brassicae* *Pieris brassicae* *Pieris rapae* *Evergestis forficalis* *Plutella xylostella*
Spirotetramat (150)	Batavia Movento	*Aleyrodes proletella* *Brevicoryne brassicae*
Indoxacarb	Steward	*Mamestra brassicae* *Pieris brassicae* *Pieris rapae* *Evergestis forficalis* *Plutella xylostella*
Lambda-Cyhalothrin (100)	Insect Plus Insect Plus Concentraat Insect-Ex Concentraat Insect-Ex Kant en Klaar Karate Garden Karate Garden Spray -- Goldorak Karate Zeon Ninja	*Aleyrodes proletella* *Brevicoryne brassicae* *Macrosiphum euphorbiae* *Myzus persicae* *Thrips tabaci* -- *Pieris brassicae* *Pieris rapae* *Plutella xylostella* *Thrips tabaci*
Spinosad (480)	Tracer	*Mamestra brassicae* *Pieris rapae* *Plutella xylostella*
Esfenvaleraat (25)	Sumi-Alpha 2.5 EC Sumicidin Super	*Mamestra brassicae* *Pieris brassicae* *Pieris rapae* *Plutella xylostella*

Table A2b – Overview of diseases, fungicides and active ingredients

Active chemical ingredient	Chemical fungicides	Diseases
Azoxystrobin (200)/Difenoconazool (125)	Amistar Top	*Alternaria brassicae* *Alternaria brassicicola* *Mycosphaerella brassicicola* *Albugo candida* *Erysiphe cruciferarum*
Azoxystrobin (250)	Dynasty	*Phoma lingham* *Pyrenopeziza brassicae* *Rhizoctonia solani* *Alternaria brassicae* *Alternaria brassicicola* *Mycosphaerella brassicicola* *Albugo candida* *Erysiphe cruciferarum*
	--	--
	Ortiva Amiplus Azoxystrobin Amistar Globaztar AZT 250 SC Mirador Profi AZ 250 SC Zakeo 250 SC	*Alternaria brassicae* *Alternaria brassicicola* *Mycosphaerella brassicicola* *Albugo candida* *Erysiphe cruciferarum*
Fluopicolide (63), Propamocarb (524)	Infinito Matix	*Albugo candida*
Prothioconazool (480)	Rudis	*Mycosphaerella brassicicola*

Appendix B – Example questionnaire used during the group discussion with insect frass experts

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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	
Upper Bound of Range	
Best Estimation	

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

Lower Bound of Range	
Upper Bound of Range	
Best Estimation	

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

Lower Bound of Range	
Upper Bound of Range	
Best Estimation	

Submit

Appendix C – Insect frass experts' expectations for frass' performance in reducing pests and diseases

Table C1 - Expected reduction in pest and disease presence when applying insect frass compared to no frass application

Pests	Nr. of experts	Year 0	Year 4	Year 8
Lepidoptera				
Pieris brassicae	3	-0.01, 0.05, 0.11	0.00, 0.08, 0.17	0.02, 0.10, 0.18
Pieris rapae	3	-0.01, 0.05, 0.11	0.00, 0.08, 0.17	0.02, 0.10, 0.18
Plutella xylostella	5	0.04, 0.07, 0.12	0.06, 0.12, 0.18	0.08, 0.14, 0.20
Mamestra brassicae	2	0.04, 0.08, 0.11	0.05, 0.13, 0.20	0.08, 0.15, 0.23
Evergestis forficalis	1	0.10, 0.15, 0.20	0.10, 0.20, 0.30	0.10, 0.20, 0.30
Agrotis segetum	1	0.10, 0.15, 0.20	0.10, 0.20, 0.30	0.10, 0.20, 0.30
Autographa gamma	1	0.10, 0.15, 0.20	0.10, 0.20, 0.30	0.10, 0.20, 0.30
Hemiptera				
Macrosiphum euphorbiae	3	-0.02, 0.04, 0.10	0.03, 0.09, 0.15	0.07, 0.16, 0.20
Brevicoryne brassicae	6	0.02, 0.06, 0.12	0.05, 0.10, 0.15	0.07, 0.15, 0.19
Myzus persicae	4	0.00, 0.05, 0.11	0.03, 0.09, 0.15	0.07, 0.16, 0.19
Aleyrodes proletella	2	0.05, 0.13, 0.20	0.13, 0.15, 0.20	0.18, 0.23, 0.28
Other				
Delia radicum	6	0.07, 0.13, 0.19	0.10, 0.16, 0.23	0.10, 0.16, 0.23
Phyllotreta sp.	4	-0.04, 0.00, 0.05	-0.03, 0.02, 0.07	-0.03, 0.02, 0.07
Thrips tabaci	6	0.03, 0.07, 0.13	0.05, 0.11, 0.16	0.07, 0.13, 0.18
Diseases				
Fungi				
Rhizoctonia solani	3	0.03, 0.18, 0.28	0.06, 0.23, 0.33	0.08, 0.24, 0.34
Phoma lingham	3	0.00, 0.17, 0.27	0.03, 0.22, 0.33	0.03, 0.23, 0.33
Alternaria brassicae & *Alternaria brassicicola*	2	-0.05, 0.18, 0.30	-0.05, 0.20, 0.35	-0.03, 0.20, 0.35
Mycosphaerella brassicicola	1	0.10, 0.15, 0.20	0.10, 0.20, 0.30	0.15, 0.20, 0.30
Erysiphe cruciferarum	1	0.10, 0.15, 0.20	0.10, 0.20, 0.30	0.15, 0.20, 0.30
Pyrenopeziza brassicae	1	0.10, 0.15, 0.20	0.10, 0.20, 0.30	0.15, 0.20, 0.30
Bacteria				
Pseudomonas sp.	4	0.03, 0.11, 0.18	0.05, 0.15, 0.23	0.08, 0.16, 0.23
Xanthomonas campestris pv. campestris	4	0.03, 0.11, 0.18	0.05, 0.15, 0.23	0.08, 0.16, 0.23
SAR [a]				
Hyaloperonospora brassicae	2	0.05, 0.10, 0.20	0.10, 0.18, 0.20	0.15, 0.20, 0.25
Albugo candida	2	0.10, 0.13, 0.20	0.13, 0.18, 0.23	0.18, 0.20, 0.28
Plasmodiophora brassicae	4	0.05, 0.09, 0.15	0.06, 0.11, 0.19	0.06, 0.11, 0.19

[a] *SAR – Stramenopiles, Alveolates, and Rhizaria*

The table provides three estimates per year: average lowest estimate, average most likely estimate, average highest estimate. The estimates in the table are listed as percentages. For example, 0.05 translates to a 5% reduction of the pest or disease. A negative value means that the presence of the pest or disease is expected to increase when applying insect frass. A positive value means that the presence will decrease the presence of the pest or disease.

Experts voluntarily provided estimations. As such, not all experts were comfortable providing estimations for all pests and diseases. The column "Nr. of experts" specifies how many of the six experts provided estimations for the given pest or disease.

Table C2 - Justifications for frass performance estimations regarding pests and disease

Take home message - Pests	**Discussion points**
Flea beetles are not expected to be affected by frass.	Based on one year of monitoring field research, there was no significant difference in beetle performance except for on a few frass-treated plants where it was a slightly decreased.
Frass is expected to cause a slight reduction of the presence of thrips.	During an accidental thrips infestation, thrips were appearing first on the control plants and later on the frass-treated plants. This may be because thrips induces mainly jasmonic acid pathways.
Frass is not expected to change the populations of Lepidopteran and aphids in the short-term but are expected to be reduced long-term.	In the first year, the parasitization will not be that effective yet because a stable population of parasitoids is needed. As an example, what was seen in recent field experiments was that the aphids and *Plutella* were more present on the frass-treated plants at first; then the recruitment of parasitoids increased on frass-treated plants. Such parasitoid recruitment is expected to be stronger over time. Therefore, in the first year, a positive effect of frass on aphid and Lepidopteran presence is not expected (maybe there is even an increase), but in later years, the parasitoid population is expected to be better established.
The cabbage root fly is not expected to be affected by frass over the long-term.	The bacterial composition or microbiome reverts back between 8 and 16 weeks; it does not buildup over the years. Therefore, it is not expected that the beneficial microbes against *Delia radicum* are stimulated long-term. Also, *Delia* has quite a dispersive range (for kilometers). If *Brassica* crops are located in the region over consecutive years, a resident population could be continuously present and fluctuating over time. Because of this, it matters less what the farmer is doing on other parts of his field (e.g., establishing parasitoid populations), and it matters more what is taking place throughout the whole province. Therefore, a reduction of the *Delia* population is not expected overtime.
Take home message - Diseases	**Discussion points**
Frass will reduce soil-borne diseases more than leaf-borne diseases.	The distinction between soil-borne and leaf-infectious diseases is important. With soil-borne pathogens, there can be direct interactions with the microbes. The effects of the frass are expected to serve as a biocontrol by creating interference of the recruited microbiome directly on the soil-borne pathogens. Soil-borne fungal diseases have chitin in their cell walls, so it is assumed then that this enrichment of chitin degrading microorganisms following the addition of insect frass can have an effect on reducing the population, particularly for *Rhizoctonia*. With leaf-borne pathogens, the effects are more indirect and relate to induced systemic resistance of the plant.
Frass is expected to reduce the presence of *Pseudomonas* and *Xanthomonas*.	*Pseudomonas* and *Xanthomonas* are gammaproteobacteria, which is a group of microbes that were found to be stimulated during early stage of decomposition that happens in insect exuviae or frass. It raises questions whether these bacteria (that causes spear rot or black rot) may also exist while the microbes are stimulated; thus far, it is unknown. Granted, the presence of gammaproteobacteria is temporary; after about four weeks they are gradually replaced by an increasing presence of *Bacillus* - believed to play a major role during this biocontrol of diseases in the soil. The Bacilli would eventually destroy the gammaproteobacteria in approximately eight to sixteen weeks.

Appendix D – Estimations of frass' influence on crop yield and qualitative explanation

Table D1 - Expected increase in Brassica production yield when applying insect frass compared to no frass application

	Nr. of experts	Year 0	Year 4	Year 8
Frass experts				
Conventional production	6	0.01, 0.08, 0.14	0.03, 0.10, 0.17	0.04, 0.13, 0.18
Organic production	6	0.03, 0.09, 0.15	0.06, 0.12, 0.18	0.05, 0.13, 0.18
Crop advisors				
Conventional broccoli	3	0.00, 0.06, 0.13	0.03, 0.14, 0.25	0.05, 0.16, 0.28
Organic broccoli	3	0.00, 0.04, 0.08	0.05, 0.13, 0.20	0.05, 0.13, 0.20
Conventional Brussels sprouts	3	0.00, 0.03, 0.07	0.00, 0.06, 0.12	0.00, 0.06, 0.12
Organic Brussels sprouts	3	0.00, 0.03, 0.06	0.03, 0.11, 0.18	0.00, 0.13, 0.25

The table provides three estimates per year: average lowest estimate, average most likely estimate, average highest estimate. The estimates in the table are listed as percentages. For example, 0.05 translates to a 5% increase in yield. A positive value means that the crop yield is expected to increase with the application of frass.

Experts voluntarily provided estimations. Notably all six frass experts and all three crop advisors provided estimations for frass' expected effects on crop yield (noted in the column "Nr. of experts").

Table D2 - Justifications for frass performance estimations regarding yield

Take home message	Discussion points
Frass will improve organic yields more than conventional.	Frass experts: Organic farmers are more ready to reap the potential benefits of insect frass in the first year(s), especially for those who already depend on and have biological control agents (e.g., microbes or insects) present in the fields. Crop advisors: There is more crop loss in organic than conventional production. With the frass stimulating the bacteria life, potentially less of the organic yield is lost.
Frass will improve conventional yields more than organic.	Frass experts: On conventional fields, more pathogens and pests are completely eradicated in the previous season because of pesticide use. Therefore, from the beginning of each year, conventional farms have the advantage of less pest and disease pressure to cope with. Frass experts: In conventional production, it is assumed that there is lower bacterial diversity and a lower biocontrol agent availability because of their use of pesticides. Therefore, in earlier years, insect frass will not be as effective on conventional farms (compared to on organic farms), but there is a steeper increased effectiveness overtime for conventional farms as they become more dependent on biological control agents and reap more benefits from insect frass. Crop advisors: In organic production, the producers are already increasing the soil life and resilience in other ways. The extra effects that are prompted by frass will therefore be less in organic production.
Frass will only slightly improve conventional yields.	Frass experts: Conventional farm fertilization is already quite optimal, and they achieve high yields; there is no shortness in fertilizer. Though insect frass contains nutritional elements, its main purpose is for better controlling diseases and pests by building up a community of microbes in the soil over time. Crop advisors: Conventional production is already very optimal. Potential conventional yield increases more than 5% would be difficult to achieve.
Frass will improve conventional broccoli yield more than Brussels sprouts.	Crop advisors: A lot of the end product that is lost is because there are caterpillars hiding in it and then it is not a consumable product. The losses can be severe. Crop advisors: In broccoli, if chitin will stimulate and create more bacteria life and in doing so creates more activity in the soil and better mineral uptake by the plant, then the plant develops a better root system and can grow steadier and more efficiently.
Frass will improve organic Brussels sprouts yield more than broccoli.	Crop advisors: Organic Brussels sprouts yield will be more than the yield in broccoli because the growers must throw away a lot more end product due to its quality. There is a lot of room for improvement for reducing crop loss especially when the Bacilli are optimal and can make the plant grow well and in balance.

Appendix E – Estimations of frass' influence on insecticide and fungicide use and qualitative explanation

Table E1 – Stochastic parameters used to model the net profit of applying insect frass as a crop and soil health promoter

Parameter	PERT Distribution Parameters [a]		
	year 0	**year 4**	**year 8**
Broccoli			
Insecticides *Dose reduction (%):*			
Chlorantraniliprole (200)	-0.05, 0.10, 0.25	0.08, 0.23, 0.38	0.20, 0.40, 0.60
Deltamethrin (25)	-0.05, 0.00, 0.05	0.00, 0.05, 0.10	0.00, 0.10, 0.20
Indoxacarb	-0.05, 0.10, 0.25	0.08, 0.23, 0.38	0.20, 0.40, 0.60
Insecticides used in organic production *Dose reduction (%):*			
Bacillus thuringiensis	0.00, 0.10, 0.30	0.10, 0.30, 0.50	0.30, 0.50, 0.70
Tracer (Spinosad)	0.00, 0.10, 0.20	0.10, 0.20, 0.30	0.25, 0.35, 0.45
Fungicides *Dose reduction (%):*			
Azoxystrobin (200)/Difenoconazool (125)	-0.05, 0.10, 0.25	0.08, 0.23, 0.38	0.20, 0.40, 0.60
Brussel sprouts			
Insecticides *Dose reduction (%):*			
Spinosad (480)	-0.05, 0.03, 0.13	0.00, 0.10, 0.25	-0.03, 0.18, 0.38
Spirotetramat (150)	-0.05, 0.03, 0.13	-0.03, 0.05, 0.20	-0.05, 0.10, 0.30
Lambda-Cyhalothrin (100)	-0.05, 0.03, 0.13	0.00, 0.10, 0.25	-0.03, 0.18, 0.38
Esfenvaleraat (25)	-0.05, 0.03, 0.13	0.00, 0.10, 0.25	-0.03, 0.18, 0.38
Insecticides used in organic production *Dose reduction (%):*			
Bacillus thuringiensis	0.00, 0.05, 0.10	0.05, 0.10, 0.15	0.10, 0.15, 0.20
Tracer (Spinosad)	0.00, 0.03, 0.05	0.00, 0.03, 0.05	0.00, 0.03, 0.05
Fungicides *Dose reduction (%):*			
Fluopicolide (63), Propamocarb (524)	-0.03, 0.05, 0.13	-0.03, 0.13, 0.28	0.00, 0.20, 0.40
Azoxystrobin (250)	-0.03, 0.05, 0.13	-0.03, 0.13, 0.28	0.00, 0.20, 0.40
Prothioconazool (480)	-0.03, 0.05, 0.13	-0.03, 0.13, 0.28	-0.03, 0.18, 0.38

[a] *Key: minimum, most likely, maximum*

The error bars indicate the net change in profit at 90% certainty.

The estimates in the table are listed as percentages. For example, 0.05 translates to a 5% reduction of the insecticide or fungicide.

Table E2 - Justifications for frass performance estimations regarding insecticides and fungicides

Take home message - Insecticides	**Discussion points**
Conventional insecticides	The effects in the first year of use will be less than subsequent years because the bacteria must perform several processes before the chitin is usable, and the resilience in the soil requires years to build-up with subsequent applications. If the farmer (especially considering those in conventional systems) only applies pesticides based on a schedule and not based on monitoring, frass is not going to be an effective product. The farmer must be willing to monitor the crop and apply crop protection based on what they see and what they expect to take place.
Organic insecticides	There are few insecticides used in organic broccoli. For instance, Tracer might be used, but it is not a selective insecticide. If farmers use the frass for several years, the Tracer application could be removed in broccoli production. Because organic Brussels sprouts are so difficult to grow, the small amount of Tracer that the farmers may be using cannot be reduced.
Take home message - Fungicides	**Discussion points**
Conventional fungicides	Not many fungicides are used in conventional broccoli. A reduction in fungicides would be expected most for those targeting soilborne diseases, but this will take time, as resilience is built up in the soil overtime; that does not happen in one year. Chitin can stimulate the soil life in a way that makes the plant stronger against fungi.
More affect is expected in reducing fungicides than insecticides.	Frass can be applied to the soil where it can directly affect soil-borne diseases. For diseases like *Albugo candida*, if you had a field with crop residue with the fungi living on it, then the resilience built up in the soil from the frass will make the next proximal parcel of land less susceptible to it.
No fungicides are used in organic broccoli nor Brussels sprouts production.	

Appendix F – Example sensitivity analysis for conventional broccoli (year 4)

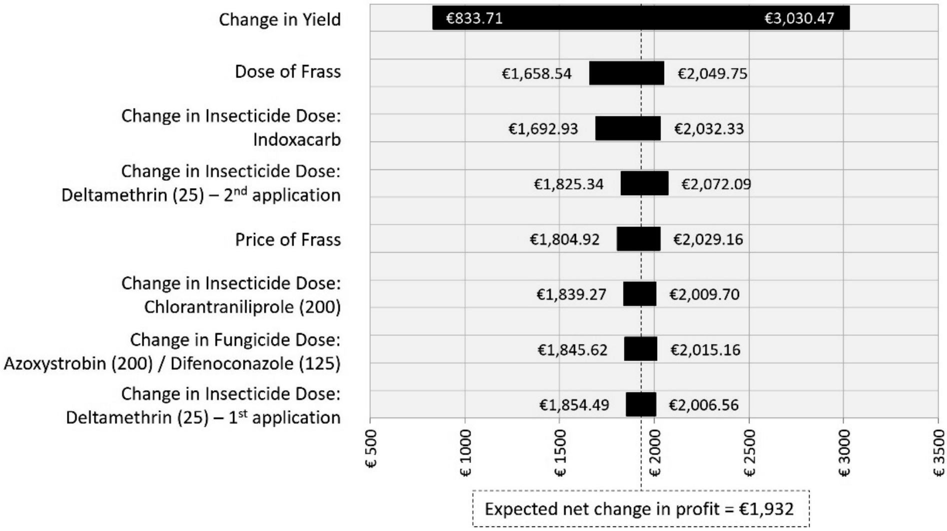

Figure F1 – Example net change in profit input sensitivity (tornado) graph – conventional broccoli (year 4)

Figure F1 shows a tornado graph of conventional broccoli production in year 4 as an example to illustrate the net change in profit's sensitivity to yield. The graph shows to which input variables the uncertainty behind the expected net change in profit can be attributed to. In this example, the expected net change in profit for conventional broccoli (year 4) is €1,932. The x-axis likewise is a scale for the sensitivity of the expected net change in profit. Each stochastic input that was inserted in the model appears on the y-axis. Next to each input is a horizontal bar of varying lengths. The bar indicates how much the expected net change in profit can differ, holding all other inputs constant and varying the one input only. The longer the bar, the more uncertainty it brings into the calculation of the expected net change in profit.

The inputs on the y-axis are ordered from having the most to the least influence on the expected net change in profit. All the tornado graphs generated for each type of production indicated that the change in yield attributes the most uncertainty to the expected net change in profit.

CHAPTER 4

How social contexts influence farmers' decision-making processes: adopting insect by-products for crop and soil health promotion

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Abstract

Innovation adoption research has considered, among countless others, the effects of social influences on adoption behavior. This Means-End Chain research examines how farmers make crop and soil health management decisions and investigates how the social context in which farmers receive and discuss innovation-related information (specifically information on the use of insect by-products as a crop and soil health promoter) can influence their decision-making process. In doing so, this research offers suggestions as to how to effectively promote the adoption of promising innovations, which is crucial for improving soil quality and the future of food production.

The results of this research provide an overview of farmers' decision-making processes regarding the use of crop and soil health promoting products. The results also suggest that farmers who shared their thoughts regarding insect by-products in a group discussion realized less salient considerations, which ultimately influenced the attributes farmers expressed as necessary to achieve their goals. Such a result could stem from the group discussions creating awareness of more relevant aspects to consider in a new crop and soil health promoting product and therefore broadening the farmers' perspectives. Additionally, this research makes an important methodological contribution by conducting a Means-End Chain analysis comparing two groups.

Keywords

means-end chain, hierarchical value map, decision-making process, innovation adoption, group discussions, insect frass

4.1 Introduction

Soil is an invaluable component of sustainable food production in which farmers play a critical role in its management (USDA-NRCS, 2019). Farmers' decisions influence the soil's longevity, fertility and quality that in turn determine its long-term productivity and biodiversity capacity. As politicians and the public have become more aware of the importance of environmentally friendly and sustainable soil management, farmers are pressured to implement and use more sustainable products and practices (National Academies of Sciences Engineering and Medicine, 2017; The Nature Conservancy, 2016). Reliable innovations in crop and soil health promotion and an understanding of how farmers make decisions regarding crop and soil health promoting product selection can be a valuable step towards the long-term preservation of agricultural land.

One crop and soil health promoting innovation is the by-products of insects reared in a production setting – insect manure, undigested feed and shed skins which are collectively referred to as "frass" (Barragán-Fonseca et al., 2022). The crop and soil health promotion aspects are suggested to be caused by the chitin present in the shed skins. The chitin stimulates chitin-degrading microbes in the soil that in turn produce compounds which can be absorbed by the plant and stimulates induced systemic resistance. The induced systemic resistance protects the plant from various above- and belowground pests and diseases (Bai, 2015; Debode et al., 2016; Francesca et al., 2015; Gadhave & Gange, 2016; Sharma et al., 2013; Vickerson et al., 2017). Additionally, the frass is composed of organic matter, which contributes to the nutritional needs of the crops and soil (Kebli & Sinaj, 2017; Quilliam et al., 2020; Temple et al., 2013; Vickerson et al., 2017). Ongoing research continues to test the effectiveness of frass as a crop and soil health promoter, though more time is needed to determine its full potential and the most appropriate crop application. If deemed effective, the frass can be repurposed for use on arable farms in a way that adds value to the soil and contributes to circular agriculture.

Farmers' decision-making processes can be investigated using Means-End Chain (MEC) theory. MEC theory was originally based on personal construct psychology (Kelly, 1955) and was further developed by Gutman (1982) and Reynolds and Olson (2001). To map a decision-making process, the theory links together means to ends with three types of constructs: attributes (product characteristics), consequences (expected outcomes from using a product), and values (personal goals). Attributes are sought to reach various consequences; consequences ultimately play a role in achieving values. The line of reasoning between constructs (from an attribute to a value) is called a ladder. Ladders are compiled from a sample population and visually presented in a map known as a hierarchal value map (HVM).

Though the MEC approach is more readily applied in consumer decision-making research, it has also been applied to farmers' decision-making. For example, in Europe, MEC research has been used to explore farmers' decision-making regarding wetland restoration (Hansson & Kokko, 2018), winery supply chains (Escobar & Gil, 2016), beef and pork production

(Bosmans et al., 2005) and animal welfare (Hansson & Lagerkvist, 2015). More specifically for crop farmers, MEC research was used to investigate herbicide use for grazing in Brazil (de Andréa Picolli et al., 2020), organic practices in Lebanon (Naspetti et al., 2016), biological control adoption in Iran (Abdollahzadeh et al., 2016), soil fertility management and pesticide use in Kenya (Lagerkvist et al., 2012; Lagerkvist et al., 2015; Okello et al., 2014) and sourcing banana planting materials in Uganda (Kilwinger et al., 2020). Applied to the context of this research, the theory assumes that farmers utilize various crop and soil health promoting measures (means) to achieve abstract personal values (end). The resulting HVMs can therefore ultimately serve as a visualization of the reasoning farmers use when selecting crop and soil health promoting products.

To understand farmers' reasoning regarding innovation decisions, it is important to consider the influence of interactions within a social context in which farmers encounter innovation-related information as it plays a role in the formation of their perceptions, attitudes and dispositions (Glover et al., 2019; Katz, 1961; Rogers, 2003; Werner et al., 2008). Specifically in the agricultural context, the influence of social interactions has been studied by, for example, Ambrosius (2021), who investigated how social interactions (and price dynamics) influence organic pig farming in the Netherlands. Beedell and Rehman (2000) determined that farmers' conservation related behavior was influenced by various reference groups. Kaufmann et al. (2009) determined that economic factors and social influence together improve adoption rates of organic farming practices. These previous findings suggest that the social context could influence whether or not farmers adopt products like insect frass. However, literature is lacking an understanding of how the social context could influence the reasoning (or the decision-making process) behind an adoption decision.

The objective of this research was two-fold. The first objective was to envisage farmers' reasoning regarding their use of innovations like insect frass by utilizing the MEC approach to visualize farmers' decision-making processes regarding crop and soil health promoting products. The second objective was to contribute to the understanding of a social context's influence on decision-making processes by comparing HVMs of farmers who discussed their first impressions of frass amongst a group of farmers to the HVMs of farmers who were not given the opportunity to discuss the innovation in a group. More specifically, this research addresses the questions: what is the decision-making process farmers implement regarding the selection of crop and soil health promoting products? How does the decision-making process differ between farmers who discuss their first impressions of frass with other farmers and farmers who do not? If there is a difference, what are the potential implications for the dissemination of circular crop and soil health promoting innovations like insect frass?

MEC research has been subject to criticism regarding its lack of standardized analysis methods. Kilwinger and van Dam (2021) revisited some of the most relevant concerns relating to MEC analysis. To address some of the concerns raised and improve the transparency and quality of MEC analysis methods, this research (1) calculates the percentage of data retained in the HVMs under varying assumptions, (2) investigates the output generated from coding on different levels of abstraction, (3) visually integrates direct and indirect relationships between constructs in the HVMs, and (4) analyses MEC using the state-of-the-art MEC Analysis Tool (Foolen-Torgerson & Kilwinger, 2021). We also perform a novel MEC analysis by comparing the HVMs of two groups under differing conditions.

4.2 Methods

4.2.1 Research design

To investigate if and how altering social contexts influences farmers' decision-making processes, farmers were split into two groups: the group with a social context where farmers participated in group discussions with other farmers (Group A) or the group without a social context where no group discussions were organized (Group B). Farmers in both groups were presented with an informational video about frass. The video was produced based on the findings of Torgerson et al. (2021) and presented (1) what insect frass is, (2) how it promotes the health of crops and soil, and (3) how farmers should apply it. The video encompassed the three types of knowledge according to Rogers' Innovation Decision Process – awareness, how-to and principles knowledge (Rogers, 2003). The informational video with English subtitles can be viewed using this link: https://youtu.be/s4Y4t7uQo0s.

Farmers in Group A watched the video in a group setting. Afterwards, Group A participated in discussions that facilitated sharing their first impressions of frass. To do this, farmers were asked to share (by writing down) their general impressions, opinions and concerns regarding frass and then discuss them with the group. The written notes were arranged on a chart in three categories: advantages, disadvantages and concerns. The three most frequently discussed topics included what the expected costs and associated profitability were regarding frass' use, how easy to use and applicable frass is on their farms, and because the use frass as a crop and soil health promoter is new and currently lacks evidence of its effectiveness, there can be significant consequences for farmers who try to use it. More generally speaking, the groups most often reached the conclusion that as long as frass eventually works as it is supposed to, is cost effective, and addresses their remaining concerns, they would be open to trialing it on their farms. See Appendix A for an overview the advantages, concerns and disadvantages raised during the six group discussions. Farmers in Group B received the informational video via an e-mailed link and were asked to watch it individually.

After having watched the video and (for Group A) participating in a group discussion, all farmers participated in an interview. Figure 4.1 presents a schematic overview of the research design.

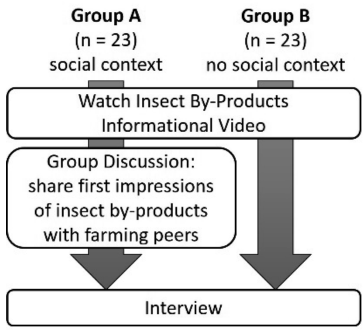

Figure 4.1 - Research design

4.2.2 Interviews

Two research assistants underwent training prior to conducting the interviews. The training (1) explained the theoretical background of the MEC approach, (2) provided an overview of the logistical conduct of laddering interviews and advice for handling more challenging interviews, and (3) facilitated mock interviews. Most of the interviews were conducted face-to-face at the farmer's residence or farm office. However, due to the COVID-19 pandemic restrictions, the last five interviews were conducted online using Microsoft Teams. The interviews took place within sixteen days after the farmers had initially watched the informational video. The timespan varied depending on when contact details could be acquired and the farmer's availability.

During the interview, the farmers were informed of the goals of the research, presented with an informed consent and were asked for permission to audio record; all agreed. The farmers were also asked if they would like to re-watch the informational video; most of whom did. Farmers in Group A were reminded of the general conclusions (advantages, disadvantages and concerns) from the specific group discussion they had participated in.

The interview was split into two parts: attribute elicitation followed by soft-laddering.

Attribute elicitation

The interviews began by generating a list of the crop and soil health promoting products that the farmer had used within the last five years. A range of five years was useful in understanding farmers' motivations for using products they had recent and past experience with including those that are now banned from the marketplace (e.g., neonicotinoids). A two-step approach was used to combine salient products – ones that come most quickly to mind – with the benefits of a pre-defined list which aids in more complete recollection. To do this, the farmer was first asked, "What are the products you use to promote the health of your crops and soil?". Then a list of more general crop and soil health promoting products was presented, and the farmer was asked to mark the ones he had used within the last five years. "Insect frass" was also included in the list.

Once a list of products was developed, attributes were elicited. Some examples of attribute elicitation include free, triadic and dyadic sorting, free elicitation, and attribute selection tasks (Landfield, 1971; Reynolds & Olson, 2001). There are pitfalls to each approach; therefore, a combination of elicitation methods is recommended to ensure that key distinctions between products are not missed (Reynolds & Olson, 2001). In this research, we implemented dyadic sorting followed by free elicitation. Dyadic sorting involves presenting two products and asking the participant to make distinctions. Free elicitation elicits the most salient attributes, which are the easiest for participants to recall (van Ittersum et al., 2007). It involves asking participants to indicate product characteristics that they believe are important. One disadvantage of more free elicitation methods is that consequences and values can also be elicited in addition to attributes. Therefore, to avoid confusion, we refer to them as "product characteristics" as opposed to "attributes".

For each product characteristic mentioned, the farmers were asked their preference if they had the choice between two products. For example, the farmer may state that Product A contains organic matter and Product B does not, and if given the choice, the farmer prefers a product that contains organic matter. After generating a list of preferred product characteristics, the next step was to understand how important each one was to the participant. Direct-rating was used to elicit the relevance of an attribute's importance (van Ittersum et al., 2007) and was conducted by asking farmers to rate on a scale from 1 to 5 (unimportant to very important) how important each of the indicated preferred product characteristics were to him if he were to buy a new crop and soil health promoter. The rated characteristics are here forth referred to as Preferred Product Characteristic Ratings (PPCR).

Soft-laddering

Interviews were conducted using soft laddering as it is recommended for exploratory research with less than fifty participants (Costa et al., 2004). Preferred product characteristics rated as a 5 were used as the starting points for the laddering interviews (Reynolds & Olson, 2001). If time allowed, the preferred product characteristics rated as a 4 were then discussed, followed by those rated as a 3.

Farmers were asked why a particular preferred product characteristic was important to consider when looking to buy a new crop and soil health promoting product. For each response given by the participant, the follow up question, "And why is *that* important to you?" was asked until a value (e.g., quality of life) was reached or the farmer could not reason any further, at which point the next most important preferred product characteristic was discussed.

4.2.3 Analysis

The interviews were conducted in Dutch; therefore, Dutch native speakers transcribed and translated the interviews into English. Involving Dutch native speakers proved useful for interpreting Dutch sayings (e.g., 'earning a sandwich' in Dutch refers to earning money). Their contributions arguably improved the coding accuracy.

The transcripts were coded in ATLAS.ti 9 Windows. Initially, coding was conducted by the first author and a research assistant independently. The two coded files were compared to identify inaccurate or inconsistent coding by the first author. After comparing the codes of nine interviews, the coding style (accuracy and consistency) between researchers was comparable, and the remaining interviews were coded by the first author.

Coding was performed on two levels of abstractness. For example, the code "shape" (parent code) can become more detailed by specifying "circle" and "square" (child codes). Shifting the analysis to a lower level of abstractness (from analyzing parent codes to analyzing child codes) results in more complex and information-rich HVMs (Reynolds & Olson, 2001).

Within ATLAS.ti 9, codes were linked to one another in the text and labelled as either direct or indirect links. Using an example, consider that a farmer states that A is important because of B, and B is important because of C [A to B to C]. A is therefore directly linked to B and indirectly linked to C (via B), and B is directly linked to C. Continuing with the example, consider two other farmers reasoned as follows: [A to D to C] and [A to F to C]. By only accounting for direct links, A would be in no way recognized as being associated with C, even though all three farmers have similar, though slightly differing ways of reasoning that associates A with C. Accounting for both direct and indirect links in the analysis therefore preserves more relations between constructs.

There are two ways to analyze MEC data: in terms of the frequency-of-responses (links are counted as many times as they are mentioned by the participant) and the number-of-respondents (a link is only counted once regardless of how often the participant mentions it) (Kilwinger & van Dam, 2021). The links in this research were counted on the basis of the number-of-respondents because of how the interviews were conducted. Using an example, consider that a farmer linked A to B and B to C. Then, the farmer indicated that D also links to B. The researcher did not ask again why B is important, as the farmer already linked it to C. Rather, the researcher asked if there were any other reasons (besides B) why D is important. Therefore, links were not elicited more than once in a given interview making the analysis on a frequency-of-responses level inappropriate.

To generate the HVMs, an analysis of the appropriate PPCR and cut-off levels was conducted. Once determined, HVMs were generated accordingly for Groups A and B. The data was analyzed using the MEC Analysis Tool (Foolen-Torgerson & Kilwinger, 2021). The output of the MEC Analysis Tool was used to create visual presentations of the HVM results in NodeXL.

Determining the level of preferred product characteristic ratings

The data can be analyzed on a PPCR level 5 which includes only attributes rated as a 5 (and their subsequent ladders), or on PPCR level 4 or 5 which includes only attributes rated as 4 or 5 (and their subsequent ladders), or on PPCR level 3, 4 or 5 which includes only attributes rated as 3, 4 or 5 (and their subsequent ladders). The level of PPCR used in the analysis was determined by how many links between codes and how many constructs were retained at the various PPCR levels (Figures 4.2 and 4.3 respectively).

Figure 4.2 shows that thirteen and six percent of the total links made were lost when including only PPCR 4 or 5 in the Groups A and B respectively. A forty-five and thirty-five percent reduction was seen when including only PPCR 5 in Groups A and B respectively. When conducting a similar analysis for constructs lost, including only PPCR 4 or 5 results in 0-4% loss of constructs in Group A and a 0% in Group B. Including only PPCR 5 results in 0-25%

loss of constructs in Group A and 19-26% in Group B. As we were interested in both the most important reasons and the secondary reasons that farmers have for using the products they do, it was decided to analyze and compare HVMs on PPCR level 4 or 5 to HVMs of PPCR level 5.

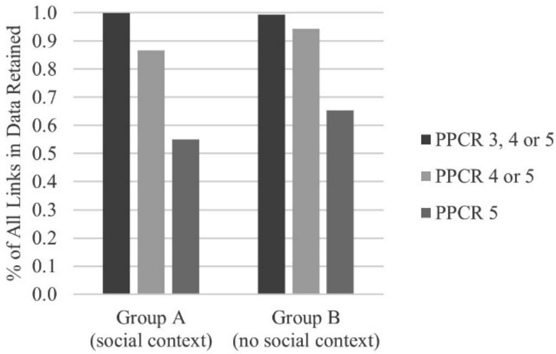

Figure 4.2 - Percent links retained per group and PPCR (Preferred Product Characteristic Rating) level

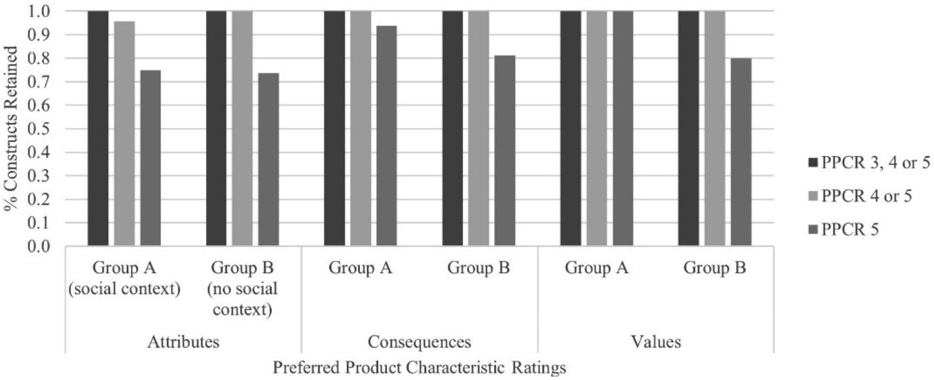

Figure 4.3 - Percent constructs retained per group and PPCR (Preferred Product Characteristic Rating) level

Determining a cut-off level

For a link between two constructs to appear in the final HVM, a minimum number of participants must have (directly or indirectly) linked the two given constructs together; the minimum number of participants chosen is called a cut-off level. A high cut-off level can reduce the complexity of the HVM by retaining only the most important ladders. However, a cut-off level that is too high can also fail to retain important ladders. Therefore, a balance had to be found between data retention and readability. Cut-off level decisions are often unjustified as there is little theoretical or statistical criteria for the selection (Rogers, 2003).

In this research, the cut-off levels considered for the analysis were between two and seven participants. A cut-off level higher than seven was not considered as the percent of values retained in the HVMs of PPCR level 5 dropped to 0% in both groups. Selecting a cut-off level was done by calculating the Concentration Index (CI) (Pieters et al., 1994). The CI is defined as the percentage of all links that are retained at the cut-off level divided by the percent of all constructs retained at the cut-off level (Reynolds & Olson, 2001). Appendix B presents an overview of the CI at cut-off levels two through seven for both groups. Notably, no single cut-off level resulted in the highest CI across the groups. The decision was made to use a cut-off level of 5 because it had, on average, the highest CI across the groups. The percentage of constructs retained at a cut-off level of 5 is presented in Appendix C along with the percent of constructs retained at cut-off levels two through seven.

4.2.4 Sample

Forty-six Dutch arable farmers participated in this research between February 2020 and March 2021. Twenty-three participants were in Group A, and twenty-three participants were in Group B. The farmers in Group A were recruited from three pre-existing farmer study groups, resulting in six group discussions of three to six farmers. Group B participants were recruited from pre-existing farmer study groups and snowball sampling.

A larger sample size was initially planned, however, due to the COVID-19 pandemic, the data collection was postponed several times. In an attempt to achieve a larger sample without extending the research timeline further, the last two group discussions and subsequent interviews were conducted online (as opposed to face-to-face). When conducting the group discussions virtually, idea sharing was limited to verbal communication.

Demographics

Of the 46 participating farmers, 37 identified as conventional farmers, 2 as organic farmers, and 7 as mixed (organic and conventional) farmers. Farms ranged in size (24 – 450 hectares) and percentage of land owned (average of 64%). Farmers were almost exclusively male and ranged in years of experience (3 – 45 years), age (26 – 70 years old), and percentage of family income derived from the farm (10% - 100%) (see Table 4.1). Two-sample t-tests assuming equal variances were conducted, and no significant (at 5%) differences were found in the demographics of Table 4.1 between the two groups.

Table 4.1 - Demographics of farmers that participated in Groups A and B

	Group A (social context)			Group B (no social context)		
	Min	Max	Average	Min	Max	Average
Land owned (%)	0	100	61	0	100	67
Hectares of arable land	18	370	116	30	488	129
Years of arable farming experience	3	45	28	4	45	27
Age	26	67	52	26	70	50
Family income derived from farm (%)	10	100	77	35	100	83

Figure 4.4 shows a map of the Dutch provinces where the participants' farms were located (on a province level). Noticeably, the spread of participants in Group B is more dispersed than of those in Group A. The reason for this difference is due to how participants were acquired. Group A participants originated exclusively from study groups (where participants are located relatively closer together), and Group B was acquired by study groups and snowball sampling, which resulted in more dispersion.

Figure 4.4 - Map of participants by province

4.3 Results

The results are presented in two parts: the elicited attributes and the HVMs.

4.3.1 Attribute elicitation

Tables 4.2a and 4.2b provide an overview of the sixteen elicited attributes mentioned by more than one farmer during the interview, the number of farmers in Groups A and B who rated the attribute, the median ratings for each attribute, and an indication of if the attribute appears in the HVMs. As a note, not all of the attributes mentioned by farmers appear in the HVMs although the median PPCR may be 5. This is either because not enough farmers initially stated it or that the farmers did not uniformly associate it with similar constructs. For example, in Group B, *Effectiveness* is associated 14 times to 5 consequences and 3 values. However, it is never associated more than 5 times (the determined cut-off level) to any specific consequence or value. Thus, even though *Effectiveness* has a median of 5, it does not appear in Group B's HVM. The attributes are organized in six categories: price, extended effects, applicability, composition, performance, and availability.

Group B more frequently stated attributes relating to composition and price, whereas Group A more frequently stated and gave higher importance ratings to attributes relating to price, extended effects, and usability. The difference between the groups' elicited attributes may be due to the influence of the social context. In the group discussion, the three most discussed concerns regarding frass were the monetary considerations, the applicability and usability, and the potential long-term harm (e.g., toxicity) as a pure/natural product (see Appendix A for a summary of the group discussion outcomes).

As expected, Group A more frequently stated and gave higher importance ratings to attributes most closely relating to the most frequently expressed concerns in the group discussion (i.e., price, extended effects and applicability) compared to Group B. This suggests that the group discussions ultimately made certain aspects of frass more salient, which influenced the attributes elicited and their importance ratings.

Table 4.2a - Constructs elicited from Group A

	Group A (social context)					
	Frequency of attribute mentioned (n)	**Median**	**Count PPCR 4 or 5**	**HVM PPCR 4 or 5[a]**	**Count PPCR 5**	**HVM PPCR 5[a]**
PRICE						
Low Price; Good Price Quality	14	5.00	11	y	8	y
EXTENDED EFFECTS						
Natural or Environmentally Friendly (when deemed safe)	16	4.75 [b]	12	y	9	y
Long/Short Term Effects; Works Long Term	1	4.00	1	-	0	-
APPLICABILITY						
Easy to Apply/Use; Fits Machine	14	4.00	10	y	4	y
Specificity of Application	9	3.00	4	-	2	-
Dose	7	4.00	4	-	2	-
Form (Liquid or Solid)	5	4.00	3	-	1	-
COMPOSITION						
Organic Matter	7	4.00	4	-	3	-
Nutrients	5	4.00	3	-	1	-
Chitin	0	-	0	NA	0	NA
PERFORMANCE						
Familiar; Trusted; Reliable; Proven; Consistent	3	4.00	2	-	1	-
Effectiveness	4	4.00	3	-	1	-
Fast Result	1	1.00	0	-	0	-
Preventative	3	4.00	2	-	1	-
Fast Degrading; Speed of Decomposition	2	4.00	2	-	0	-
AVAILABILITY						
Wide Availability	1	5.00	0	-	0	-

Table 4.2b - Constructs elicited from Group B

	Group B (no social context)					
	Frequency of attribute mentioned (n)	**Median**	**Count PPCR 4 or 5**	**HVM PPCR 4 or 5[a]**	**Count PPCR 5**	**HVM PPCR 5[a]**
PRICE						
Low Price; Good Price Quality	17	4.00	9	y	5	-
EXTENDED EFFECTS						
Natural or Environmentally Friendly (when deemed safe)	8	4.00	6	-	2	-
Long/Short Term Effects; Works Long Term	2	5.00	2	-	2	-
APPLICABILITY						
Easy to Apply/Use; Fits Machine	8	3.50	4	-	1	-
Specificity of Application	5	3.00	2	-	2	-
Dose	4	4.00	3	-	1	-
Form (Liquid or Solid)	1	3.00	0	-	0	-
COMPOSITION						
Organic Matter	15	5.00	14	y	10	y
Nutrients	13	4.00	8	y	3	-
Chitin	2	3.00	1	-	0	-
PERFORMANCE						
Familiar; Trusted; Reliable; Proven; Consistent	6	5.00	5	-	4	-
Effectiveness	6	5.00	6	-	4	-
Fast Result	1	4.00	1	-	0	-
Preventative	4	4.50	3	-	2	-
Fast Degrading; Speed of Decomposition	1	4.00	1	-	0	-
AVAILABILITY						
Wide Availability	1	4.00	1	-	0	-

[a] *"y" means "yes"; the attribute appears in the specified HVM.*

[b] *In some cases, the farmer mentioned characteristics that fall under the same (parent) code. For example, differentiations "natural" and "environmentally friendly" both fall under the code "Natural or Environmentally Friendly (when deemed safe)". In such cases, the average rating assigned by the farmer to these two characteristics was used so that a farmer is not represented in a code more than once. Therefore, a median of 4.75 is feasible as the median fell between 4.5 and 5.*

4.3.2 Hierarchal value maps of Groups A and B

Figures 4.5(a-d) portray the hierarchal value maps (HVMs) that were generated from Groups A and B at PPCR level 5 and PPCR level 4 or 5 respectively with a cut-off level of 5. For a deeper exploration of the data, Appendix D provides an overview of the same HVMs but using child codes. The HVMs in Appendix D have a cut-off level of two so more information would be retained; granted the complexity increased. To combat the increased complexity and to make them comparable to the HVMs in Figure 4.5, child codes not embedded under a parent code shown in Figures 4.5 (a-d) were removed. The results of the HVMs provide a

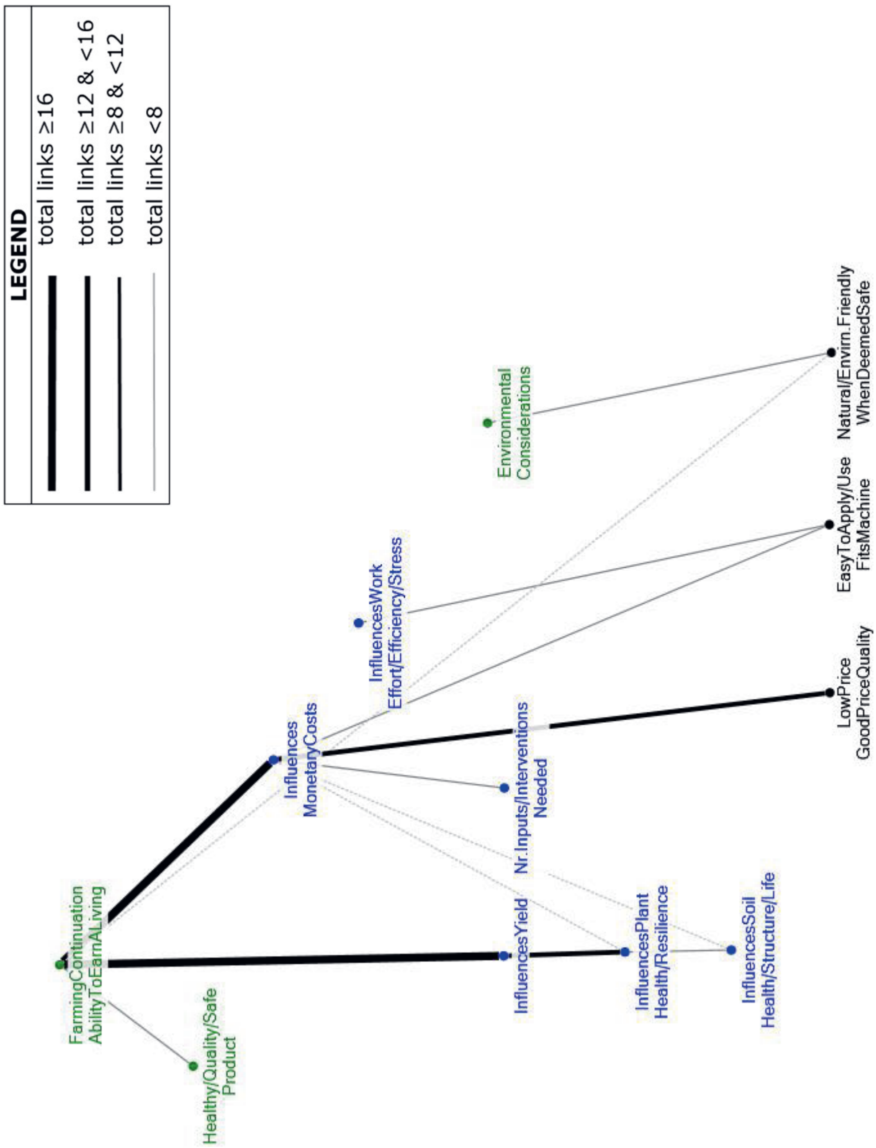

Figure 4.5a – Group A (PPCR level 5)

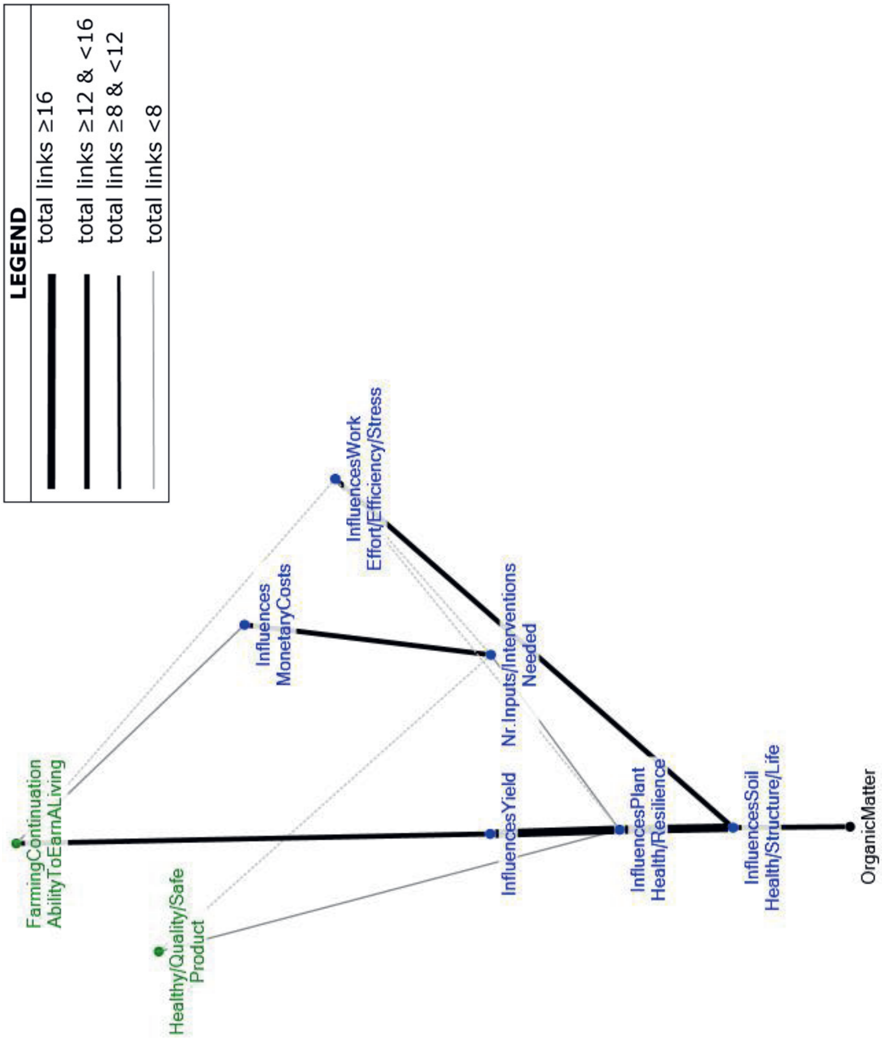

Figure 4.5b – Group B (PPCR level 5)

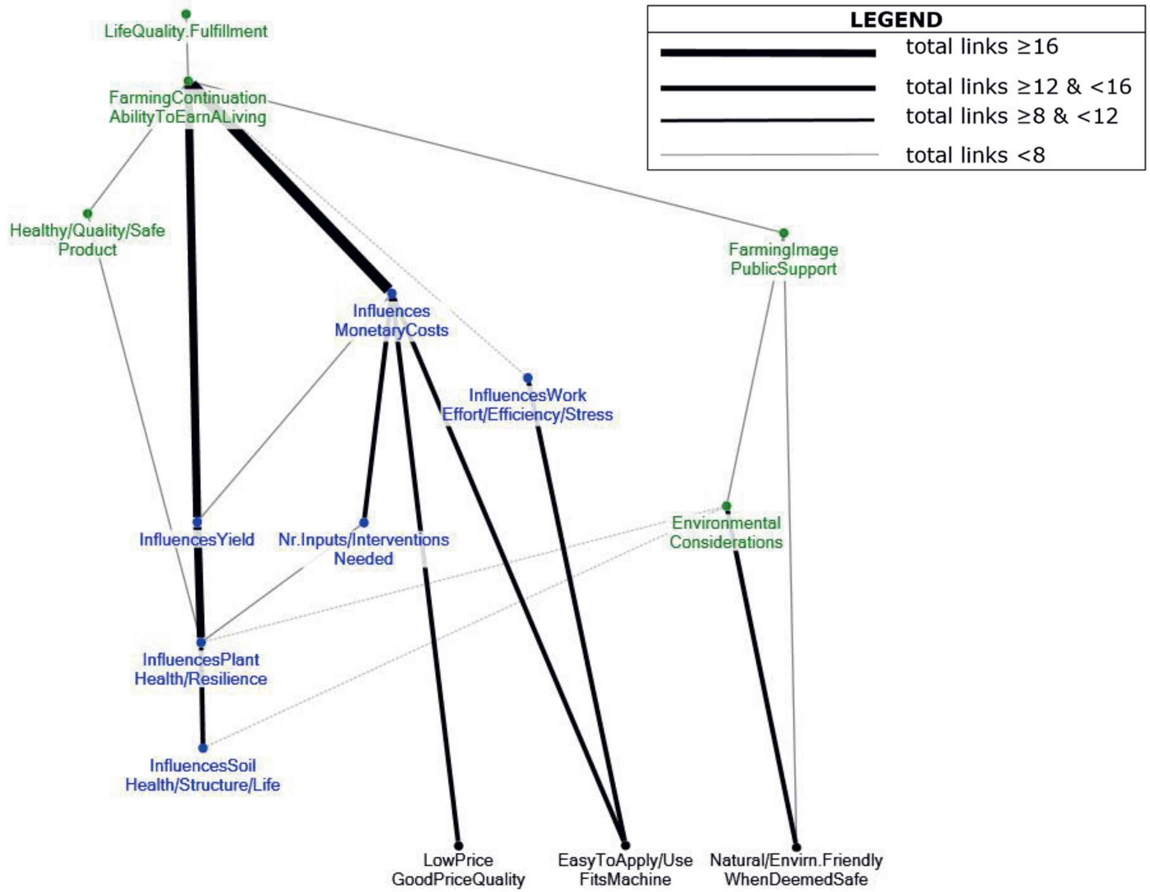

Figure 4.5c – Group A (PPCR level 4 or 5)

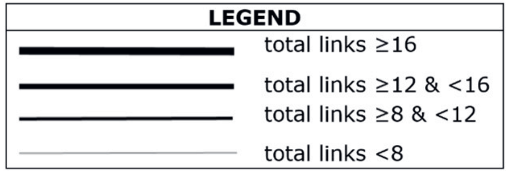

Figure 4.5d – Group B (PPCR level 4 or 5)

Attributes appear in black text. Consequences appear in blue text, and values appear in green text. Solid lines indicate that there are as many or more direct links between the two constructs than indirect links. Dotted lines indicate that there are more indirect than direct links. The line thickness varies for the solid lines depending on the number of total links made between the two constructs, shown in the legend. The primarily indirect links (dotted lines) all have a total number of links less than eight. In Figures 4.5a-b, data from twenty-three participants are presented in each HVM at a cut-off level of 5. In Figures 4.5c-d, data from twenty-three participants are presented in each HVM at a cut-off level of 4 or 5. Farmers in group A participated in a group discussion; farmers in group B did not.

visualization of the reasoning farmers applied when selecting the crop and soil health promoters that they have used.

Comparing Group A (Figures 4.5a and 4.5c) to Group B (Figures 4.5b and 4.5d), it appears that farmers in Group B share a single line of reasoning; they look for a product that improves their plant and soil health. Specifically, *Organic Matter* seems to play a role for Group B in achieving this. Improving soil and crop health is beneficial for improving yields and reducing the number of inputs (and interventions), work effort and costs. In doing so, they can achieve their goals of creating a quality and safe product, earning a living and continuing to farm. When investigating PPCR level 4 or 5, *Nutrients* and *Price Quality* play a role in achieving this goal. Additionally, *Environmental Considerations* are also taken into account.

Farmers in Group A also followed this logic, but with a few modifications. Already in PPCR level 5 (what farmers found most important), *Environmentally Friendly* and *Easy to Use* products are also sought to achieve goals related to *Environmental Considerations* and *Farming Continuation and Ability to Earn a Living*. Broadening to PPCR level 4 or 5, the additional value *Farming Image and Public Support* appears. Notably, ladders associated with attributes *Natural/Environmentally Friendly* and *Easy to Use* thicken, and *Organic Matter* and *Nutrients* are not attributes that are specifically related to achieving their goals as is the case in Group B.

When comparing Groups A and B, the consequences (blue text) are the same, and the values (green text) are similar. The attributes (black text) however differ completely at PPCR level 5 except for one common attribute – *Price Quality* – at PPCR level 4 or 5. This suggests that all farmers share a common line of reasoning for how crop and soil health promotion impacts their farm (consequences) in terms of improved crop and soil health, improved yields, interventions needed, the influence the changes have on work effort, efficiency and stress and monetary costs. Why they strive to achieve these outcomes (values) differs slightly, but more interestingly, how they achieve these outcomes (attributes) differs greatly as also seen in the attribute elicitation results (see Section 4.3.1). Group B has attributes *Price Quality, Organic Matter* and *Nutrients* as the base of the HVM. Group A has attributes *Price Quality, Natural/Environmentally Friendly* and *Easy to Use* as the base, which parallel the three biggest concerns for using frass discussed in the groups.

The results all together suggest that discussing, in this case, the advantages, concerns and disadvantages of frass in a social context made the shared content more salient and important. Group A therefore drew upon the content that was discussed in the group discussions when explaining their decision-making processes in the interviews days to weeks after. They were in a way nudged by one another to prioritize certain attributes. The desired consequences and values remained relatively uninfluenced, as would be expected. Therefore, the results suggest that the social context can influence the attributes believed to be important to achieve farmers' desired consequences and goals.

4.4 Discussion

The first objective of this research was to contribute to the understanding of farmers' reasoning regarding their use of more sustainable and circular crop and soil health promoting innovations. The results showed that farmers seek crop and soil health promoting products that they believe will improve yields and reduce work effort, costs, inputs and interventions, which ultimately aids them in creating a high-quality and safe product, earning a living and continuing to farm. Two studies investigate topics comparable to this research. Specifically, these studies investigated Kenyan farmers' decision-making processes regarding the use of pesticides (Lagerkvist et al., 2012) and various sorts of manure and fertilizer (Okello et al., 2014) in kale production. Despite the markedly different contextual differences, the healthy/good looking plants, making money, increasing yield, and improving soil fertility are all examples of shared findings.

The second objective of this research was to contribute to the understanding of a social context's influence on decision-making processes. The results suggest that the communication between farmers in a social context influenced the product attributes that farmers expressed when verbalizing their decision-making processes. More specifically, the group discussions were useful in realizing the less salient characteristics and effects (e.g., topics related to *Natural/Environmentally Friendly* and *Easy to Use*). Farmers who did not participate in group discussions may have also shared the same decision-making process had they been exposed in discussions to more considerations. Previous research, like that of Ambrosius (2021), Beedell and Rehman (2000) or Kaufmann et al. (2009), has explored the influence of social contexts on adoption decisions using more quantitative means (i.e. surveys, games and agent based models). The results of this research provide the first insights into the influence of social contexts on the decision-making process using a softer approach – MEC analysis.

Using MEC approach provides crucial and more in-depth insights into the rationale farmers follow when choosing their crop and soil health promoters, and our results suggest that the product's attributes deemed relevant for achieving these goals can vary depending on the social context. This is an important finding as it suggests that group discussions may be able to influence how farmers evaluate frass. For instance, without a group discussion, evaluations may be primarily based on the perceived performance of frass as an organic matter addition. With group discussions, however, the evaluation may be based more on the perceived ease of use, price and environmental friendliness. Farmers' willingness to adopt frass could then depend on their perceptions on its ability to fulfill/contribute the attributes they deem necessary to ultimately achieve their goals.

Because frass is still in an early phase of R&D, many of the basic concerns expressed by the farmers in the discussion groups could not be addressed (e.g., price, application details and effectiveness). Had these more basic details been available, the farmers could have had more in-depth discussions. But already, without providing such basic details, one can see that simply sharing concerns about these details was enough to integrate them into the decision-making process regarding crop and soil health promoters. Therefore, if insect frass (or other innovations in crop and soil health promotion) is eventually found to be (and perceived by farmers as) for example, more easily applied, cost effective, and environmentally friendly, it would be beneficial to listen to the farmers' concerns and address them, as these concerns are the bedrock of their decision-making process. Granted, such innovations are only interesting when economically feasible for farmers. One should not forget, farmers' top values relating to crop and soil health promoters are to ultimately produce a healthy, high-quality and safe product that can earn them a living and stay in business; new products must therefore be financially feasible.

4.4.1 Research limitations

Three limitations are worthwhile discussing for this research. First, considering the relatively small sample size and the split in our sample, we refrain from making claims regarding the generalizability and external validity of the results. However, we can conclude that among the farmers interviewed in this research, the social context seems to have influenced the attributes they found necessary to achieve their goals.

Second, though the farmers were split into two groups and compared, a clearer picture of how the social context impacted the participants would be achieved if laddering interviews were conducted before and after the group discussions. In doing so, the effects of existing differences between the two groups could be mitigated. However, participants can already find one laddering interview unpleasant and time consuming; asking them to partake in two laddering interviews will likely result in dropouts, boredom and frustration. Therefore, we interpret these results acknowledging that there could be external influences of, among others, the difference in participant acquisition or regional (and often thereby cultural) differences.

Finally, as discussed in Kilwinger and van Dam (2021), "a construct that is not mentioned can still be important to a respondent." Failing to mention particular constructs may stem from, for example, a difference in product-use scenarios in mind. During the interviews, farmers were asked to what extent the preferred product characteristics they distinguished were important to them when looking to buy a new crop and soil health promoter. Some farmers considered health promotion as a means of ridding their fields of pests and diseases, while others considered health promotion as a more holistic process of building crop and soil resilience over the long-term. This led to, for instance, differences in importance assigned to *[Containing] Organic Matter*. The farmers with the product scenario of pest and disease riddance already use other products (e.g., composts or manures) for replenishing the organic matter content in their fields. For them, organic matter is not rated with high importance in a new product because it is already supplied by a product they use. Therefore, the absence of elicited constructs from either group should not be overly interpreted.

4.4.2 Future research

Follow up research can proceed in several directions; we discuss three potential avenues. Further research can build on this study's investigation of the role social contexts play in farmers' decision-making processes in terms of their crop and soil health promoters. For example, a survey could be used to quantitatively investigate how social contexts influence farmers based on Theory of Planned Behavior constructs (i.e., attitudes, subjective norms, perceived behavioral control and intentions).

As frass advances further in the R&D process, ideally it will be implemented on test farms where farmers can observe the results. At that time, it would be interesting to carry out an experiment that compares farmers' intentions to use frass under four conditions: farmers who only watch an informational video about frass (control), and farmers who watch the informational video and (1) participate in group discussions (only social context influence), (2) visit the test farm (experience), and (3) participate in group discussions and visit the test farm (interaction effect). Such research would test the impact of experience, the influence of social contexts, and the interaction effect of both to see what the most effective way is in promoting the uptake of frass.

Finally, future research could investigate farmers' preferences using a choice experiment that varies crop and soil health promoters based on the most frequently discussed attributes with the highest importance in this research. Such a study would aid in understanding which attributes are most persuasive when farmers are selecting a crop and soil health promoting product and gauge farmers' willingness to pay for such innovations.

4.5 Conclusion

The results of this research suggest that sharing first impressions of an innovation like the by-products of insect production in a social context can lead to the realization of less salient though important considerations regarding crop and soil health promoters. Ultimately, the social interaction that took place influenced the attributes farmers expressed as necessary to achieve their goals. If this is true, such group discussions play a vital role in broadening the perspectives and decision-making processes of farmers. Effectively communicating new findings and addressing farmers' uncertainties regarding circular innovations while encouraging (or facilitating) a dialogue amongst farmers can guide their decision-making processes that in turn, could lead to more uptake of proven and economically feasible circular innovations.

4.6 Acknowledgements

We would like to extend a special thank you to our research assistants – Wouter Aben and Jort van Alphen – for their persistent dedication to the data collection process and data processing. Additionally, we would like to sincerely thank all of the farmers who participated in our research for the opportunity to meet with each of them. Your time and contributions are genuinely appreciated. We would also like to sincerely thank Dr. Gerard Korthals for assisting us throughout the data collection process.

Wageningen University's Ethics Committee Social Science (ECSS) approved the conduct of this research. Farmers who participated agreed to the research conduct by signing informed consent forms. This work was supported by The Dutch Research Council NWO [grant number ALWGK.2016.010].

Appendix A – Conclusions from the six group discussions

To track the topics discussed in each group, one researcher served as the group moderator, a second researcher served as the note taker. Also, during the in-person discussion, the group members wrote down their thoughts on sticky notes and placed them on a large sheet of paper for further discussion. The group discussions were not audio recorded. The numbers presented in this table (n) represent how often the statement was noted in the summaries of the note takers or found on a sticky note. It is the minimum number of times that the topic was mentioned by a group. For example, (4) means that summaries from 4 group discussions included this statement, but the remaining 2 groups may have also discussed (or mentioned) the topic but it did not get documented in the group's summary by the note taker or was not found on a sticky note.

Table A1 – Summary of topics discussed during group discussions

Advantages	Concerns	Disadvantages
• Frass can increase resistance and immunity of crops and the soil diversity/life. (4) • If frass is proven to be effective, is not harmful, is easily applied and is not too expensive, farmers will use it. (4) • Frass is a biological and natural product that can replace or reduce the use of other chemical products. (3) • Frass is a good alternative for banned plant protection products. (2) • Frass could increase crop yields. (2) • Frass can make the process of farming easier and less intensive. (1) • Consumers will like the circular aspects. (1)	• What are the associated costs (application and investment)? Will frass be profitable and cost effective? (6) • Is frass easy to use? Are new machines or apparatus needed to apply it? How is frass applied on farmland and in what dose? Do farmers have to change their current systems to apply it? (6) • Are there negative or harmful short- or long-term side effects on the soil? Is frass pure, and does it contain any toxic substances? (5) • Is there independent scientific research carried out without any commercial interest? (4) • Does frass work effectively? (4) • Will frass be widely available to sustain all farmers' needs? (2) • Is frass legally approved? (2) • How does frass work together with other pesticides and soil improvement products and techniques? (1) • Is frass proven on the various soil types throughout the Netherlands? (1) • Does frass influence soil structure and resilience or improve crop quality? (1)	• Frass is new, unknown, and not yet well understood. A lot can go wrong. If it goes wrong, the consequences for farmers are huge. There is not enough evidence to try frass yet. (6) • Biological products are expensive and less effective compared to conventional products. Natural products can be toxic. (3) • Other products already have proven to be effective. Why should farmers change their systems? (1) • Previous experience using chitin was not positive. (1) • There could be ethical considerations towards insects with a growing vegan/vegetarian movement. (1) • Frass could create better circumstances for weeds to grow. (1) • Frass will probably not increase the value of the end-product sold and would therefore only work for high value products. (1) • Frass will probably be more difficult to use and require more intensive labor. (1) • The legislative approval needed to allow frass in practice will not happen quickly. (1)

Appendix B – Concentration Index

Table B1 – Concentration Index

Cut-off level	PPCR 4 or 5: Group A (social context)			PPCR 4 or 5: Group B (no social context)			PPCR 5: Group A (social context)			PPCR 5: Group B (no social context)		
	Nr. of retained linkages	Nr. of retained constructs	CI	Nr. of retained linkages	Nr. of retained constructs	CI	Nr. of retained linkages	Nr. of retained constructs	CI	Nr. of retained linkages	Nr. of retained constructs	CI
1	701	48	**0.89**	682	45	**0.94**	445	42	**0.64**	473	35	**0.84**
2	499	34	**0.89**	516	30	**1.07**	295	28	**0.64**	356	24	**0.92**
3	363	26	**0.85**	414	20	**1.29**	221	17	**0.79**	284	16	**1.10**
4	300	19	**0.96**	351	17	**1.29**	191	15	**0.77**	254	12	**1.32**
5	256	14	**1.11**	323	13	**1.55**	139	12	**0.70**	226	9	**1.56**
6	221	13	**1.03**	283	10	**1.76**	119	10	**0.72**	196	9	**1.36**
7	197	12	**1.00**	259	9	**1.79**	95	9	**0.64**	178	9	**1.23**

CI: Concentration Index = [Nr. of retained linkages / Total nr. of linkages] / [Nr. of retained constructs / Total nr. of constructs]

Group A:
Total number of linkages = 808
Total number of constructs = 49

Group B:
Total number of linkages = 723
Total number of constructs = 45

Appendix C – Percent of attributes, consequences and values retained per cut-off level

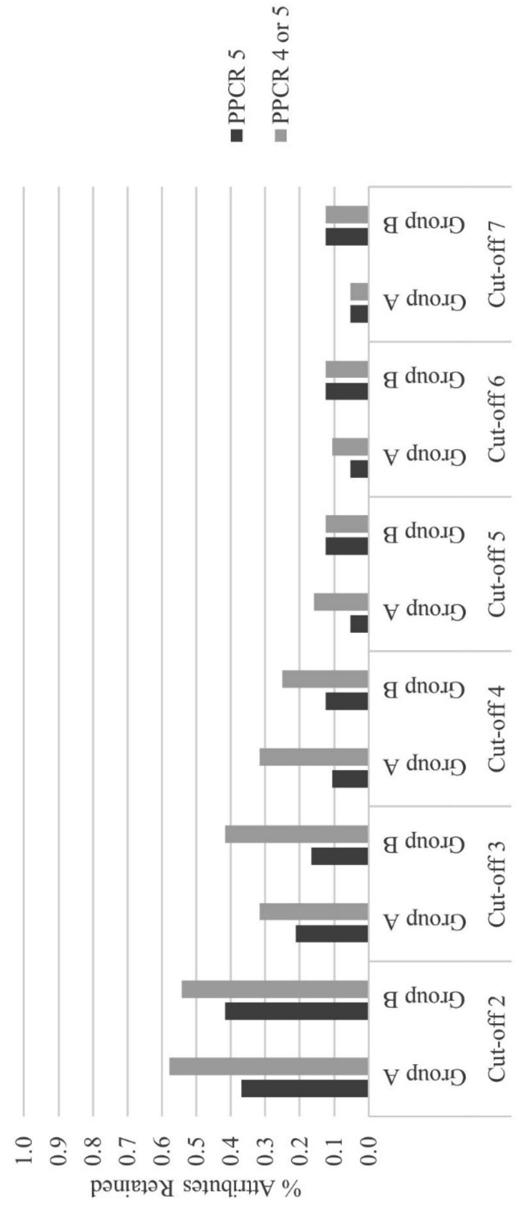

Figure C1 – Percent of attributes retained per cut-off level

Where Group A was with a social context, and Group B had no social context.

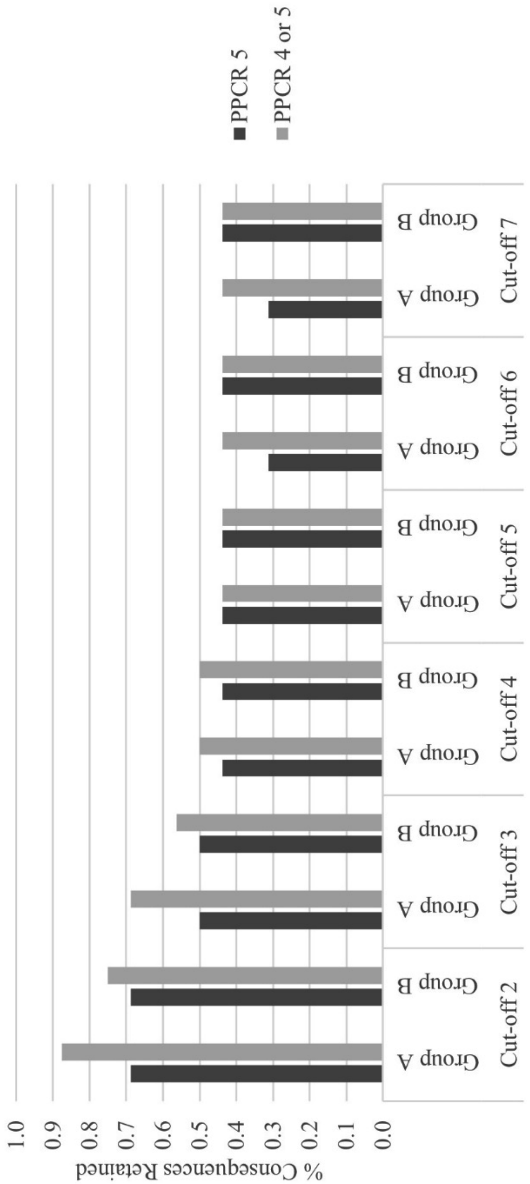

Figure C2 – Percent of consequences retained per cut-off level

Where Group A was with a social context, and Group B had no social context.

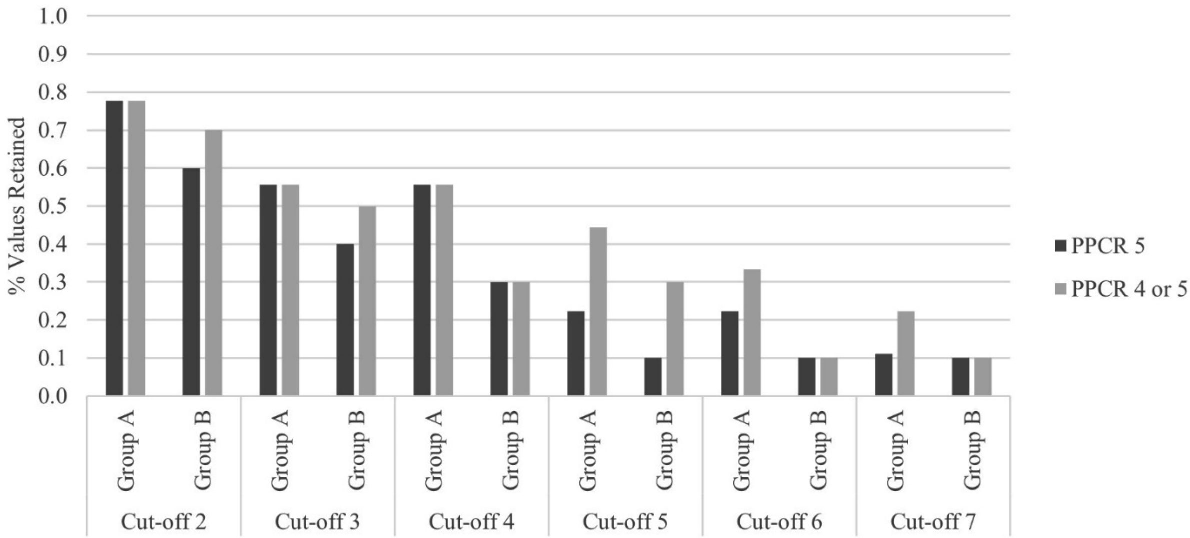

Figure C3 – Percent of values retained per cut-off level

Where Group A was with a social context, and Group B had no social context.

Appendix D – Child code HVMs

Figures D1-D4 correspond respectively to Figures 4.5 (a-d) and were analyzed using child codes as opposed to parent codes. Child codes were only included in Figures D1-D4 if they were embedded under a parent code presented in Figures 4.5 (a-d). This was done to reduce the complexity of HVM while gaining more information regarding the parent codes.

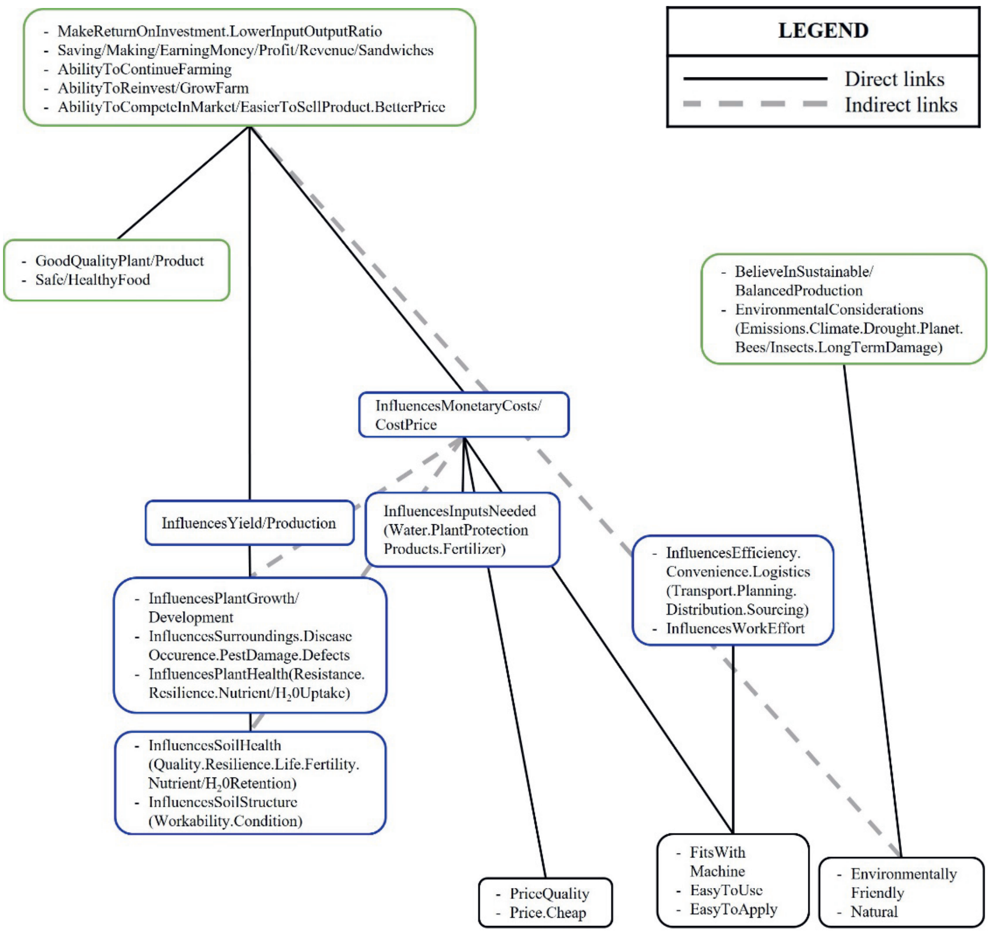

Figure D1 – Group A (PPCR 5)

Attributes appear in a black text box. Consequences appear in a blue text box, and values appear in a green text box. Solid lines indicate that there are as many or more direct links between the two constructs than indirect links. Dotted lines indicate that there are more indirect than direct links. Data from twenty-three participants are presented in each HVM at a cut-off level of 2. This HVM corresponds to Figure 4.5a, which presents the HVM of Group A using parent codes at a PPCR level 5 and cut-off level 5.

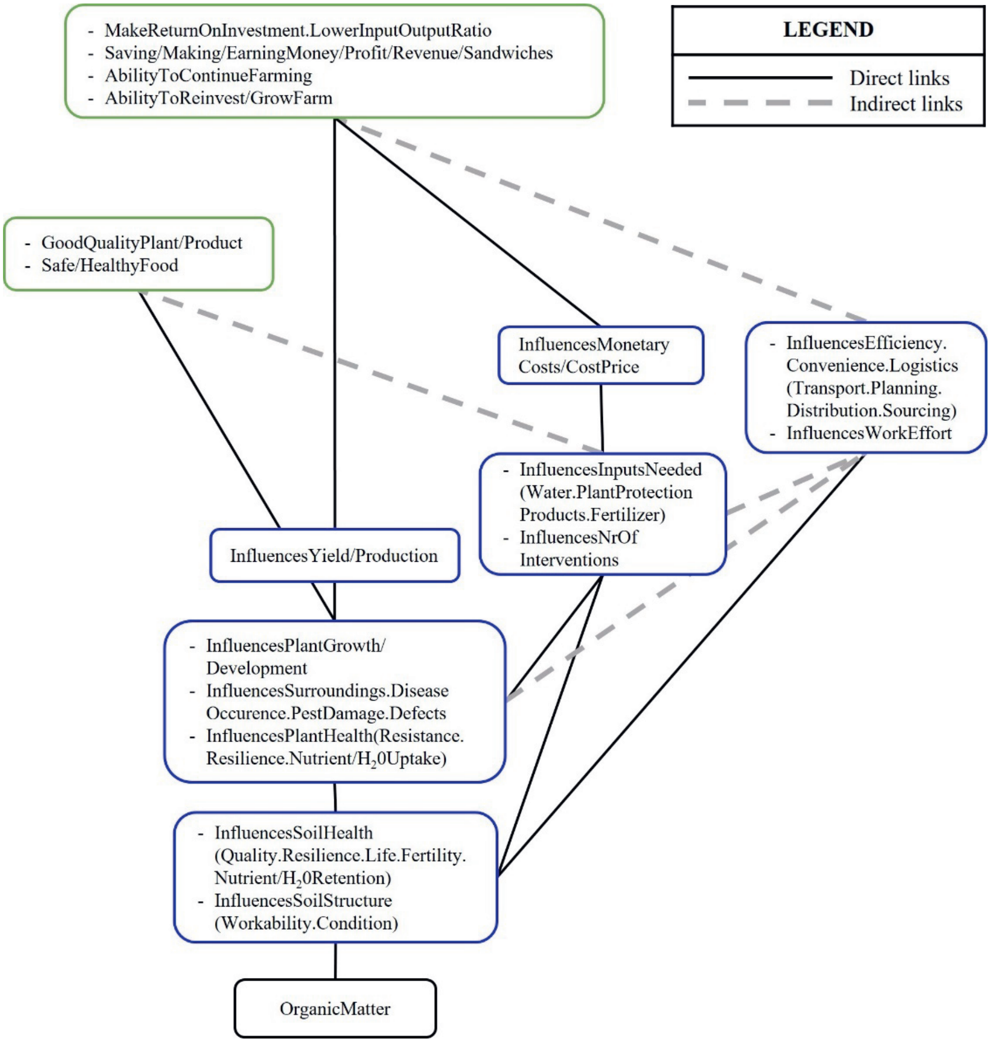

Figure D2 – Group B (PPCR 5)

Attributes appear in a black text box. Consequences appear in a blue text box, and values appear in a green text box. Solid lines indicate that there are as many or more direct links between the two constructs than indirect links. Dotted lines indicate that there are more indirect than direct links. Data from twenty-three participants are presented in each HVM at a cut-off level of 2. This HVM corresponds to Figure 4.5b, which presents the HVM of Group B using parent codes at a PPCR level 5 and cut-off level 5.

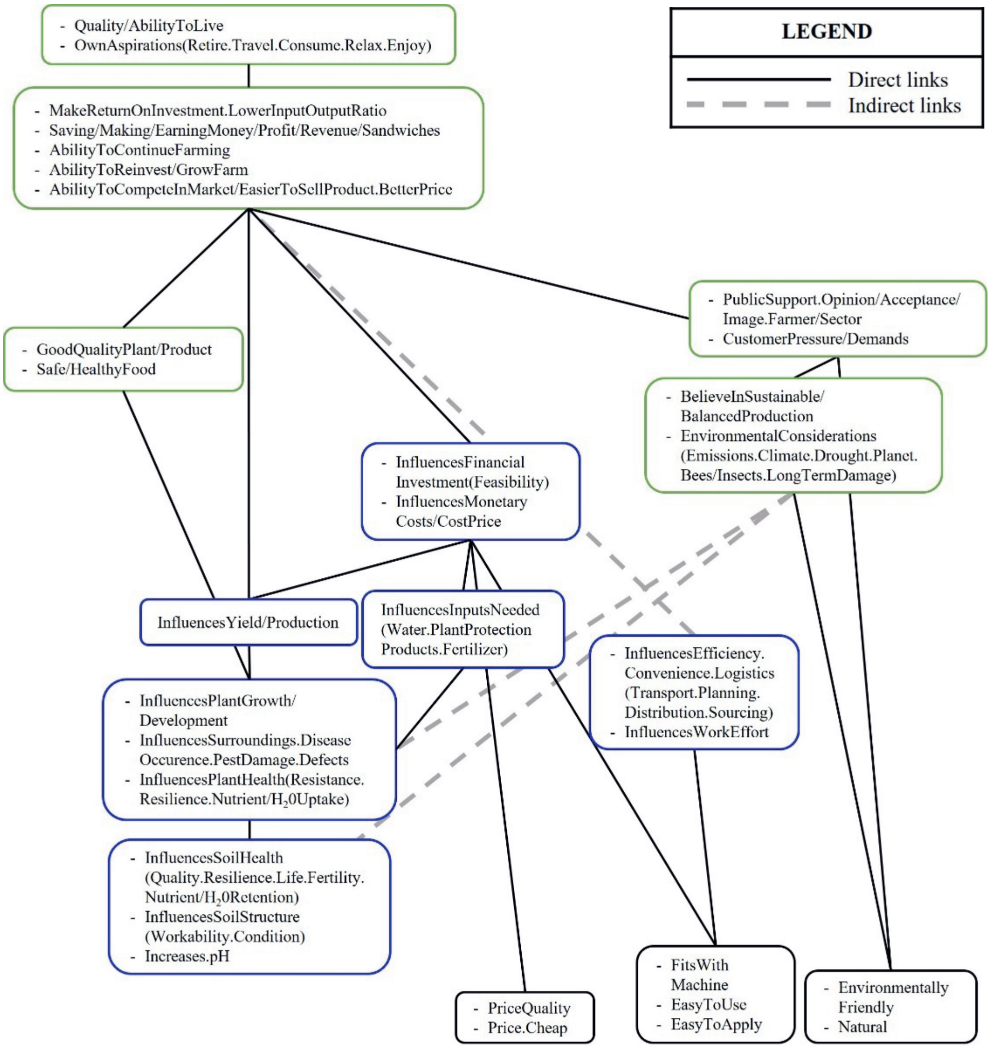

Figure D3 – Group A (PPCR 4 or 5)

Attributes appear in a black text box. Consequences appear in a blue text box, and values appear in a green text box. Solid lines indicate that there are as many or more direct links between the two constructs than indirect links. Dotted lines indicate that there are more indirect than direct links. Data from twenty-three participants are presented in each HVM at a cut-off level of 2. This HVM corresponds to Figure 4.5c, which presents the HVM of Group A using parent codes at a PPCR level 4 or 5 and cut-off level 5.

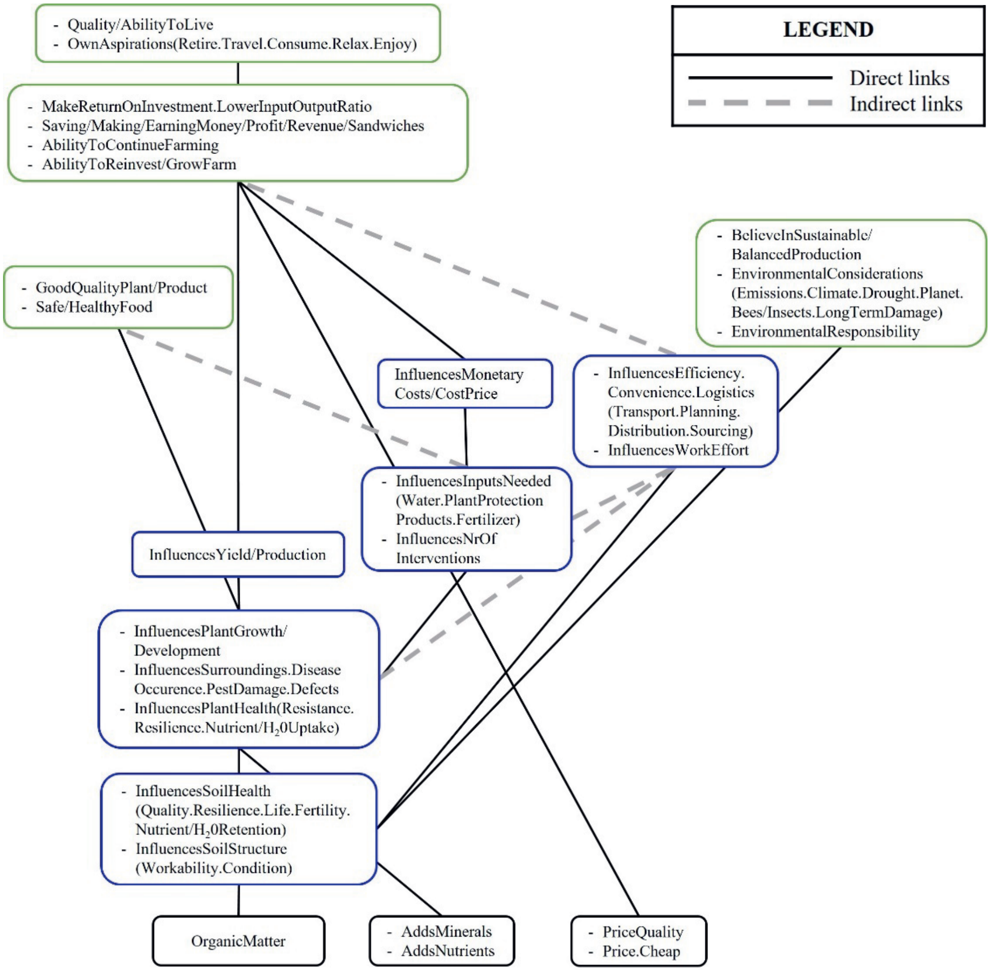

Figure D4 – Group B (PPCR 4 or 5)

Attributes appear in a black text box. Consequences appear in a blue text box, and values appear in a green text box. Solid lines indicate that there are as many or more direct links between the two constructs than indirect links. Dotted lines indicate that there are more indirect than direct links. Data from twenty-three participants are presented in each HVM at a cut-off level of 2. This HVM corresponds to Figure 4.5d, which presents the HVM of Group B using parent codes at a PPCR level 4 or 5 and cut-off level 5.

CHAPTER 5

How group discussions influence arable farmers' intentions to trial the by-products of insect production

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Abstract

Circularity in agriculture regarding the recycling of by-products from one form of production for use as inputs in another has become an urgent initiative as resources become more scarce and valuable. One potential example of circular agriculture is recycling the by-products of insect production (frass) as a crop and soil health promoter. This research investigates the drivers of arable farmers' intentions to trial insect frass as an input on their farms using two theoretical lenses – the Theory of Planned Behavior and the Innovation Decision Process. In addition, the influence of group discussion participation on the drivers of farmers' intentions is investigated to identify potential opportunities to influence the uptake of frass. Two questionnaires at two time-points (t_1 and t_2) were distributed to forty-six Dutch arable farmers. Between these time-points, half of the farmers participated in group discussions where their first impressions of frass were shared amongst each other. The results from several ordinary least squares regression models suggest that the initial drivers of farmers' intentions in t_1 differ from the drivers expressed in t_2. More specifically, initially, farmers' attitudes, perceived (descriptive) social norms and perceived behavioral control drive their intentions to trial frass. By t_2, for those who did not participate in group discussions, attitudes were the only significant predictors of their intentions. For those that participated in the group discussion, the descriptive norm had a larger association with intentions than for those that did not participate in the group discussions. Group discussions also influenced farmers' perceptions of frass' relative advantages. The results of this research contribute to an informed discussion on how group discussions can be used to influence the adoption of agricultural innovations like frass.

Keywords

circular economy, repeated measures design, Diffusion of Innovations, OLS regression, biopesticide, decision-making process, willingness-to-consider

5.1 Introduction

As an alternative to waste generation and accumulation, a circular economy recognizes and capitalizes on the value of waste. By recycling by-products as useful inputs, a circular economy aids in minimizing unnecessary use of limited resources (Geissdoerfer et al., 2020). Agriculture has been identified as an industry where resources are avoidably leaking throughout the supply chain. There are opportunities for the by-products of one form of production to be recycled as valuable inputs for another; as such, the movement towards circular agriculture has become urgent (Dagevos & de Lauwere, 2021).

One example of a circular relationship exists between insect producers and arable farmers. The by-products of insect production – the insect manure, shed exoskeletons and uneaten feed, collectively termed "frass" (Barragán-Fonseca et al., 2022) – can be repurposed as a crop and soil health promoter for use on arable farms. Several mechanisms are suggested to be responsible for frass' health promotion capabilities. For example, the shed exoskeletons in the frass contain chitin. Though chitin is not directly useable for the plant, its presence can trigger, for instance, the expression of defense-related genes (Parada et al., 2018) and can stimulate beneficial microbes that populate next to the plant's roots (Bai, 2015). The beneficial microbes can digest the chitin. While doing so, the microbes make the nutrients of the frass more accessible and digestible, which boosts the plants' potential yield and gives it the opportunity to prioritize and allocate its resources for self-defense purposes (Pangesti et al., 2013). Also, the beneficial microbes produce compounds that impede the growth of pathogens and herbivores via direct and indirect methods. Direct methods include being pathogenic when in contact with the plant pathogens or herbivores (Cawoy et al., 2011; Kupferschmied et al., 2013); indirect methods include inducing the plant's systemic resistance by activating hormonal signal transduction throughout the plant (Pieterse et al., 2014). For a more in-depth explanation of the expected crop and soil health promoting mechanisms of frass, we refer to Barragán-Fonseca et al. (2022). With such properties, frass can be a valuable and recycled input for arable farms.

Frass represents a promising circular input in agriculture that is not yet widely available in the market. To successfully diffuse into the market, it must be deemed a feasible input by farmers. Previous research has found that when considering the adoption of sustainable practices, farmers considered, among others, the cost effectiveness of the product, the farm's future trajectory, the farmers' opinions regarding environmentally friendly practices (Defrancesco et al., 2008), farmers' risk aversion and the relative riskiness of the innovation (Ghadim et al., 2005), and social factors (Michel-Guillou & Moser, 2006). For a more detailed overview of the behavioral factors that affect farmers' adoption of sustainable practices, see Dessart et al. (2019). However, much of what is already known regarding the drivers affecting farmers' adoption behavior was derived from reflective research – research that investigates farmers' decision-making processes after having adopted the innovation (Rogers, 2003). In the case of insect frass, the innovation is not widely available for use, and therefore, most farmers have not yet been faced with the consideration to use insect frass. The literature lacks insights from the perspective of farmers' decision-making process prior to the adoption of the innovation – also known as willingness-to-consider research (Dessart et al., 2019; Ma et al., 2012). Such insights are crucial for broadening the understanding of farmers' adoption of sustainable practices like the uptake of insect frass. The gap in the literature is addressed in this research by investigating farmers' decision-making process regarding insect frass as a crop and soil health promoter prior to an adoption or rejection decision.

In addition, there is a lack of understanding of how farmers' decision-making process can be externally influenced from the perspective of willingness-to-consider research. Previous studies have investigated, among others, the use of group discussions to provide social reinforcement when decisions are being made (Cialdini, 2001; Lewin, 1952). Marra et al. (2003) found that sharing information with others and social learning were critical for farmers when considering the adoption of an agricultural innovation. This research builds on the premise of the influence of group discussions by examining how group discussions can influence farmers' decisions regarding the use of insect frass. Such insights can be useful for effectively encouraging the uptake of circular agricultural inputs.

The objective of this research is thus two-fold: (1) to determine what drives farmers' intentions to trial insect frass as a crop and soil health promoter and (2) to determine how group discussions affect the drivers of farmers' intentions to trial insect frass. We do so by conducting this research prior to frass' diffusion into the market from a willingness-to-consider perspective. This research provides practical insights for parties such as insect producers and policy makers that may be interested in the successful diffusion of insect frass in the future.

5.2 Theory

Two theoretical lenses were used to investigate what drives farmers' intentions to trial insect frass – the Theory of Planned Behavior (TPB) (Ajzen, 1991, 2012) and the Innovation-Decision Process (IDP) (Rogers, 2003).

5.2.1 Theory of Planned Behavior

The TPB, from social psychology, posits that attitudes, perceived social norms and perceived behavioral control predict one's intention to perform a given behavior. Each of these predictors is broken down further into two sub-constructs. Attitudes (one's disposition in favor or against the behavior) are measured by the positive or negative felt experiences (experiential attitudes) and consequences (instrumental attitudes) perceived as being associated with the behavior. Social norms (the perceived social pressure associated with the behavior) are measured by the perception that others are or are not performing the behavior (descriptive norm) and by the perception of what ought to be done (injunctive norm).

Perceived behavioral control (PBC; the extent of control over the behavior's execution and capability of executing the behavior) is measured by perceived capacity (one's belief in his/her own capabilities associated with executing the behavior) and autonomy (one's belief regarding the control over the behavior's execution) (Fishbein & Ajzen, 2010).

The TPB has been readily applied in agricultural research to determine what motivates farmers' behavior. For example, Hijbeek et al. (2018) investigated the drivers of Dutch farmers' intentions to increase the organic matter contents of their soil. Brazilian farmers' intentions were investigated regarding the diversification of their production (Senger et al., 2017) and the adoption of natural grassland for cattle grazing (Borges et al., 2014). Zeweld et al. (2017) investigated the drivers of farmers' engagement in sustainable agricultural practices. For a critical review of TPB research conducted in agriculture, see Sok et al. (2021). In accordance with the TPB, we test the following hypotheses:

H1a: Attitudes positively correlate with farmers' intentions to trial insect frass.
H1b: Perceived social norms positively correlate with farmers' intentions to trial insect frass.
H1c: Perceived behavioral control positively correlates with farmers' intentions to trial insect frass.

Research on social influence and conformity has shown that behaviors are often performed to impress others (Cialdini & Trost, 1998). Specifically, descriptive norms influence behavior – if someone else is performing a behavior, others may follow suit (Cialdini, 2001). Werner and Stanley (2011) found that indeed descriptive norms played a role in the context of sharing leftover toxic home and garden chemicals with friends (instead of discarding them). Considering the findings of the previous research, we test the following hypothesis:

H1d: Participating in group discussions influences the role of descriptive norms as predictors of farmers' intentions to trial insect frass.

5.2.2 Innovation-Decision Process

The IDP stems from technology adoption and communication research and is part of the Diffusion of Innovations theory (Rogers, 2003). It is a five-stage process where first knowledge about the innovation is gained, then an impression of the innovation is formed, and an adoption or rejection decision is made. If one chooses to adopt the innovation, then it is implemented and the decision of adoption is confirmed (Rogers, 2003). Provided that insect frass is still in its research and development phase, we investigate the second stage (the persuasion stage) of the IDP.

In the persuasion stage, how an individual perceives an innovation's attributes is especially important when formulating their impressions towards it. Rogers describes five attributes an individual perceives: relative advantages, compatibility, complexity, observability and trialability. As frass is not widely available, nor is its effectiveness being openly demonstrated on test farms (making it observable), we focus on three of the attributes. The attributes are defined as the extent to which the innovation is perceived to be better than comparable products (relative advantage), consistent with one's existing values, needs and past experience (compatibility), and difficult to use or understand (complexity) (Rogers, 2003). To further develop an impression, individuals may perform a forward-thinking exercise where they imagine applying the innovation within their situation (Rogers, 2003). This mental exercise dictates the individual's intentions to trial the innovation.

The IDP has a long history of being applied in agriculture to grasp farmers' perceptions of various innovations and innovative practices. As a few examples, researchers have investigated farmers' perceptions of hybrid corn (Ryan & Gross, 1943), precision agricultural technology (Aubert et al., 2012), conservation practices (Mascia & Mills, 2018), and ecological intensification (Kernecker et al., 2021). In accordance with the IDP, we test the following hypotheses:

> H2a: Perceived relative advantage positively correlates with farmers' intentions to trial insect frass.
> H2b: Perceived compatibility positively correlates with farmers' intentions to trial insect frass.
> H2c: Perceived complexity negatively correlates with farmers' intentions to trial insect frass.

Interpersonal channels play an important role in the persuasion stage. This is because individuals may have doubts or uncertainties regarding the innovation; therefore, social reinforcement is sought to ascertain that their impressions are similar to their peers' (Rogers, 2003). For example, Rosen (2000) describes how EndNote's successful diffusion could be attributed to its diffusion through interpersonal networks. In that respect, group discussions can play a role of creating an interpersonal network situation; additionally, group discussions provide a platform where participants can learn what the group's impression towards a given behavior is, thereby creating social reinforcement (Cialdini, 2001; Lewin, 1952). Considering the findings of the previous research, we test the following hypothesis:

> H2d: Participating in group discussions influences the farmers' perceptions of the relative advantage, compatibility and complexity that predict their intentions to trial insect frass.

5.3 Materials and Methods

5.3.1 Research design

The research was conducted by first assembling two groups of farmers: those who participated in group discussions with farming peers (Group A) and those who did not (Group B). Farmers in Group A came exclusively from study groups. This made organizing group discussions more convenient. Farmers in Group B came from study groups and via snowball sampling.

To test H1a-c, a questionnaire (denoted as the t_1 questionnaire) was used. Prior to distributing the questionnaire, farmers needed to have (at least) a basic understanding of what insect frass was. Therefore, an informational video about insect frass was first presented to the farmers. The video was produced based on the findings of Torgerson et al. (2021) and presented (1) what insect frass is, (2) how it promotes the health of crops and soil, and (3) how farmers should apply it. The video encompassed the three types of knowledge in accordance with the first stage (the knowledge stage) of the IDP (Rogers, 2003). Use the following link to view the informational video with English subtitles: https://youtu.be/s4Y4t7uQo0s .

All farmers completed the t_1 questionnaire immediately after watching the video. Eighteen of the twenty-three farmers in Group A completed a hardcopy of the t_1 questionnaire before splitting off into discussion groups. The remaining five farmers in Group A could not be met in person due to COVID-19 restrictions. Therefore, they completed the t_1 questionnaire via a link and then participated in a group discussion via Microsoft Teams. The group discussions facilitated sharing their first impressions of insect frass. More specifically, farmers were asked to share the advantages and disadvantages they foresaw when using frass on their farms along with any outstanding questions (or concerns) that they had.

For seventeen of the twenty-three farmers in Group B, the t_1 questionnaire was provided in an emailed link immediately after the video; the time in which the link to the video and questionnaire was open was recorded to ensure that they had taken enough time to watch the video and fill in the questionnaire, all of which did. The remaining six farmers in Group B were approached during a farmers' study group session. After having watched the informational video, they completed a hardcopy of the t_1 questionnaire; they did not participate in group discussions.

To address H1d, a second questionnaire (denoted as the t_2 questionnaire) was distributed. For all farmers, the t_2 questionnaire was distributed in person on their farms (with the exception of five conducted online due to restrictions related to the COVID-19 pandemic) within sixteen days of having watched the informational video.

The t_1 and t_2 questionnaires both measured the TPB constructs using the same questions. However, only the t_2 questionnaire additionally measured farmers' perceptions on the relative advantage, complexity and compatibility of insect frass. This was done to reduce the total amount of time the farmers spent filling in questionnaires. As such, H2a-d were addressed using the data obtained from the t_2 questionnaire. Demographics were also collected in the t_2 questionnaire.

Figure 5.1 presents a schematic overview of the research design. Tables 5.1a and 5.1b present an overview of the t_1 and t_2 questionnaires regarding the constructs, variables, statements in the questionnaire, scales and references for the questionnaire's development.

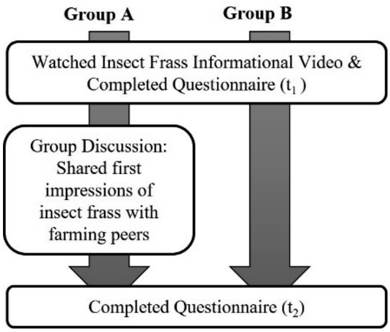

Figure 5.1 - Research design

5.3.2 Measurement and internal consistency of questionnaire design

The TPB items were formulated as direct measures of each construct, and as such, the TPB items represent reflective measures. Reflective measures must demonstrate internal consistency, unlike formative measures. As the perceptions items are formative measures, we did not assess the internal consistency of the indicators (Bollen & Lennox, 1991). However, we did check for multicollinearity in the model by inspecting Pearson and Spearman rank correlations and the Variance Inflation Factor (VIF). The correlation matrices did not reveal any concerning results, and the VIF results were all below 10.

The internal consistency of how well the TPB items collectively represented their assumed construct was checked within the t_1 and t_2 questionnaire output. Appendix A presents Tables A1-4 that include the Kendall's tau and Pearson correlation coefficients, means and standard errors for the TPB indicators for t_1 and t_2 respectively. The Kendall's tau and Pearson's correlations were compared to check for consistency, which were deemed robust to the various correlation specifications.

Cronbach's alpha using Pearson correlation coefficients were calculated to check the internal consistency of the questions within their respective constructs based on the TPB (see Table 5.2). In addition, the (unstandardized) Cronbach's alpha using covariances and the standardized Cronbach's alpha using Kendall's tau correlation coefficients were calculated to check that the results do not depend on the type of Cronbach's alpha calculation conducted. The results were robust to the alternative Cronbach's alpha specifications. Internal consistency is generally accepted at an alpha above 0.7 (Field, 2018).

Table 5.1a - Description of variables for representing Theory of Planned Behavior constructs in regression analysis

TPB constructs - t_1 & t_2 questionnaires	Description of the statement [a]	Scale [b]
Attitude (instrumental)$_1$	Using insect by-products [on parts of my arable cropping land within the next 5 years] is...	... unimportant – important
Attitude (instrumental)$_2$		... disadvantageous – advantageous
Attitude (instrumental)$_3$		... unnecessary – necessary
Attitude (experiential)$_1$		... unsatisfying – satisfying
Social Norm (injunctive)$_1$	Most people who are important to me would think that I should use insect by-products [...] .	
Social Norm (injunctive)$_2$	The people who influence my decisions would think that I should use insect by-products [...]	
Social Norm (descriptive)$_1$	Most people like me would use insect by-products on a portion of their farm's arable cropping land within the next 5 years.	
PBC (capacity)$_1$	I am confident that I can use insect by-products [...] .	
PBC (capacity)$_2$	If I really wanted to, I could use insect by-products [...] .	
PBC (autonomy)$_1$	For me to use insect by-products [...] is under my control.	
PBC (autonomy)$_2$	The number of events outside my control which could prevent me from using insect by-products [...] are...	... numerous – few
Intention$_1$	I intend to use insect by-products [...].	
Intention$_2$	I plan to use insect by-products [...].	
Intention$_3$	I am willing to use insect by-products [...] .	

PBC: Perceived Behavioral Control

[a] *Sources used for the TPB questionnaire development include: Aubert et al. (2012), Fishbein and Ajzen (2010), Taylor and Todd (1995), Vasquez et al. (2019) and Zeweld et al. (2017).*

[b] *The scale was disagree – agree, unless specified otherwise. All were 5-point Likert scales.*

Table 5.1b - Description of variables for representing perceptions constructs in regression analysis

Perceptions constructs – t_2 questionnaire	**Description of the statement** [a]	**Scale** [b]
Relative advantage$_1$	[Compared to my currently used crop and soil health promoting products, using insect by-products] reduces my soil's long-term susceptibility to pests and disease.	
Relative advantage$_2$	[...]reduces the environmental impact of my activities.	
Relative advantage$_3$	[...]improves my soil's long-term quality (e.g., structure).	
Compatibility$_1$	Using insect by-products is compatible with most aspects of my work (machinery, etc.).	
Compatibility$_2$	Using insect by-products fits well with how my farm currently operates.	
Compatibility$_3$	Using insect by-products fits well with the way I like to work.	
Complexity$_1$	Insect by-products will be easy to use. [c]	
Complexity$_2$	Using insect by-products will be frustrating to learn.	
Complexity$_3$	I clearly understand how to use insect by-products. [c]	

[a] *Sources used for the perceptions (IDP – persuasion stage) questionnaire development include: Aubert et al. (2012), Moore and Benbasat (1991) and Taylor and Todd (1995).*

[b] *The scale was disagree – agree, unless specified otherwise. All were 5-point Likert scales.*

[c] *Variable was reversely coded for the statistical analysis.*

Table 5.2 - Standardized Cronbach's alpha using Pearson correlation coefficients

	Number of Indicators	Standardized Cronbach's alpha (t_1)	Standardized Cronbach's alpha (t_2)
Attitude	**4**	**0.79**	**0.73**
- Instrumental	3	0.74	0.71
- Experimental	1	NA	NA
Perceived Social Norm	**3**	**0.74**	**0.68**
- Injunctive	2	0.82	0.70
- Descriptive	1	NA	NA
Perceived Behavioral Control	**4**	**0.15**	**0.42**
- Perceived Capacity	2	0.61	0.68
- Perceived Autonomy	2	-1.10	0.27
Intention	**3**	**0.89**	**0.85**

The level of analysis was determined using the results from the standardized Cronbach's alpha. Three levels of analysis were possible for the TPB items: construct-level, subconstruct-level, and the indicator-level (analyzed per question). Attitudes were analyzed at a construct-level, which consisted of the average of all four indicators measuring attitudes. The standardized Cronbach's alpha was larger in t_1 and t_2 at the construct-level compared to the subconstruct-level. Perceived social norms were analyzed at the subconstruct-level, which consisted of one indicator measuring descriptive norms and two indicators averaged to represent injunctive norms. In this way, we were able to address H1d, which tests the distinction between injunctive and descriptive norms. To represent perceived behavioral control, the standardized Cronbach's alphas for the construct-level and subconstruct-level were unacceptable. Therefore, it was decided to analyze PBC on the indicator-level using only one of the items. Due external uncertainty around frass (e.g., legal allowance and availability of supply), the perceived autonomy indicators were not considered. The question, "I am confident that I can use insect frass on parts of my arable cropping land within the next 5 years" was selected because it provides an indication to farmers' perceived capability to use insect frass. The items measuring intention resulted in the highest standardized Cronbach's alphas. Intentions were therefore analyzed at the construct-level where all three indicators measuring intentions were averaged.

5.3.3 Analysis of relationships

We conducted five of ordinary least squares (OLS) linear regressions and used robust standard errors to compute p-values. The regressions were conducted in R using "lm" function in the "stats" package (version 3.6.2).

In the first model, we addressed H1a-c by investigating which TPB constructs drive intentions in t_1 (the dependent variable). The independent variables therefore included attitude, descriptive norms, injunctive norms and perceived behavioral control (capacity)$_1$ from t_1.

In the second and third models, we addressed H1d by investigating how group discussions influence the drivers of intention. To do so, we introduced the dummy variable "Group Discussion" to discriminate between farmers that participated in group discussion [1] and farmers that did not participate in group discussions [0]. The dependent variable was intentions in t_2, and the independent variables included attitude, descriptive norms, injunctive norms and perceived behavioral control (capacity)$_1$ and the product of these independent variables and the dummy variable.

In the fourth and fifth models, we addressed H2a-d by investigating perceptions from the IDP and the influence of group discussions on the perceptions. The dependent variable was intentions in t_2, and all of the items corresponding to relative advantage, compatibility and complexity and the product of these variables and the dummy variable served as independent variables.

5.3.4 Sample demographics and data

Of the forty-six participating farmers, thirty-seven identified as conventional farmers, two as organic farmers, and seven as mixed (organic and conventional) farmers. Farms ranged in size (24 – 450 hectares) and percentage of land owned (0 – 100%). Farmers were almost exclusively male and ranged in years of experience (3 – 45 years), age (26 – 70 years old), and percentage of family income derived from the farm (10 – 100%) (see Table 5.3). Two-sample t-tests assuming equal variances were conducted, and no significant (at 5%) differences were found in the demographics of Table 5.3 between the two groups. The participants' farms were located throughout the Netherlands.

Table 5.3 - Demographics of farmers - Groups A and B

	Group A (group discussion)			Group B (no group discussion)		
	Min	Max	Average	Min	Max	Average
Land owned (%)	0	100	61	0	100	67
Hectares of arable land	18	370	116	30	488	129
Years of arable farming experience	3	45	28	4	45	27
Age	26	67	52	26	70	50
Family income derived from farm (%)	10	100	77	35	100	83

Table 5.4 provides an overview of the means and standard deviations of all of the variables used in the OLS models. The table is split horizontally in two sections where the top section provides an overview of the data collected in t_1, and the lower section provides an overview of the data collected in t_2. A few farmers failed to answer all of the questions. The missing data points are also noted in the table.

Table 5.4 – Descriptive overview of data

	Group A (n=23)		Group B (n=23)		All (n=46)	
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
t_1 questionnaire						
Attitude	3.19[a]	0.52[a]	3.38	0.70	3.29[b]	0.62[b]
Social Norm (descriptive)	2.96	0.93	2.52	1.28	2.74	1.12
Social Norm (injunctive)	2.69	0.85	2.48	1.06	2.58	0.96
Perceived Behavioral Control $(Capacity)_1$	3.65	0.98	3.70	1.26	3.67	1.12
Intention	3.14	0.64	3.09	1.10	3.11	0.89
t_2 questionnaire						
Attitude	3.13	0.51	3.14[a]	0.79[a]	3.13[b]	0.65[b]
Social Norm (descriptive)	3.00	0.83	2.70	1.15	2.83	1.00
Social Norm (injunctive)	2.78	0.74	2.59	1.22	2.69	1.00
Perceived Behavioral Control $(Capacity)_1$	3.70	1.06	4.35	0.71	4.02	0.95
Intention	3.25	0.69	3.03	0.86	3.14	0.78
Relative $Advantage_1$	3.35	0.71	3.46[a]	0.67[a]	3.40[b]	0.69[b]
Relative $Advantage_2$	3.78	0.74	3.64[a]	0.95[a]	3.71[b]	0.84[b]
Relative $Advantage_3$	3.57	0.59	3.46[a]	0.74[a]	3.51[b]	0.66[b]
$Compatibility_1$	3.30	1.02	3.04	0.98	3.17	1.00
$Compatibility_2$	3.65	0.78	3.26	0.96	3.46	0.89
$Compatibility_3$	3.78	0.67	3.48	0.67	3.63	0.68
$Complexity_1$	3.00	0.67	3.09	0.90	3.04	0.79
$Complexity_2$	1.96	0.71	2.48	1.12	2.22	0.96
$Complexity_3$	2.78	1.04	2.96	1.19	2.87	1.11

[a] *22 observations (1 participant did not provide ratings)*
[b] *45 observations (1 participant did not provide ratings)*

5.4 Results

5.4.1 TPB regression analysis

Table 5.5 presents three linear regression models. In Model A, attitudes, social norms (descriptive), social norms (injunctive) and perceived behavioral control $(capacity)_1$ collected in t_1 were implemented as predictors of intention. Model A shows that when all four predictors are regressed on intention, injunctive norms play an insignificant role.

The lack of added value contributed by the injunctive norm is also demonstrated when each construct of Model A is broken down as a sole predictor of intention. In doing so, the injunctive social norms explain the least amount of variance of intentions (adjusted R^2 is

Table 5.5 - Linear models of TPB predictors of intentions

	t_1 analysis	t_2 analysis	
Model Spec.	**A**	**B**	**C**
Exogenous constructs inserted	**1 - 4**	**1 - 4**	**1 - 8**
Intercept	-0.92 * (0.43)	0.31 (0.70)	0.33 (0.47)
1. Attitude	0.76 *** (0.15)	0.54 * (0.21)	0.80 ** (0.27)
2. Social Norm (descriptive)	0.19 * (0.08)	0.18 (0.14)	0.00 (0.12)
3. Social Norm (injunctive)	0.13 (0.09)	0.08 (0.13)	-0.01 (0.17)
4. Perceived Behavioral Control (Capacity)$_1$	0.19 ** (0.06)	0.10 (0.14)	0.05 (0.16)
5. Attitude x Group Discussion			-0.44 (0.37)
6. Social Norm (descriptive) x Group Discussion			0.48 · (0.27)
7. Social Norm (injunctive) x Group Discussion			-0.02 (0.25)
8. Perceived Behavioral Control (Capacity)$_1$ x Group Discussion			0.06 (0.17)
Adjusted R^2	**0.67**	**0.43**	**0.47**

*The level of significance is denoted with the following: *** for $P < 0.001$, ** for $P < 0.01$, * for $P < 0.05$ and · for $P < 0.10$. Robust standard errors (provided in parentheses below each coefficient) were used to compute the p values. The dummy variable was assigned 1 for Group A (those in the group discussion) and 0 for Group B (those not in the group discussion). Data from t_1 was used in Model A. Data from t_2 was used in Models B and C.*

0.12) compared to when perceived behavioral control (capacity)$_1$, descriptive social norms or attitudes are independently regressed on intentions (adjusted R^2 is 0.20, 0.41 and 0.54 respectively; see Appendix B). Model A was also run with interaction terms included (e.g., [construct] x Group Discussion) to check that there were no significant interaction effects. All of the interaction terms were insignificant (see results Appendix B).

The results from Model A suggest that without considering any additional affects from a group discussion intervention, attitudes, descriptive social norms and perceived behavioral control (capacity)$_1$ are associated with intention. Therefore, H1a and H1c were not rejected. H1b was rejected in terms of injunctive norms but was not rejected in terms of descriptive norms.

Models B and C used data from t_2. In t_2, half of the farmers had participated in group discussions. Models B and C were constructed to compare how well the data explains the variance of intentions when not considering and considering (respectively) the additional effects of the group discussion. Model B therefore investigated the explanatory value of attitudes, social norms (descriptive), social norms (injunctive) and perceived behavioral control $(capacity)_1$ with regards to intentions. In Model C, attitudes, social norms (descriptive), social norms (injunctive), perceived behavioral control $(capacity)_1$ and the interaction of these four constructs with the group discussion dummy variable were used as the predictors of intention. Comparing the adjusted R^2 of Model B with C, the variance of intention was better explained when including the interaction terms. In other words, accounting for the effect of the group discussion resulted in a better model fit than not accounting for the group discussion.

Furthermore, Model C shows that for those who did not participate in group discussions, attitudes were the only significant predictors of intentions; the role of social norms and perceived behavioral control $(capacity)_1$ was insignificant. This result is also supported when investigating the role each construct with its subsequent interaction term has on explaining the variance of intention when used as sole predictors. Perceived behavioral control $(capacity)_1$ and its subsequent interaction term explained the least amount of variance (R^2 is 0.04). Descriptive norms, injunctive norms, attitudes and their subsequent interaction terms independently explained 21%, 26% and 39% of intention's variance respectively (see Appendix C).

The group discussion resulted in an additional affect regarding the role of the descriptive norm. For those who did participate in the group discussion, their intentions to trial frass were more associated with the descriptive social norms (0.48; at $p<0.10$) than for those not in the group discussion. Therefore H1d, was not rejected.

5.4.2 Perceptions regression analysis

Table 5.6 presents Models D and E, which were based on farmers' perceptions of frass' relative advantages (compared to similar products), compatibility and complexity from t_2. Model D evaluated how well the relative advantage, compatibility and complexity indicators alone explained the variance in intentions. Model E expanded on Model D by including the interaction terms (e.g., [item] x Group Discussion) to account for the group discussion. The results suggest that accounting for the group discussion produces a better fit model.

Model E shows that for those who did not participate group discussions, two of the three measures of frass' relative advantages (i.e., its ability to reduce the soil's long-term susceptibility to pests and diseases [Relative $Advantage_1$] and its ability to reduce the environmental impact of the farmers' activities [Relative $Advantage_2$]) were associated with intentions. Compatibility and complexity perceptions were not associated with intentions. A similar result was found when each construct (in Model E) with its subsequent interaction term was independently regressed on intention. Complexity indicators (and their subsequent interaction terms) explained the least amount of intention's variance (R^2 is 0.06). Relative

Table 5.6 - Linear model of Perception predictors of intentions (t_2 analysis)

Model Spec.	**D**	**E**
Exogenous constructs inserted	**1 – 9**	**1 - 18**
Intercept	0.05 (1.07)	0.82 (0.83)
1. Relative Advantage$_1$	0.63 * (0.23)	1.11 *** (0.21)
2. Relative Advantage$_2$	0.36 ** (0.12)	0.29 * (0.13)
3. Relative Advantage$_3$	-0.02 (0.24)	-0.36 (0.24)
4. Compatibility$_1$	0.15 (0.16)	-0.14 (0.19)
5. Compatibility$_2$	0.01 (0.17)	0.23 (0.14)
6. Compatibility$_3$	-0.12 (0.17)	-0.18 (0.17)
7. Complexity$_1$	0.00 (0.11)	-0.08 (0.14)
8. Complexity$_2$	-0.17 (0.13)	-0.29 (0.21)
9. Complexity$_3$	0.00 (0.10)	-0.06 (0.07)
10. Relative Advantage $_1$ x Group Discussion		-0.90 ** (0.27)
11. Relative Advantage $_2$ x Group Discussion		0.03 (0.20)
12. Relative Advantage $_3$ x Group Discussion		0.70 * (0.29)
13. Compatibility$_1$ x Group Discussion		0.42 (0.25)
14. Compatibility$_2$ x Group Discussion		-0.57 (0.36)
15. Compatibility$_3$ x Group Discussion		0.30 (0.50)
16. Complexity$_1$ x Group Discussion		-0.10 (0.27)
17. Complexity$_2$ x Group Discussion		0.00 (0.34)
18. Complexity$_3$ x Group Discussion		0.19 (0.19)
Adjusted R^2	**0.39**	**0.51**

*The level of significance is denoted with the following: *** for $P < 0.001$, ** for $P < 0.01$, and * for $P < 0.05$. Robust standard errors (provided in parentheses below each coefficient) were used to compute the p values. The dummy variable was assigned 1 for Group A (those in the group discussion) and 0 for Group B (those not in the group discussion). Data from t_2 was used in Models D and E.*

advantage and compatibility indicators and their subsequent interaction terms independently explained 10% and 44% of the variance respectively (see Appendix D).

For those in the group discussion, two differences were found. First, the farmers' perceptions of frass' ability to improve the soil's long-term quality (relative $advantage_3$) were more associated with intentions for those in the group discussion. Second, the farmers' perceptions of frass' ability to reduce the soil's long-term susceptibility to pests and diseases (relative $advantage_1$) was less associated with intentions for those in the group discussion. This suggests that the group discussion influenced the relevance of some of the relative advantages of frass.

Overall, Model E suggests that for all the farmers, only frass' relative advantages played a significant role in predicting intentions. Therefore, H2a was not rejected. Compatibility and complexity indicators played an insignificant role as predictors of intention; therefore, H2b and H2c were rejected. In addition, the relevance of various perceived relative advantages of frass differed for those in the group discussion than those not in the group discussion. H2d was therefore not rejected in terms of perceived relative advantages but was rejected in terms of perceived compatibility and complexity.

5.5 Discussion

This research set out to achieve two objectives. The first objective was to determine what drives farmers' intentions to trial insect frass as a crop and soil health promoter. Two theoretical lenses were used to determine the drivers of farmers' intentions: the TPB and the IDP. Using the TPB lens, the results showed that attitudes, descriptive norms and perceived behavioral control all associated with the farmers' intentions to trial frass. Notably, the injunctive social norms were not associated with intention. Farmers were therefore not motivated by the norms of what ought to be done. In t_2, for the farmers who did not participate in group discussions, only their attitudes towards insect frass were associated with their intentions to trial frass. The results suggest that farmers initially base their intentions on multiple criteria, but only attitude towards frass dictate their intentions to trial it by t_2. Therefore, attitudes that farmers develop based on the initial encounter with the information regarding frass are key. As it is not expected that farmers decide to trial insect frass immediately after the first encounter, it is critical for frass' successful diffusion that farmers have an initial positive attitude towards it.

Using the IDP lens, the results show that farmers' perception of frass' ability to reduce the soil's long-term susceptibility to pests and diseases had the strongest association with their intentions. A second predictor was farmers' perception of frass' ability to reduce the environmental impact of their activities. Notably, farmers' perceptions of frass' compatibility and complexity were not associated with their intentions to trial it. As no perceptions data were collected in t_1, we could not investigate how the drivers of intentions may have changed from t_1 to t_2. However, we can conclude that by t_2, the perceived relative advantages were the most important predictors. As such, for frass to successfully diffuse into the market, it is critical that farmers recognize the relative advantages frass has over comparable crop and soil health promoting products.

The second objective of this research was to determine how group discussions affected the drivers of farmers' intentions. Using the TPB lens, the results suggest that participating in a group discussion significantly increased the importance of descriptive social norms. The importance of social influences on adoption decisions aligns with several other agricultural studies. For example, Borges and Oude Lansink (2016) found that farmers' perceptions of the social pressures around improved natural grassland was the most important predictor for its adoption. Descriptive norms, more specifically, were found to play a role in the uptake of conservation tillage practices (D'Emden et al., 2008) and in the participation in agri-environmental schemes (Defrancesco et al., 2008). Similarly, membership in a farmer group was found by Meijer et al. (2015) to positively influence tree planting behavior. In research experimenting with group discussions, Werner and Stanley (2011), who conducted group discussions to persuade individuals to share leftover toxic garden and home chemicals, found that persuasion was in part due to normative influences. In marketing research, Melnyk et al. (2011) found that the effect of the descriptive norm is increased when there is more cognitive deliberation. Granted, they also saw a subsequent decrease in the importance of the injunctive norm, which was not found in this research. Furthermore, participating in the group discussions may have provided the farmers with an opportunity to apply a heuristic shortcut where they could base their intentions more on what they perceived other farmers would do (Farrow et al., 2017).

Using the IDP lens, the results suggest that the group discussion influenced the relevance of various perceptions related to relative advantages for predicting intentions. The ideas shared between the farmers during the group discussion provide additional insights to the regression results. At least half of the groups discussed that frass, as a biological and natural product, could potentially reduce their use of other chemical products. This discussion point aligns with relative advantage$_2$ measured using the statement, "compared to my currently used crop and soil health promoting products, using insect frass reduces the environmental impact of my activities". However, the regression results suggest that discussing this topic did not influence its level of association with intention. This may be because after watching the informational video, this particular relative advantage was already clear and relevant.

Half of the groups also discussed to what extent frass was effective in the soil. This discussion point relates to relative advantage$_{1\&3}$ measured using the statements – "compared to my currently used crop and soil health promoting products, using insect frass..." "...reduces my soil's long-term susceptibility to pests and disease" and "...improves my soil's long-term quality". As the group discussions were not audio recorded (only a written summary was recorded), further detail into these discussion topics is unknown. However, the results from the regression suggest that farmers may have been more convinced after the discussion of frass' influence on the soil's long-term improved quality than its reduced susceptibility to pests and disease.

Group discussions provide an opportunity to influence the uptake of frass. They can be used to emphasize the importance of various aspects of frass, which if convincing enough, may influence farmers' intentions to trial it. However, a key first step before conducting the group discussions would be to ensure that there is enough evidence (also from test farms) that supports the acclaimed health promotion characteristics of frass. With the additional information at hand, a discussion can be facilitated in a way that farmers can share their initial impressions and express their concerns as a group, which can be addressed in the moment. In doing so, maybe the group's impression of frass improves, influencing farmers' individual attitude towards frass and their perception of what other farmers would do regarding the use of frass. Such an approach would be more effective than informing farmers individually and hoping their attitudes towards frass and their perceptions of frass' relative advantages are positive. If positive impressions are shared amongst the group, farmers may believe that the others in the group would try using insect frass. In this way, the group discussions could potentially facilitate the uptake of frass.

5.5.1 Limitations

The data collection process of this research began prior to the COVID-19 pandemic; however, it was severely hindered as the lockdown in the Netherlands set in. Conducting group discussions in person was no longer possible. In an attempt to continue, we conducted one group discussion online. Though the discussion was still fruitful, the retention of participants was minimal. Therefore, we accepted the sample size that we managed to obtain.

The amount of time each farmer spent participating in our research was considerable. In addition, the farmers of course recognized the repetition in the TPB questions from t_1 to t_2, many of which commented on it while filling in the second questionnaire. Though it would have been interesting to test the perceptions hypotheses (H2a-d) in the same manner as the TPB hypotheses (H1a-d), the farmers would not have appreciated nine additional repeated questions, and it would have increased the time to complete the first questionnaire by more than 50%. Out of respect for the farmers' time we chose to investigate the TPB lens in further detail and restrict the investigation of the perceptions lens to t_2.

5.5.2 Future research

Several research directions can stem from this study. For instance, in this research, perceptions were not collected in t_1. Therefore, a follow up study could look into the perceptions that drive farmers' initial intentions (in t_1). As another example, this research investigated the drivers of farmers' intentions at two time points in the persuasion stage. A questionnaire conducted at a third time point, specifically when an adoption (or rejection) decision is made can be used to determine if the drivers of intentions differ by the time the adoption stage is reached.

Another direction for future research can build on this research's group discussion investigation. In this research, the group discussions were conducted in an open and unbiased way; the discussion moderators posed questions to the group that prompted the farmers to reflect on their own impressions. Future research could investigate whether nudging can be used to incentivize farmers similar to that conducted by Werner and Stanley (2011) to identify effective ways of promoting the adoption of green agricultural inputs amongst farmers. Notably, Dessart et al. (2019) discourages such an approach with farmers because farmers are business oriented; nudging is intended for normal consumption persuasion.

Rogers (2003) discusses the importance of the change agent – one who attempts to influence the client's innovation decision process towards (in the case of this research) trialing insect frass. Most often change agents are higher educated or possess technical knowledge regarding the innovation, and because of this, they are often not like the target group. This gap can cause communication challenges if not managed well. Therefore, in addition to introducing nudging into the group discussions, future research can also investigate which sorts of change agents such as young versus well-established university researchers, young versus well-established industry researchers or leaders of farmer study groups.

5.6 Conclusion

The objectives of this research were (1) to determine what drives farmers' intentions to trial insect frass as a crop and soil health promoter and (2) to determine how group discussions affect the drivers of farmers' intentions to trial insect frass. The results suggest that upon learning about insect frass, farmers' attitudes, perceived descriptive norms and perceived behavioral control were associated with their intentions to trial insect frass. Within sixteen days after learning about frass, farmers completed a second questionnaire (in t_2), which suggested that by t_2, only farmers' attitudes towards frass were associated with their intentions to trial it. Group discussions influenced the predictors of farmers' intentions in two ways. Their beliefs that other farmers would trial insect frass were more important as a predictor of their intentions, and farmers' perceptions of the relative advantages of frass differed between those who were and were not in group discussions. The results and discussion of this research contribute practical insights that can be used when diffusing insect frass as a crop and soil health promoter into the market.

5.7 Acknowledgments

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Wageningen University's Ethics Committee Social Science (ECSS) approved the conduct of this research. Farmers who participated agreed to the research conduct by signing an informed consent. This work was supported by The Dutch Research Council NWO [grant number ALWGK.2016.010].

Appendix A – Kendall's Tau versus Pearson correlation coefficients

Table A1 - Kendall's tau correlations, means and standard deviations for TPB indicators (t_1)

Variable		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Attitude (instrumental)$_1$	1													
2	Attitude (instrumental)$_2$	**0.52**	1												
3	Attitude (instrumental)$_3$	**0.40**	**0.42**	1											
4	Attitude (experiential)$_1$	**0.52**	**0.54**	**0.41**	1										
5	Social Norm (injunctive)$_1$	0.21	0.07	0.26	0.11	1									
6	Social Norm (injunctive)$_2$	0.25	0.12	0.29	0.31	**0.62**	1								
7	Social Norm (descriptive)$_1$	0.41	0.26	0.30	0.29	0.36	0.28	1							
8	PBC (capacity)$_1$	0.10	0.12	0.13	0.09	0.06	-0.01	0.34	1						
9	PBC (capacity)$_2$	-0.04	0.07	-0.07	-0.05	0.09	0.01	0.11	0.40	1					
10	PBC (autonomy)$_1$	0.03	-0.03	-0.20	0.02	-0.04	0.18	0.03	0.03	0.13	1				
11	PBC (autonomy)$_2$	0.02	0.01	0.10	0.15	-0.17	-0.16	-0.01	0.00	-0.01	-0.30	1			
12	Intention$_1$	0.57	0.52	0.38	0.53	0.20	0.32	0.50	0.22	0.09	-0.01	0.21	1		
13	Intention$_2$	0.40	0.37	0.52	0.58	0.31	0.30	0.48	0.32	0.06	-0.04	0.12	**0.61**	1	
14	Intention$_3$	0.39	0.37	0.30	0.48	0.19	0.20	0.44	0.40	0.17	0.01	0.10	**0.55**	**0.67**	1
Mean		3.29	3.49	3.04	3.33	2.58	2.59	2.74	3.67	4.02	3.41	2.50	3.00	2.84	3.50
Std. Dev.		0.79	0.82	0.85	0.71	1.01	1.07	1.12	1.12	1.06	1.28	1.01	0.94	0.94	1.07

PBC: Perceived Behavioral Control

Bolded values indicate the correlations for within-constructs that are combined in this research. Correlations are derived from t_1 questionnaire data.

Table A2 – Pearson correlations for TPB indicators (t_1)

Variable		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Attitude (instrumental)$_1$	1													
2	Attitude (instrumental)$_2$	**0.55**	1												
3	Attitude (instrumental)$_3$	**0.46**	**0.46**	1											
4	Attitude (experiential)$_1$	**0.52**	**0.46**	**0.47**	1										
5	Social Norm (injunctive)$_1$	0.12	0.16	0.26	0.09	1									
6	Social Norm (injunctive)$_2$	0.22	0.17	0.35	0.39	**0.68**	1								
7	Social Norm (descriptive)$_1$	0.52	0.38	0.40	0.39	0.39	0.32	1							
8	PBC (capacity)$_1$	0.26	0.12	0.25	0.16	0.07	-0.04	0.44	1						
9	PBC (capacity)$_2$	0.02	0.04	-0.19	0.13	-0.13	0.14	0.01	-0.09	1					
10	PBC (autonomy)$_1$	0.08	-0.05	0.13	0.18	-0.24	-0.19	0.00	0.12	-0.35	1				
11	PBC (autonomy)$_2$	0.09	0.00	0.02	-0.05	0.05	-0.05	0.12	0.43	0.05	0.04	1			
12	Intention$_1$	0.61	0.58	0.48	0.61	0.28	0.43	0.65	0.32	0.04	0.19	0.11	1		
13	Intention$_2$	0.52	0.46	0.57	0.66	0.38	0.41	0.62	0.44	0.05	0.09	0.13	**0.74**	1	
14	Intention$_3$	0.49	0.41	0.44	0.58	0.17	0.25	0.54	0.51	-0.03	0.16	0.20	**0.68**	**0.77**	1

PBC: Perceived Behavioral Control

Bolded values indicate the correlations for within-constructs that are combined in this research. Correlations are derived from t_1 questionnaire data.

Table A3 - Kendall's tau correlations, means and standard deviations for TPB indicators (t_2)

Variable		15	16	17	18	19	20	21	22	23	24	25	26	27	28
15	Attitude (instrumental)$_1$	1													
16	Attitude (instrumental)$_2$	**0.43**	1												
17	Attitude (instrumental)$_3$	**0.44**	**0.28**	1											
18	Attitude (experiential)$_1$	**0.35**	**0.21**	**0.39**	1										
19	Social Norm (injunctive)$_1$	0.38	0.18	0.61	0.41	1									
20	Social Norm (injunctive)$_2$	0.50	0.25	0.49	0.44	**0.44**	1								
21	Social Norm (descriptive)$_1$	0.36	0.08	0.25	0.42	0.15	0.46	1							
22	PBC (capacity)$_1$	-0.09	-0.25	-0.06	0.25	-0.03	0.04	0.10	1						
23	PBC (capacity)$_2$	0.01	-0.21	0.20	0.27	0.26	0.16	-0.03	0.33	1					
24	PBC (autonomy)$_1$	0.08	0.02	-0.05	0.12	0.13	0.04	0.10	0.25	-0.11	1				
25	PBC (autonomy)$_2$	-0.11	-0.33	-0.17	-0.04	-0.11	0.01	-0.02	0.06	-0.08	0.16	1			
26	Intention$_1$	0.45	0.18	0.42	0.38	0.36	0.36	0.39	0.03	0.10	-0.04	0.09	1		
27	Intention$_2$	0.62	0.15	0.43	0.49	0.37	0.51	0.51	0.07	0.16	0.09	0.07	**0.78**	1	
28	Intention$_3$	0.16	0.29	0.23	0.44	0.25	0.17	0.26	0.08	0.10	-0.13	0.05	**0.49**	**0.38**	1
Mean		3.18	3.44	2.69	3.22	2.72	2.65	2.83	4.02	4.22	3.94	2.66	2.85	2.96	3.61
Std. Dev.		0.91	0.73	1.00	0.88	1.21	1.08	1.00	0.95	0.84	1.04	0.90	0.92	0.84	0.91

PBC: Perceived Behavioral Control

Bolded values indicate the correlations for within-constructs that are combined in this research. Correlations are derived from t_2 questionnaire data.

Table A4 – Pearson correlations for TPB indicators (t_2)

Variable		15	16	17	18	19	20	21	22	23	24	25	26	27	28
15	Attitude (instrumental)$_1$	1													
16	Attitude (instrumental)$_2$	**0.50**	1												
17	Attitude (instrumental)$_3$	**0.51**	**0.32**	1											
18	Attitude (experiential)$_1$	**0.38**	**0.27**	**0.42**	1										
19	Social Norm (injunctive)$_1$	0.42	0.27	0.71	0.48	1									
20	Social Norm (injunctive)$_2$	0.61	0.31	0.57	0.49	**0.56**	1								
21	Social Norm (descriptive)$_1$	0.38	0.05	0.31	0.46	0.20	0.51	1							
22	PBC (capacity)$_1$	-0.06	-0.27	0.01	0.37	0.03	0.09	0.17	1						
23	PBC (capacity)$_2$	0.08	0.04	0.02	0.07	0.20	0.10	0.05	0.25	1					
24	PBC (autonomy)$_1$	-0.09	-0.33	-0.17	-0.02	-0.11	0.04	0.05	0.15	0.16	1				
25	PBC (autonomy)$_2$	0.01	-0.27	0.19	0.39	0.29	0.21	0.15	0.52	-0.14	-0.01	1			
26	Intention$_1$	0.54	0.19	0.50	0.52	0.48	0.45	0.39	0.13	-0.06	0.10	0.27	1		
27	Intention$_2$	0.66	0.17	0.51	0.63	0.51	0.59	0.53	0.20	0.05	0.07	0.36	**0.85**	1	
28	Intention$_3$	0.22	0.23	0.24	0.51	0.33	0.21	0.35	0.16	-0.19	0.14	0.32	**0.59**	**0.52**	1

PBC: Perceived Behavioral Control

Bolded values indicate the correlations for within-constructs that are combined in this research. Correlations are derived from t_2 questionnaire data.

Appendix B – Investigation of Model A

Table B1 – Investigation of Model A

Model Spec.	A.1	A.2	A.3	A.4	A	A with dummy
Exogenous constructs inserted	1	2	3	4	1 - 4	1 - 8
Intercept					-0.92 * (0.43)	-1.01 · (0.55)
1. Attitude	1.08 *** (0.15)				0.76 *** (0.15)	0.74 ** (0.23)
2. Social Norm (descriptive)		0.51 *** (0.10)			0.19 * (0.08)	0.14 (0.14)
3. Social Norm (injunctive)			0.35 * (0.14)		0.13 (0.09)	0.14 (0.14)
4. Perceived Behavioral Control $(Capacity)_1$				0.38 *** (0.10)	0.19 ** (0.06)	0.25 * (0.10)
5. Attitude x Group Discussion						0.07 (0.23)
6. Social Norm (descriptive) x Group Discussion						0.08 (0.19)
7. Social Norm (injunctive) x Group Discussion						0.02 (0.17)
8. Perceived Behavioral Control $(Capacity)_1$ x Group Discussion						-0.12 (0.12)
Adjusted R^2	**0.54**	**0.41**	**0.12**	**0.20**	**0.67**	**0.64**

*The level of significance is denoted with the following: *** for $P < 0.001$, ** for $P < 0.01$, * for $P < 0.05$ and · for $P < 0.10$. Robust standard errors (provided in parentheses below each coefficient) were used to compute the p values. The dummy variable was assigned 1 for Group A (those in the group discussion) and 0 for Group B (those not in the group discussion).*

Appendix C – Investigation of Models B and C

Table C1 – Investigation of Models B and C

Model Spec.	B (without dummy)	C.1	C.2	C.3	C.4	C
Exogenous constructs inserted	**1 - 4**	**1 & 5**	**2 & 6**	**3 & 7**	**4 & 8**	**1 - 8**
Intercept	0.31 (0.70)	0.74 (0.45)	2.10 *** (0.53)	2.01 *** (0.34)	2.35 ** (0.67)	0.33 (0.47)
1. Attitude	0.54 * (0.21)	0.75 *** (0.14)				0.80 ** (0.27)
2. Social Norm (descriptive)	0.18 (0.14)		0.33 * (0.20)			0.00 (0.12)
3. Social Norm (injunctive)	0.08 (0.13)			0.40 ** (0.12)		-0.01 (0.17)
4. Perceived Behavioral Control $(Capacity)_1$	0.10 (0.14)				0.16 (0.16)	0.05 (0.16)
5. Attitude x Group Discussion		0.05 (0.06)				-0.44 (0.37)
6. Social Norm (descriptive) x Group Discussion			0.07 (0.05)			0.48 · (0.27)
7. Social Norm (injunctive) x Group Discussion				0.04 (0.07)		-0.02 (0.25)
8. Perceived Behavioral Control $(Capacity)_1$ x Group Discussion					0.09 (0.05)	0.06 (0.17)
Adjusted R^2	**0.43**	**0.39**	**0.21**	**0.26**	**0.04**	**0.47**

*The level of significance is denoted with the following: *** for $P < 0.001$, ** for $P < 0.01$, * for $P < 0.05$ and · for $P < 0.10$. Robust standard errors (provided in parentheses below each coefficient) were used to compute the p values. The dummy variable was assigned 1 for Group A (those in the group discussion) and 0 for Group B (those not in the group discussion).*

Appendix D – Investigation of Models D and E

Table D1 – Investigation of Models D and E

Model Spec.	D	E.1	E.2	E.3	E
Exogenous constructs inserted	**1 – 9**	**1-3 & 10-12**	**4-6 & 13-15**	**7-9 & 16-18**	**1 - 18**
Intercept	0.05 (1.07)	-0.55 (0.79)	2.14 *** (0.48)	3.56 *** (0.51)	0.82 (0.83)
1. Relative Advantage$_1$	0.63 * (0.23)	0.83 *** (0.13)			1.11 *** (0.21)
2. Relative Advantage$_2$	0.36 ** (0.12)	0.25 * (0.10)			0.29 * (0.13)
3. Relative Advantage$_3$	-0.02 (0.24)	-0.07 (0.12)			-0.36 (0.24)
4. Compatibility$_1$	0.15 (0.16)		-0.01 (0.24)		-0.14 (0.19)
5. Compatibility$_2$	0.01 (0.17)		0.34 (0.26)		0.23 (0.14)
6. Compatibility$_3$	-0.12 (0.17)		-0.06 (0.22)		-0.18 (0.17)
7. Complexity$_1$	0.00 (0.11)			0.03 (0.16)	-0.08 (0.14)
8. Complexity$_2$	-0.17 (0.13)			0.04 (0.15)	-0.29 (0.21)
9. Complexity$_3$	0.00 (0.10)			-0.24 · (0.13)	-0.06 (0.07)
10. Relative Advantage $_1$ x Group Discussion		-0.59 * (0.27)			-0.90 ** (0.27)
11. Relative Advantage $_2$ x Group Discussion		0.14 (0.16)			0.03 (0.20)
12. Relative Advantage $_3$ x Group Discussion		0.49 * (0.24)			0.70 * (0.29)
13. Compatibility$_1$ x Group Discussion			0.32 (0.36)		0.42 (0.25)
14. Compatibility$_2$ x Group Discussion			-1.01 ** (0.34)		-0.57 (0.36)
15. Compatibility$_3$ x Group Discussion			0.76 ** (0.26)		0.30 (0.50)
16. Complexity$_1$ x Group Discussion				-0.17 (0.25)	-0.10 (0.27)
17. Complexity$_2$ x Group Discussion				-0.39 · (0.23)	0.00 (0.34)
18. Complexity$_3$ x Group Discussion				0.52 * (0.25)	0.19 (0.19)
Adjusted R^2	**0.39**	**0.44**	**0.10**	**0.06**	**0.51**

*The level of significance is denoted with the following: *** for P < 0.001, ** for P < 0.01, * for P < 0.05 and · for P < 0.10. Robust standard errors (provided in parentheses below each coefficient) were used to compute the p values. The dummy variable was assigned 1 for Group A (those in the group discussion) and 0 for Group B (those not in the group discussion).*

CHAPTER 6

General Discussion

Arable farmers continually face restrictions on the use of various chemical plant protection products; reliable and long-term crop and soil health promoting innovations are thus needed. Insect frass not only has the potential to improve crop and soil health but is also a recyclable by-product. Therefore, frass represents a circular agricultural input created on insect farms that can be used on arable farms. As researchers continue to investigate the extent of frass' effectiveness as a crop and soil health promoter, this thesis analyzes frass' potential from the farmers' perspective. More specifically, the objective of this research was to investigate factors that influence arable farmers' intentions to trial insect frass. To meet this objective, four studies were conducted and presented in Chapters 2-5. Chapters 2 and 3 describe insect frass as a crop and soil health promoter in terms of its characteristics, application and the expected net change in profit from applying it on conventional and organic arable farms. Chapters 4 and 5 then explore the factors that influence farmers' decision-making processes and intentions to trial frass. Figure 6.1 provides a conceptual framework that corresponds with the chapters in this thesis.

To conduct the research, first, the information on the characteristics of frass collected in Chapter 2 was summarized in an informational video and presented to the farmers in Chapters 4 and 5. The economic analysis of frass from Chapter 3 was however not provided in the informational video. Chapter 3 – the last of the four studies conducted – capitalized on what the experts learned over the four years of experiments, as this thesis was conducted simultaneously with field and lab experiments testing frass' effectiveness as a crop and soil health promoter. Without information provided on frass' economic analysis, farmers gave more focus to non-economic considerations that influenced their decision-making.

By fulfilling the research objective, this thesis offers both practical and scientific contributions. Practically, this research informs arable farmers, insect rearers and policy makers on how to successfully diffuse frass into the market as a circular agricultural input. It does so by exploring farmers' decision-making processes towards the use of frass, and therefore identifying potential drivers and barriers of frass' dissemination as a crop and soil health promoter on Dutch arable farms. Scientifically, this thesis explores the effects of group discussions on the decision-making process, which is sparsely investigated in the agricultural context. In addition, this thesis serves as one of the few examples of "acceptability research" or research that investigates an innovation's diffusion prior to its adoption. Acceptability research plays an important role in guiding the R&D process of an innovation and forecasting potential barriers that could impede the adoption of innovations (Rogers, 2003).

The remainder of this chapter begins with a synthesis of the results, then offers some implications for businesses and policy makers, reflects on the research methods, postulates avenues of future research and finally states the conclusions of this thesis.

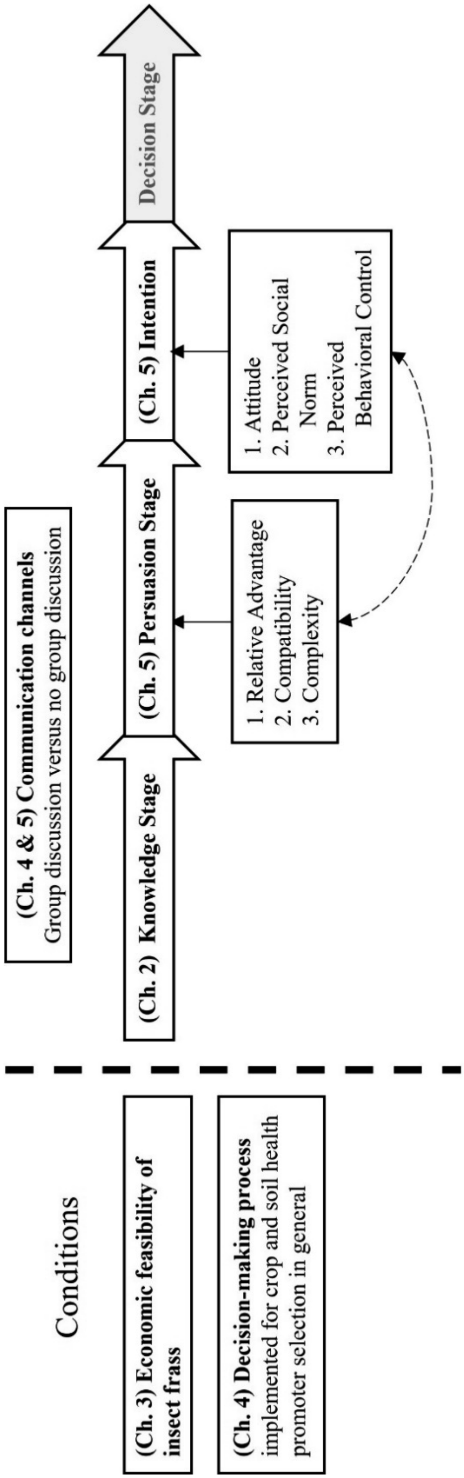

Figure 6.1 - Conceptual framework

6.1 Synthesis of the results

The results of this thesis are synthesized into three themes: the influence of group discussions on the decision-making process and stimulators and barriers of farmers' adoption of frass.

6.1.1 The influence of group discussion on the decision-making process

Evidence from Chapters 4 and 5 suggests that group discussions influenced farmers' decision-making. From Chapter 4, the resulting decision-making maps (or Hierarchal Value Maps; HVM) show more attributes are linked to consequences for those that were in the group discussion compared to those who were not. For attributes to appear in the HVM, at least five farmers had to have linked them to the same consequences or values directly or indirectly. Therefore, those in the group discussions considered more similar attributes that were linked to similar consequences and goals. The results therefore provide evidence that those in the group discussion developed a decision-making process that was more alike and more unified regarding what crop and soil health promoter attributes are important and why they are important.

Results from Chapter 5 also provide evidence of group discussions influencing farmers' decision-making. The regression results suggest that the descriptive social norm, or what a farmer believes another farmer would do, is more associated with intentions for those in the group discussion than those who were not. Furthermore, the attitudes of those in the group discussion may also have been less associated with intentions than those who were not. Though, the coefficient for the attitudes of those in the group discussion was exceptionally negative (-0.44; p-value = 0.24), it was not deemed statistically significant in this research. An experiment with a larger sample size would need to be conducted to confirm this supposition. Supposing that attitudes are found to be less associated with intentions for those in the group discussion, and the descriptive social norm is subsequently more associated with intentions, a shift in motivations would be taking place. Such a shift would be in line with the conclusions from Lewin (1952) who found that an individual will tend to follow the group's ideology; if the group changes, the individual's ideology will also more likely change. In a way, those in a group discussion, instead of relying on their own attitudes, would apply a heuristic shortcut where they could base their decisions on what they believe other farmers in the group would do (Farrow et al., 2017).

The results regarding the role of social influences on decision-making compliment other agricultural studies. For instance, information sharing and social learning between neighboring farms (Marra et al., 2003) and following other farmers on Twitter (Rust et al., 2022) were critical influences on farmers' technology adoption. Social norms and peer pressure were found in reviews by Prokopy et al. (2008) and Liu et al. (2018) to influence farmers' adoption of best management practices. The review by Dessart et al. (2019) identified descriptive norms among other social factors that influence farmers' adoption of sustainable farming practices. More specifically, social comparisons, conformism and conditional cooperation were among the descriptive norm forces that influenced farmers' adoption decisions. More specifically related to group discussion research, the results reflect what was found by Werner and Stanley (2011) whose objective was to persuade participants to use less toxic home and garden products and use more nontoxic alternative. They found that one of the factors influencing their participants' persuasion was a normative influence.

Besides influencing descriptive social norms, group discussions also provided an opportunity to gain insights into farmers' initial questions and concerns (Chapters 4 and 5). Likewise, Lewin (1952) wrote, "A group discussion gives the leader a better indication of where the audience stands and what particular obstacles have to be overcome." For the farmers, the group discussions are a way of sharing knowledge in a non-competitive environment, which can accelerate farmers' decision-making (Deffontaines et al., 2020). Furthermore, having the opportunity to address farmers' questions with relevant and reliable information is essential for farmers' decision-making (Llewellyn, 2007).

6.1.2 Stimulators of frass adoption

Two potential stimulators of farmers' adoption of frass became evident in this thesis – (1) group discussions and (2) the circular and environmental aspects of frass.

Group discussions served as extrinsic motivators that changed farmers' considerations regarding the importance of frass' characteristics. Evidence from Chapter 4 showed that, for those who did not participate in group discussions, reducing the soil's long-term susceptibility to pests and disease was most associated with their intentions to trial frass. This parallels the HVMs in Chapter 4 where the main line of reasoning to adopt crop and soil health promoters was to improve various aspects of the soil. However, for those in the group discussion, there were more lines of reasoning for using crop and soil health promoters than for just improving the soil. Chapter 5 provides more insight into what considerations changed during the group discussion. Specifically, the relative advantages of frass regarding soil health improvement were less associated with intentions for those in the group discussion, and the relative advantages of frass regarding soil quality improvement were more associated with intentions. The evidence from Chapters 4 and 5 thus further supports that the group discussions influenced the farmers' decision-making by giving them more nuanced considerations regarding the importance of various characteristics of frass.

Chapters 2 and 3 determined that, as a crop and soil health promoter, frass is expected to contribute organic matter and nutrients to the soil, protect young plants against pests and diseases, and reduce the use of harmful chemicals. The circular and environmentally friendly aspects of insect frass may serve as sources of intrinsic motivation for farmers (Greiner & Gregg, 2011). Insect frass (1) is derived from a highly efficient food and protein production (2) is a recyclable by-product and (3) can be applied to farmland in an attempt to rejuvenate the soil by improving its resilience in the pursuit of more sustainable agriculture. The farmers that care for the land as the invaluable resource it is, secure the future of food production.

Frass in this way can appeal to the moral responsibilities felt by farmers (Dessart et al., 2019). In Chapter 4, the aggregated results show that many of the farmers expressed various environmental concerns and considerations when making decisions. Previous research found that farmers' decisions to adopt sustainable practices were influenced by their concerns for the environment (Best, 2010; Läpple & Rensburg, 2011; Liu et al., 2018). Similarly, as was mentioned during the group discussion, the farmers are motivated and willing, even wanting to use more sustainable inputs, but there must be some certainty that the products work.

6.1.3 Barriers of frass adoption

The basic premise of stimulating farmers' uptake of frass assumes that frass functions effectively as a crop and soil health promoter. The uncertainties around frass' performance are current barriers to its diffusion. The following discussion delves into the concerns and skepticisms towards the use of frass derived from the group discussions with farmers.

One of the main concerns farmers had regarding the use of frass pertained to its cost effectiveness (Chapters 4 and 5). These concerns are in line with those discussed by Goldberger and Lehrer (2016) who found that high cost was a reason for farmers' non-adoption of biological control practices in US orchards. As the research of Chapter 3 took place after the group discussions, the estimations of frass' economic performance had not been presented to the farmers. Furthermore, the results of Chapter 2 determined that the experts were uncertain of frass' influence on farmers' short and long-term production costs. Therefore, no information was provided to the farmers relating to the costs and benefits associated with frass. Such information is, however, crucial for farmers to be able to make practical decisions (Mandryk, 2016; Pathak et al., 2019). The results from Chapter 4 also show evidence of the importance of the cost effectiveness for crop and soil health promoting products in farmers' decision-making process. The attribute "Low price / Good price quality" was important for all farmers and was linked to the farmers' ability to earn a living and continue farming. Notably, this was the only attribute that was shared by those who were and were not in the group discussions, which suggests that the attribute is relevant for all farmers' decision-making processes.

During the group discussions, farmers also expressed concerns regarding frass' effectiveness as a health promoter (Chapters 4 and 5). They felt that more evidence was needed to prove frass' reliability (Chapters 4 and 5). The results of Chapter 4 show that all farmers prefer crop and soil health promoting products that ultimately improve crop yield, reduce production-related costs, do not harm the environment, contribute to the end products' quality and help them earn a living while continuing to farm. Frass' health promoting effectiveness therefore takes a central role in the farmers' decision-making process. Similar findings are shared by other studies. For instance, Wensing et al. (2019) found that the extent to which German farmers perceived that practices related to the valorization of by-products were effective explained their interest in them. Similarly, Goldberger and Lehrer (2016) identified the perceived questionable effectiveness as a barrier to farmers' adoption of biological control practices in US orchards.

Finally, farmers also discussed aspects of applying frass such as what machines would be needed and how easy it would be to apply (Chapters 4 and 5). Likewise, the results of Chapter 4 show also that farmers in the group discussions relate the attribute "Easy to apply and use/fits the machine" with influencing financial costs and work efficiency. These concerns are reflected by Aubert et al. (2012) who identified perceived usefulness and ease of use as reasons barriers to farmers' adoption of precision agriculture technologies. However, the results of Chapter 5 suggest that the farmers' intentions are not associated with their perceptions of frass' compatibility nor complexity characteristics. This may be explained by the lack of information provided regarding how frass would be applied on the farm. The informational video explained only a generic idea of how and when frass should be applied, but arguably, there were not enough details provided for the farmer to image how it would work on his/her own farm. This mental exercise can be seen as a sort of vicarious trial of the innovation and is an important component for decision-making (Rogers, 2003).

Adoption barriers for using frass relate mostly to the lack of information regarding its cost-effectiveness, effectiveness as a crop and soil health promoter and how it should be applied. Prior to disseminating frass into the market, these properties and characteristics of frass need to be further researched and clarified.

6.2 Implications for business and policy

Business implications from this research are two-fold: for arable farmers and for frass suppliers. The clearest implications for arable farmers come from Chapters 2 and 3 where the potential consequences of using frass are defined. The results of Chapters 2 and 3 show that frass is expected to have positive influences on crop and soil health. It is not expected to have negative consequences for the environment nor on their own health or that of the consumers, and it is an economically attractive product especially if adopted for years. Farmers should understand that the use of insect frass requires that they monitor the health of the crops as is done using integrated pest management practices. Also along those lines, farmers would be encouraged to adopt more preventative measures that aim to build up the soil's natural resilience. In doing so, less curative, chemical interventions will be required, which benefits farmers and consumers alike.

During the group discussions, farmers asked for more details on, for example, how frass should be used and how effective it is with different crops and under various field conditions. For frass suppliers to stimulate farmers' uptake of frass, they should ensure that there is enough quality information available for early adopters to be able to make a "judicious" decision regarding the use of frass (Rogers, 2003). As early adopters are often opinion leaders of their social networks, they make well-calculated decisions (Llewellyn, 2007; Rogers, 2003). With limited information available to farmers, the use of frass becomes riskier.

Therefore, once more knowledge is available, it should be translated into relevant information for arable farmers. Demonstrating the application of frass and displaying its subsequent crop health effects on demo farms would help in lowering the adoption barrier (Goldberger et al., 2013; Pannell et al., 2006; Rogers, 2003).

Frass suppliers can also learn from Chapters 4 and 5 to gain insights into farmers' impressions of frass, what guides their decision-making processes, what drives their intentions, and what role group discussions play in influencing the drivers of farmers' intentions. For example, knowing the attributes that are most important to farmers to be able to achieve their goals (results from Chapter 4) is relevant knowledge to the frass suppliers. To market frass effectively, information should be supplied that explains frass' attributes, especially those identified in the HVMs, and how frass's attributes can achieve the desired consequences and goals.

Furthermore, group discussions can be useful in stimulating farmers' adoption of frass if organized and conducted sensibly. Considering that insect frass is only recently available on the market as a fertilizer (European Commission, 2021) and not yet available as a crop and soil health promoter, there are only a handful of farmers who have experience using it. Some of the first critical groups of farmers trialing insect frass are the early adopters. According to Rogers (2003), early adopters are often looked up to by later-adopters; in other words, they are often opinion leaders of their social system. As opinion leaders, they carefully examine innovations, trial them, and in the case of a positive experience, communicate these findings to others. It would therefore be valuable to identify and work with the early adopters of frass. By cooperating with these farmers who have had positive experiences with frass and organizing group discussions where they can share their experiences with farmers of comparable background, the uptake of frass may be stimulated (Rogers, 2003).

Frass suppliers should also consider how farmers may interpret the economic analysis results of Chapter 3. There are several economically oriented decision-making rules that farmers could potentially abide by when considering to trial frass. The rules they follow depend on, among other factors, the farmers' aversion to risk (Kay et al., 2012). Rogers (2003) suggested that early adopters of innovations are more capable of coping with risk than late adopters. Therefore, early adopters may implement decision rules that give less emphasis to the economic risks of using an innovation. For example, farmers that follow the "Most Likely Outcome" decision rule choose a strategy that has the highest financial return based on the most probable scenario. Using the "Maximum Expected Value" decision rule, the farmer chooses the strategy with the highest expected financial return (Kay et al., 2012). As the expected net change in net profit by using frass was positive (Chapter 3), farmers that follow these two decision rules would be motivated to trial insect frass; therefore, early adopters may be intrigued to trial frass. However, late adopters tend to be more risk averse and would likewise potentially follow a "Safety First" decision strategy – to select the available option that has the least harmful worst-case scenario. Notably, in the worst-case scenario based on the input from experts, using frass would result in a negative net change in profit (Chapter 3). For those that are more risk averse, the results of Chapter 3 would dissuade them from trialing insect frass. Furthermore, the first year frass is implemented has the most uncertainty regarding a positive net change in profit, and as such, the first year of applying frass has the highest chance of returning lower profits than not having applied frass. Moreover, for the farmers that strive for short-term profits over achieving long-term objectives (Ingram et al., 2014; Mandryk, 2016); insect frass is not a product that is suitable for them. Using insect frass should be sought not only for its long-term economic potential, but for the circular and environmental contributions it supplies.

In order for insect producers to be able to capitalize on the full potential of insect frass as a crop and soil health promoter, there must be more support from policy makers. A new regulation (Commission Regulation (EU) 2021/1925) was adopted that standardized insect frass processing across the EU (European Commission, 2021; International Platform of Insects for Food and Feed, 2021). Processing the frass is a necessary step in order to avoid unwanted side effects. The EU-wide standard was the first regulation made for insect frass as a fertilizing product in agriculture (International Platform of Insects for Food and Feed, 2021). Furthermore, given the findings from this research, frass is more than an organic fertilizer; it is expected to reduce the presence of pests and diseases, thus reducing the need for some of the currently used chemical insecticides and fungicides (Chapter 3; (Barragán-Fonseca et al., 2022)). Therefore, a next step in legislation would be to develop the standards required to use for insect frass as a crop and soil health promoter. With such legislation, insect farmers can recycle their by-products in a value-generating manner; arable farmers can make use of natural inputs that can make their soil healthier and more resilient, and consumers will be satisfied with the shift towards circular and more natural agricultural production.

6.3 Reflection on materials and methods

The methods in this thesis were deliberately and carefully chosen to meet the research objective. Reflecting back on the challenges faced and decisions made provides useful insights for those conducting similar research in the future. The data collection of this thesis spanned from 2019-2022. During this time, the COVID-19 pandemic arose and brought with it many social restrictions. The restrictions and precautions made the data collection process challenging to logistically plan and conduct. Ultimately, the challenges negatively influenced the sample size acquired in the studies with farmers.

In retrospect, more interviews and group discussions could have been conducted online. However, with the few interviews that were conducted virtually, the connection between the researchers and farmers was noticeably distanced. Conducting interviews in person, especially at the farmer’s location, brought with it valuable benefits some of which included a tour around the farm, discussions on the farm’s history, and brief contact with other family members. Though these additions were not a part of the research output, it is vital for researchers to make a genuine effort to get to know their participants and vice versa, so farmers have more trust in the researcher.

Trust in the information's source matters for farmers' decision-making (Liu et al., 2018). During the group discussions, the farmers emphasized the importance of independent and unbiased research investigating the usefulness and effectiveness of frass. Regardless of this research having no competing financial interests or relations that influenced the conduct or output of the research, there seemed to be an air of skepticism from the farmers. The gap between one providing information about an innovation and one receiving the information is a well-known problem in the diffusion process (Rogers, 2003). Farmers' skepticism and distrust in institutions was also identified in previous studies (Prager & Posthumus, 2010; Rust et al., 2020). Including famers more intimately in the research process and conduct could potentially aid in reducing skepticism and improving their uptake of innovations (Chambers et al., 1989; Morris & Bellon, 2004; van de Fliert & Braun, 2002). Apart from establishing trust, valuable insights as well as an appreciation for their livelihoods can be gained.

Alternative methods that did not rely on face-to-face contact (e.g., online interviews or surveys) would have been more efficient during the severe COVID-19 restrictions; however, such methods may have been less effective. Given the exploratory nature of this thesis, the knowledge gained by conducting the in-depth quantitative and qualitative explorations of farmers' decision-making processes contributes valuable insights, despite the limited sample size. Notably, the methods utilized in this research weigh more heavily on the qualitative side. As there was very little information available regarding how insect frass would work as a crop and soil health promoter, allocating two chapters to characterizing frass was useful. A mix of qualitative and quantitative methods were conducted to provide complimentary insights. The means-end chain analysis of Chapter 4 is a qualitative/quantitative hybrid approach. The content of the group discussion provides qualitative insights, and the regression analysis of Chapter 5 provides quantitative insights. Quantitative data can express results numerically, and in that way can better identify trends and patterns in data. However, the quantitative approach of Chapter 5, for instance, was limited in scope to the hypotheses that were set out to be tested. Qualitative research provides an opportunity to go further in-depth to topics that arise. By applying a mixed methods approach and employing theoretical perspectives across domains, the results of this thesis are rich and diverse.

A second decision made during this research was in regard to the informational video. Knowing that the information supplied in the video would be for most of the participants the first and only information they had about frass, the content and presentation was vital. In retrospect, an alternative approach could have been taken to construct the video. The economic feasibility of frass (Chapter 3) could have been conducted first, and the findings could have been included in the video. This approach would have been appreciated by the farmers, as many of the questions received by the research team pertained to the costs and financial benefits related to frass. However, deliberations over the economic forecast might have dominated the discussions. Also including the economic aspects in the video would have made the video longer, which could have resulted in more dropouts, especially for those who did not participate in the group discussion.

I would presume that had farmers seen the economic analysis of frass (Chapter 3), the results of the Chapter 4 might have changed slightly, but the results of Chapter 5 would not have been influenced. In Chapter 4, the content of the informational video may have triggered the farmers to think about the various characteristics presented and were in a sense reminded of their importance. Had the expected economic consequences of using frass been explained, maybe the characteristic relating to good price quality would have been more prevalent in all of the HVMs. In Chapter 5, for those in the group discussion, having seen the economic analysis may have resulted in more opinionated deliberation. Such deliberation may have intensified the effect of the descriptive norm as farmers may have formed and shared more definitive opinions regarding their interest in trialing frass.

6.4 Future research

This thesis provides a foundation for understanding what influences arable farmers' intentions to trial insect frass. However, more research is needed to determine the degree of frass' effectiveness as a crop and soil health promoter. In addition to research into frass, other innovative approaches should continue to be researched for holistically improving the soil's resilience and biodiversity while reducing the reliance on chemical inputs.

Once frass is available on the market as a crop and soil health promoter, research should continue to follow the farmers' decision-making process. Some investigations that could take place include determining what sorts of farmers choose to adopt insect frass, what are the reasons other farmers do not adopt frass, what are the barriers impeding adoption in the later phases, can the barriers be reduced, and can tools like group discussions accelerate the dissemination of frass to farmers typically characterized as late adopters.

Meanwhile, while frass is not available as a crop and soil health promoter, other facets of intentions can be investigated. Following the review by Dessart et al. (2019), dispositional, cognitive and social factors influence farmers' adoption behavior. For example, dispositional factors can include farmers' risk tolerance and resistance to change or farm resilience (Slijper et al., 2020). Interesting cognitive factors that could play a role in farmers' adoption decisions may also be time discounting and perceived risks (Dessart et al., 2019). To investigate the cognitive factors, a choice experiment could be conducted to test how various degrees of payoff over time influence farmers' adoption. Additionally, perceived risks could be investigated in the choice experiment by testing various degrees of frass' effectiveness.

An interesting social factor to explore could be to expand on the findings in this thesis regarding the role of the descriptive norm and investigate how concepts like social comparison, conformism and conditional cooperation may be influencing the decision-making behavior. Furthermore, this thesis provides evidence that group discussions can be used as tools to influence the decision-making process. Future adoption research in agriculture should follow similar methodological procedures to test if the effects of group discussions can be seen in other cases as well.

6.5 Main conclusions

- Frass can potentially be produced as a granulate-type compost or impregnated into a biodegradable seedling cup and should be applied next to the seed or by the roots of the seedlings during planting (Chapter 2).
- Insect frass is expected to reduce the presence of *Brassica* pests by 2-16% and diseases by 11-24% after 8 years and thus reduce the use of various *Brassica* insecticides by 3-50% and fungicides by 18-40% after 8 years (Chapters 2 & 3).
- Insect frass is expected to improve crop yield by 6-16% after 8 years, thereby increasing the expected profit by 9-19% after 8 years (Chapters 2 & 3).
- Farmers select crop and soil health promoters that contribute to the goals of reducing costs (and turning a profit), producing a healthy and quality end product, and not harming the environment nor the farming image (Chapter 4).
- Sharing first impressions of an innovation like the by-products of insect production in a group discussion with farming peers leads to the realization of more salient, though important, considerations regarding crop and soil health promoters (Chapter 4).
- Farmers' participation in group discussions influenced how attributes of crop and soil health promotors and perceived relative advantages of frass were accounted for in the farmers' decision-making processes (Chapters 4 & 5).
- Farmers' intentions to trial insect frass are driven initially by attitudes, descriptive social norms, and perceived behavioral control. Over time, for farmers that do not participate in group discussions, only attitudes towards insect frass are associated with their intentions to trial it (Chapter 5).
- Over time, for farmers that participate in group discussions, their perceptions regarding what other farmers may do are more associated with their intentions to trial frass compared to those who do not participate in group discussions (Chapters 5).

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Summary

As the urgency for more circular and sustainable agriculture increases, more restrictions limit the permitted use of single-solution chemical crop protection products. The by-products from insect production (known as "frass") represent an innovative solution that contributes to the movement towards circular agriculture and is a biological crop and soil health promoter. To get an indication of the potential stimulators and barriers of frass' dissemination into the market, this thesis explored the factors that influence arable farmers' intentions to trial insect frass. The objective was reached by applying a conceptual framework that integrates three theoretical perspectives: the model of Innovation-Decision Process (IDP) from the theory of Diffusion of Innovations (DOI), the Means-End Chain (MEC) Theory and the Theory of Planned Behavior (TPB).

This thesis offers both practical and scientific contributions. Practically, this thesis informs arable farmers, insect rearers and policy makers on how to successfully diffuse frass into the market as a circular agricultural input. Scientifically, this thesis explores the effects of group discussions on the decision-making process and serves as an example of research investigating an innovation prior to its diffusion into the market, both of which are sparsely investigated in the agricultural context.

Chapter 2 investigated experts' knowledge of the characteristics and application of insect frass as a crop and soil health promoter. A two-step elicitation approach was conducted consisting of semi-structured interviews and a Delphi study. The results detail three types of knowledge farmers would need to understand the basic premise of insect frass: what frass is, how it should be used, and how it works as a crop and soil health promoter. In the results, experts explained that frass can potentially be produced as a granulate-type compost or impregnated into a biodegradable seedling cup. To use frass, farmers should apply it next to the roots of each plant during the time of planting. In brief, frass promotes the health of crops and soil, among others via the chitin present in the molted insect skins present in the frass. Chitin acts as a substrate for beneficial microbes. The microbes emit compounds that promote the plant's health by supporting plant resistance against pathogens and pests.

Chapter 3 estimated the net change in profit farmers can expect by utilizing insect frass as an additional product in their array of crop and soil health promoters used in *Brassica* production. A three-step approach was conducted to ultimately construct an economic model. The first two steps consisted of a series of expert elicitations with insect frass experts and crop advisors familiar with *Brassica* production. The final step was the creation of the economic model in the form of a partial budget; inputs for the model were sourced primarily from the expert elicitations and data from the KWIN-AGV (a book of qualitative information from the Netherlands regarding arable farming and field vegetable cultivation). The results determined that frass is expected to reduce the presence of various *Brassica* pests by 2-23% and diseases by 11-24% after 8 years and is subsequently expected to reduce the use of insecticides used in broccoli and Brussels sprouts production by 3-50% and fungicides by 18-40% after 8 years. Frass is expected to improve crop yield by 6-16% after 8 years. The

results from the partial budget showed that frass is expected to return a positive change in net profit, noting that the change in net profit is highest after several years of use. The change in net profit was most sensitive to the estimations of frass' influence on crop yield; this uncertainty makes that using insect frass may not be profitable in the first year depending on the type of production. Of the four types of *Brassica* production analyzed, conventional broccoli production was expected to return the highest net change in profit of approximately €800 in the first year, €2,000 after four years, and €2,300 after eight years.

Chapter 4 examined how farmers make crop and soil health management decisions and investigated how the social context in which farmers received and discussed innovation-related information (specifically information on the use of insect frass as a crop and soil health promoter) influenced their decision-making process. To conduct this research, forty-six farmers first received information about insect frass via an informational video based on the findings of Chapter 2. Half of the farmers then participated in group discussions with other farmers to discuss their first impressions of insect frass; the second half of farmers did not participate in group discussions. Using a Means-End Chain approach, soft-laddering interviews were conducted with all farmers within sixteen days after watching the video. Aggregated hierarchical value maps (HVMs) were constructed to compare the decision-processes of those in group discussions versus those not in group discussions. HVMs were also constructed to distinguish the importance of the considerations integrated in the decision-making process. The results of the research showed that, in general, farmers select crop and soil health promoters that contribute to the goals of reducing costs (and turning a profit), producing a healthy and quality end product, and neither harming the environment nor the farming image. Group discussions influenced aspects of farmers' innovation decision-making process. Specifically, the group discussions led to the realization of less salient though important considerations regarding crop and soil health promoters, some of which pertained to environmental considerations, frass' ease of use and the farming image (and public's support).

Chapter 5 investigated the drivers of arable farmers' intentions to trial insect frass as an input on their farms using two theoretical lenses – the TPB and the IDP. To conduct this research, forty-six farmers first received information about insect frass via an informational video based on the findings of Chapter 2. Immediately after watching the video, all farmers filled in a questionnaire constructed to capture TPB constructs. Half of the farmers then participated in group discussions with other farmers to discuss their first impressions of insect frass; the second half of farmers did not participate in group discussions. Within sixteen days after watching the video, the farmers filled in a second questionnaire constructed to capture TPB and IDP constructs. The results from the ordinary least squares regression models suggest that, based on the TPB regression models from the first questionnaire, farmers' intentions to trial insect frass were initially driven by attitudes, descriptive social norms, and perceived behavioral control. Based on the TPB regression models from the second questionnaire, participating in group discussions strengthened the influence of the descriptive social norm on predicting their intentions. Those who did not participate in group discussions were instead driven only by their attitudes. Based on the IDP regression models, farmers' intentions to trial insect frass were driven by their perceptions of frass' relative advantages over similar products.

Chapter 6 synthesized the results into three themes: the influence of group discussions on the decision-making process and stimulators and barriers of farmers adoption of frass. Following the synthesis discussion, implications for business and policy are described along with a reflection on the materials and methods. Finally, ideas for future research are proposed.

The main conclusions of this thesis are:

- Frass can potentially be produced as a granulate-type compost or impregnated into a biodegradable seedling cup and should be applied next to the seed or by the roots of the seedlings during planting (Chapter 2).
- Insect frass is expected to reduce the presence of *Brassica* pests by 2-16% and diseases by 11-24% after 8 years and thus reduce the use of various *Brassica* insecticides by 3-50% and fungicides by 18-40% after 8 years (Chapters 2 & 3).
- Insect frass is expected to improve crop yield by 6-16% after 8 years, thereby increasing the expected profit by 9-19% after 8 years (Chapters 2 & 3).
- Farmers select crop and soil health promoters that contribute to the goals of reducing costs (and turning a profit), producing a healthy and quality end product, and not harming the environment nor the farming image (Chapter 4).
- Sharing first impressions of an innovation like the by-products of insect production in a group discussion with farming peers leads to the realization of more salient, though important, considerations regarding crop and soil health promoters (Chapter 4).
- Farmers' participation in group discussions influenced how attributes of crop and soil health promotors and perceived relative advantages of frass were accounted for in the farmers' decision-making processes (Chapters 4 & 5).
- Farmers' intentions to trial insect frass are driven initially by attitudes, descriptive social norms, and perceived behavioral control. Over time, for farmers that do not participate in group discussions, only attitudes towards insect frass are associated with their intentions to trial it (Chapter 5).
- Over time, for farmers that participate in group discussions, their perceptions regarding what other farmers may do are more associated with their intentions to trial frass compared to those who do not participate in group discussions (Chapters 5).

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To my parents, you have always been there for me, if not physically, then emotionally. You have supported and encouraged me to learn and work hard my whole life, and I cannot thank you enough for it. Growing up on a farm not only taught me responsibility but also appreciation for the hard work farmers do. This level of understanding came in handy when talking with the farmers in my research. You encouraged me to go to Cornell University (the launch pad of my academic career), accept various internships, pursue study opportunities abroad, and above all to stay in touch with aspects of life that matter most. Thank you for everything you have done and continue to do for me.

Nick, I always looked up to you in grade school, as your academic performance and favor amongst the teachers (ALL of the teachers) was second to none. When you left home to start your education at MIT, you inspired me to look beyond the universities in the area to find the one that fits me best; I had to keep up with my big brother! Thank you for demonstrating the importance of education early on in my life.

My grandparents – Grandma Dee, Grandpa LaVerne, Grandma Diane and Grandpa Jim – have always played an important role in my life. You have always believed in me and encouraged me in my studies and in my goals. Our time together, whether in person or on the phone has always reassured me that life is good, and things will work out. During my PhD, I lost my Grandpa LaVerne, and I just want to give an extra thank you to him for his dedicated work as a farmer but most of all as an endless supporter of me and my endeavors, wherever they took me.

Support comes from all corners of my family: my aunts, uncles, cousins, and in-laws. Despite the physical distance, we manage to share a great deal of our lives. Thank you for encouraging me throughout my PhD by asking how my day was, showing interest in my research and providing moral support.

I have been very lucky to have such amazing people around me, supporting me and working with me. From the bottom of my heart, thank you all.

About the author

Kirstin was born and raised on a hobby livestock farm in Holmen, Wisconsin, USA. She adored the animals and experienced the responsibilities and labors of farming but most especially its charm. Her affinity for working with the animals motivated her to study Animal Science at Cornell University in Ithaca, New York for her bachelor's degree. Her father, Kevin Torgerson, had worked as an agricultural engineer where he designed dairy milking equipment, which further inspired her to specialize in Dairy Nutrition. During her time at Cornell, she took up agricultural internships in Italy and Kenya and studied for a semester at Harper Adams University in Newport, England. These experiences made her comfortable with travelling, working and studying abroad.

Alongside her studies in Cornell, she was involved in calf nutritional studies – her first engagement with research. Though she learned a lot, working in a lab was not her favorite activity, so she looked to study more of the social sciences side of farming. She chose the master's program at Wageningen University in Marketing and Consumer Behavior, which got her in touch with the consumer end of the chain. Her masters also contained an emphasis in Entrepreneurship. Towards the end of the course work, she worked in an entrepreneurial-oriented project for a care farm in India. The experience was a step back from the consumer side of the chain and focused on helping the farmer meet his business objectives. She enjoyed working with the farmer and appreciated his perspective. Therefore, when the opportunity for this research topic in examining decision making from the farmer's perspective presented itself as a PhD position, she felt it was a good fit and thus began her PhD research at Wageningen University's Business Economics group.

Education certificate

Kirstin Foolen-Torgerson
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Name of the learning activity	Department/Institute	Year	ECTS*
A) Project related competences			
A1 Managing a research project			
WASS Introduction Course	WASS	2018	1
Writing PhD Research Proposal	WUR	2018	3
'Adopt a Bug? Farmers' motives for using insects and insect waste streams to promote soil, plant, and animal health'	EAAE Seminar, Uppsala, Sweden	2019	1
'Towards circular agriculture – exploring insect waste streams as a crop and soil health promoter'	Insects to Feed the World, Online Conference	2020	1
Business Economics Department PhD Meetings (multidisciplinary content)	WUR	2018-2022	2
Consortium meetings	WUR	2018-2022	1
A2 Integrating research in the corresponding discipline			
Behavioral and Experimental Economics, UEC 51306	ECH-WUR	2018	6
Advanced Behavioral Economic Theory	WASS	2018	4
Theories for Business Decisions, BEC 54806	WUR	2019	6
B) General research related competences			
B1 Placing research in a broader scientific context			
Risk Analysis and Risk Management in Agriculture: Updates on Modelling and Applications	WASS	2018	3
Quantitative Data Analysis: Multivariate Techniques, YRM 50806	WUR	2020	6
NWO meetings (seminar)	NWO, Utrecht	2018-2020	1
B2 Placing research in a societal context			
Workshops with Dutch arable farmers	WUR	2020-2021	0.3
WUR Open Day with farmers	WUR	2022	0.3
C) Career related competences/personal development			
C1 Employing transferable skills in different domains/careers			
Searching and Organising Literature	Wageningen Library	2018	0.6
Teaching Assistant: aid practicals of Agricultural Business Economics	WUR	2018-2020	1.5
Research Data Management	Wageningen Library	2019	0.45
Introduction to R & R Studio	PE&RC and WIMEK	2020	0.9
Co-supervising MSc student	WUR	2020-2021	2
Total			**41.05**

*One credit according to ECTS is on average equivalent to 28 hours of study load

About the book cover

The photo on the book cover was taken in a field close to Peter and Hermine Foolen's farm (my in-laws) in Breugel, the Netherlands. Peter's hands are in the photo. He is a retired Dutch farmer and kindly served as the model for this thesis cover. He is holding black soldier fly frass in his hands.

The stick figure people are portraying the innovation decision process. The first person on the left is in the first stage (knowledge stage), where he first learns about insect frass. The second person is continuing the learning process by exploring the frass more closely. The third person is showing the insect frass to a farming peer and asking for their opinion, which can help him further form his own opinion in the persuasion stage. The final stage represented is the decision stage where one farmer has decided to trial frass (the person on the top right) and another farmer has decided against it (the person on the bottom right).

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Cover design by Kirstin Foolen-Torgerson

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