The Journal of Agricultural Education and Extension
Competence for Rural Innovation and Transformation

ISSN: 1389-224X (Print) 1750-8622 (Online) Journal homepage: www.tandfonline.com/journals/raee20

Knowledge-implementation processes in crop protection literature

Helena Nordström Källström, Amelia Mutter, Sara Westerdahl & Anna Berlin

To cite this article: Helena Nordström Källström, Amelia Mutter, Sara Westerdahl & Anna Berlin (2025) Knowledge-implementation processes in crop protection literature, The Journal of Agricultural Education and Extension, 31:2, 159-179, DOI: 10.1080/1389224X.2024.2339806

To link to this article: https://doi.org/10.1080/1389224X.2024.2339806

THE JOURNAL OF AGRICULTURAL EDUCATION AND EXTENSION
2025, VOL. 31, NO. 2, 159–179
https://doi.org/10.1080/1389224X.2024.2339806

Knowledge-implementation processes in crop protection literature

Helena Nordström Källström[a], Amelia Mutter [a], Sara Westerdahl[a] and Anna Berlin[b]

[a]Urban and Rural Development, Swedish University of Agricultural Sciences, Uppsala, Sweden; [b]Department of Forest Mycology and Plant Pathology, Swedish University of Agricultural Sciences, Uppsala, Sweden

ABSTRACT

Purpose: The purpose of this paper is to explore how new research on crop protection practices is communicated to end-users by investigating which knowledge-implementation processes are recommended in crop protection literature.

Design/methodology/approach: This analysis is completed through a qualitative systematic review of literature on knowledge-implementation in crop protection where six knowledge-implementation processes are identified from 65 articles: information and communication technologies (ICT), management models and approaches, education platforms and events, advisory and extension services, networks, and collaborative approaches. We place special emphasis on the gaps and trends around networks and collaborative processes, building on communication theory research.

Findings: While many articles discussed multiple knowledge-implementation processes, it was found that most of the processes discussed aligned with a transmission communication model and the traditional agricultural knowledge and innovation system. While 11 articles described networks and 22 articles described collaborative processes in line with a constitutive model of communication, these tended to provide limited advice on how these processes could be achieved in practice, identifying a need for further investigation of how multilateral communication can be used to better crop protection practice.

Practical Implications: These findings can help facilitate better communication between researchers and farmers, promoting processes that include farmers and other actors as sources of knowledge and improving the efficiency and effectiveness of crop protection practices.

Theoretical implications: This study enhances the understanding of knowledge-implementation in agriculture, emphasizing the need to draw on multiple forms of communication to address the knowledge-to-action gap.

Originality/Value: There is limited research that examines the knowledge-to-action gap in agriculture, particularly in relation to

ARTICLE HISTORY
Received 30 August 2023
Accepted 26 March 2024

KEYWORDS
Agricultural extension; communication; crop protection; research communication; knowledge-to-action gap; knowledge-implementation

CONTACT Amelia Mutter amelia.mutter@slu.se

Supplemental data for this article can be accessed online at https://doi.org/10.1080/1389224X.2024.2339806.

crop-protection practices. As a review study, this manuscript provides an overview of how this topic is described in the field.

Introduction

Effective crop protection is central for sustainable and secure food production. Damages on crops from pests and pathogens such as fungi, viruses, and bacteria have a significant impact on crops, resulting in decreased quality and quantity of food production (Savary et al. 2019). To cope with this situation agriculture has utilized different chemicals, some hazardous, which can risk environmental damage and human health. The future challenge for crop production is to maintain or even increase the production of quality crop production while ensuring the protection of environment and human health from hazardous chemicals. Plant protection research has focuses on effective methods to protect crops and enhance yields (Berlin et al. 2018) using all different tools at hand, such as resistant cultivars, agronomic practices such as crop rotation, biological control, and different types of forecasting methods (Karlsson Green, Stenberg, and Lankinen 2020). Still, for many practitioners crop protection poses a challenging situation as it is a complicated system with many aspects to consider. Crop protection decision making must take into consideration how crop protection is: (1) A highly complex area of knowledge where different forms of knowledge and regulation have played a significant role, (2) A complex and constantly transforming subject where, for example, diseases caused by fungi or viruses may be difficult to spot but still can lead to significant losses in production. Because of the complexity and constant development of knowledge around these issues, treatment and prevention of pests and diseases are still widely debated with different perceptions on how much chemical intervention should be allowed. As such, the threat of losing yield might tempt the practitioner to use unnecessary chemical pesticide applications as a prevention measure. This in turn leads to negative impacts from exposure to hazardous chemicals and the risk of pests and pathogens becoming resistant to different chemical pesticides (Corkley, Fraaije, and Hawkins 2021).

As crop protection is a complex and constantly developing issue, communication of knowledge about best practices and new developments is particularly important. This paper focuses on communication of knowledge around crop protection practices because this was the empirical focus of the research project this paper is a result of. While many of the findings may be relevant to communication of other types of knowledge, focusing on crop protection practices enables us to delimit our analysis to communication with a similar type of message. Additionally, Crop health is central in crop production – both to sustain quality and quantity of the harvest/yield. Today, other agronomic practices are integrated in the concept of IPM – integrated pest management and the use of pesticide is the last option – at the same time, many farmers use pesticide to safeguard their crop. Few studies have synthesized recommendations on how knowledge on crop protection can best be implemented in farming practices. In this study we look deeper into the process of moving research findings (knowledge) into practical utilization, highlighting the specific 'knowledge-to-action' (KTA) gap that can limit the effective application of new research findings (Graham et al. 2006).

The KTA gap is a concept that describes the rift that can emerge between knowledge creation and practical implementation. The KTA gap emerges in situations where research findings are not 'taken up in practice settings' or 'making their way into practice in a timely fashion' (Graham et al. 2006, 14). This conceptualization draws on an underlying assumption that knowledge is a prerequisite to implementation, meaning that practitioners must first learn about new research in order to incorporate it into practice (Siebrecht 2020).

The purpose of this paper is to explore which knowledge-implementation processes are recommended for communication with farmer practitioners in publications discussing crop protection through a comprehensive literature review. We further aim to highlight the KTA gap present in crop protection practices by placing special emphasis on the way that collaborative processes are discussed in the literature, identifying the need of a more active role for the farmers/landowners.

With this focus in mind, we consider the following research questions:

- How does the evaluated literature suggest that formal knowledge is communicated to farmers?
- How do the suggested knowledge-implementation processes relate to traditional communication models and what trends and gaps emerge from the literature's recommendations?

In the following section, we introduce our theoretical approach to knowledge communication and implementation in agriculture. Thereafter materials and methods are described. In the results section we present the analysis of the identified knowledge-implementation processes from the materials and delve into a more in-depth discussion on some of the trends and gaps that emerge from this analysis. The final section outlines our primary conclusions from this study.

Theory: knowledge-implementation in agriculture

This section outlines the traditional structures for breaching the KTA gap in the agricultural sector. It also elaborates the theoretical framework we use in this paper, using classical, conceptual communication models to understand different processes of transferring formal knowledge to practitioners.

Understandings of knowledge and communication in agriculture

In the western context, the practice of communicating knowledge in agriculture has traditionally been described as an 'Agricultural Knowledge and Information System (AKIS)' where agricultural actors are divided into three groups; producers of knowledge (universities/institutes), transmitters of knowledge (selling, commercial and free extension and advisory services) and users of knowledge (farmers) (Yngwe 2013). This conceptual model of the AKIS suggests that knowledge is solely developed in one of these groups and that end users require an interpreter to communicate new information from the producers of knowledge.

Extension or advisory services are expected to act as the middleman for this exchange of knowledge, stemming from a need to make agriculture more effective and to produce more food. Modern extension is often considered to have developed in Ireland during the great famine in the 1840's and to have spread to Germany in the form of itinerant agricultural teachers (Jones and Garforth 1997). A cooperative extension system was authorized in the United States in 1914 and in Britain the term extension was replaced with advisory service in the twentieth century (Jones and Garforth 1997). Other terms for this activity have been used in other parts of the world. Extension or advisory services have therefore a long history of being understood as the actor group implementing new knowledge at the farmer's level and by such creating change in agricultural practices.

Many have criticized this traditional (simplistic) understanding of knowledge transfer in the AKIS, meaning that the reality is more complex than what is suggested. The traditional understanding relies on the division between actors as creators (and thereby senders) of knowledge and actors as users (receivers). Šūmane et al. (2018), among others, problematize this understanding pointing out that knowledge is also created at the practitioners' level and that formal (scientists and industry) knowledge and informal (farmers) knowledge 'are often complementary, building on each other' (237). In current systems, the lines between knowledge production and implementation can become blurred, for example, where advisory service organizations have their own research units, farmer groups share experiences, and through the more accessible knowledge sources available on social media platforms and accessible information on the internet (Rust et al. 2022). Furthermore, different systemic models dictate different interactions between the actor groups. While in many traditional AKIS structures advisors are a homogeneous group overseen by a government actor, advisory systems are becoming increasingly pluralistic incorporating private companies, government agencies, and non-governmental organizations (Birner et al. 2009). Chowdhury and Kabir (2024) find that while these pluralistic systems can offer improved services through diverse expertise, private organizations can lack coordination. Thus, the involvement of the public sector is still considered an essential part of the pluralistic advisory system.

Barriers to knowledge communication in agriculture

Our study departs from a frequently verbalized challenge among crop protection scholars and extension service officers: How can new knowledge on crop protection best be communicated to practitioners? Studies on the impact of knowledge communication or implementation within crop protection specifically and farming more generally have so far been limited. In a review of articles on implementation science (an alternative term to describe studies of the KTA gap), Siebrecht (2020) finds that while most of the studies focus on medicine, psychology and nursing, less than 2% are within the field of agricultural and biological sciences. One explanation for this gap in research could be the difficulty in attributing impact in the agricultural sector. While medical studies often include explorations of statistical impact (for example through lives saved, reduced disease spread, or extended life expectancy), similar measurements are not typical part of agricultural studies. Anderson and Feder (2004), for example, suggest that this is due to the complex factors which influence performance in agricultural studies so that 'it is difficult to attribute specific impacts at the farm level' (46). Furthermore, Siebrecht (2020) suggests that the role of farmers as decision makers can complicate knowledge-implementation in agriculture because some farmers are resistant to change their practices.

From the practitioners perspective, formal knowledge derived from agricultural institutions is not accepted uncritically (Kaup 2008; Šūmane et al. 2018). Studies show that farmers have the highest trust for their own colleagues when it comes to learning about practices (Rust et al. 2022). Farmers view other successful farmers as the experts, due to their practical experience within similar conditions (Šūmane et al. 2018). As such, informal knowledge on both personal and other practical experience is valued higher than formal knowledge. This raises the question of to what degree the traditional understanding of knowledge transfer is successful in implementation of knowledge in agricultural practices, successfully changing farmers' practices.

Conceptual models of communication

The KTA gap, an umbrella term for an abundance of different concepts (including knowledge transfer, knowledge translation, knowledge dissemination, and implementation) (Graham et al. 2006), highlights the communicative challenge of moving new knowledge into practical utilization. Our study takes a broad approach to this knowledge communication challenge, understanding this as the process by which knowledge acquired in one context is communicated for use in another. To examine knowledge communication, our analysis builds on communication literature and particularly three fundamental communication models.

Overall, communication literature outlines different models of communication based on the relationships between the actors involved in the communication act, the information, and society. Historically, communication sciences have taken a linear approach to this relationship with communication manifesting through a process where one actor ('the sender') transmits a message to their audience ('the receiver') in a one-directional process. This model is sometimes called the transmission model, the objective model, or the sender-receiver model and presents a somewhat limited understanding as it assumes that the content of the information being shared is clear and fixed and that the receiver will understand the information as long as the transmission is free from noise or interference (Leeuwis and Aarts 2011; Shannon and Weaver 1949). One key aspect of this model is that it is based on the assumption that the message has a clear objective meaning (Leeuwis 2013).

In later years, scholars began to understand that communication is also influenced by the experiences and situation of the receiver, as exemplified in the subjective model of communication (Leeuwis and Aarts 2011), also known as the receiver-oriented model (Leeuwis 2013; Nitsch 2000). This is similar to what has elsewhere been called the interactional model where the receiver can give feedback on the sender's message, even leading to dialogue between the two parties. The subjective model incorporates more complexity than its objective counterpart because it takes the situatedness of the receiver into consideration and acknowledges that this can result in the receiver having a different interpretation of the message (Leeuwis and Aarts 2011). This model, however, still leaves out several aspects influencing different interpretations of the message such as 'the historically grown relationship between the communicating parties, configurations of interest and also the influence of other actors not directly involved in the interaction' (Leeuwis and Aarts 2011, 25). A third communication model, the constitutive model (similar to the construction or transactional model) attends to these additional factors and

Table 1. Three conceptual models of communication adapted from Leeuwis and Aarts 2011.

	Communication models		
Aspect of communication	Transmission model *Objective model* *Sender-receiver model*	Subjective model *Receiver-oriented model* *Interactional model*	Constitutive model *Construction model* *Transactional model*
Parties involved in communication	Individual senders and receivers	Senders and receivers which are part of a community	Socially situated actors in a relational and historical setting
Meaning of message	Is fixed, determined by sender	Sender and receiver have different interpretations	Actors strategically mobilize meanings to achieve social ends
Main cause of differences in interpretation	Interference/noise in communication channels	Different past experiences and life-worlds	Different values, interests and struggles for power/ influence
Theorists implicit communication ideal	Effective transfer of particular meanings	Dialogue to arrive at shared meaning	None (unless a partisan position is taken)
Relevant time horizon	Present	Past and present	Past, present and (anticipated) future

emphasizes the role of all actors as dynamic communicators (Leeuwis and Aarts 2011). As Leeuwis and Aarts (2011) explain, 'In the "construction model" communication itself is regarded as an action that has direct consequences to the (social and material) world' (26). A more detailed description of the three models is included in Table 1.

Our analysis of knowledge communication builds directly on these three models of communication, emphasizing the variety of ways that new research on crop protection can be communicated with farmers. However, we believe that addressing the KTA gap also requires engaging practitioners in learning and implementation In our analysis, we therefore refer to the processes of knowledge communication as 'knowledge-implementation processes', a term that we have chosen to indicate our belief that changing practitioners' behavior requires more than the transference of expert generated knowledge.

Materials & methods

For this study, we performed a qualitative systematic review to provide a holistic picture of the discussion on communication of new crop protection research to farmers. Qualitative systematic reviews are commonly used to synthesize and interpret a large amount of literature that meets specific criteria and to create a more complete picture from the results. This method was deemed appropriate to meet our aim of providing an overarching picture of knowledge-implementation processes in crop protection literature. We developed search terms to provide a basis of publications related to knowledge transfer in crop protection and then narrowed down the results using the inclusion criteria presented in Figure 1. The final list of manuscripts was then analyzed to determine how knowledge-implementation was discussed, including by identifying which category(ies) of knowledge-implementation process were described. A detailed account of this process is described below.

The first step was to choose a set of search terms to find the body of literature which met our research aim. This process was based on the knowledge transfer framework described by Lavis et al. (2003) by focusing on three questions they propose: (1) Who

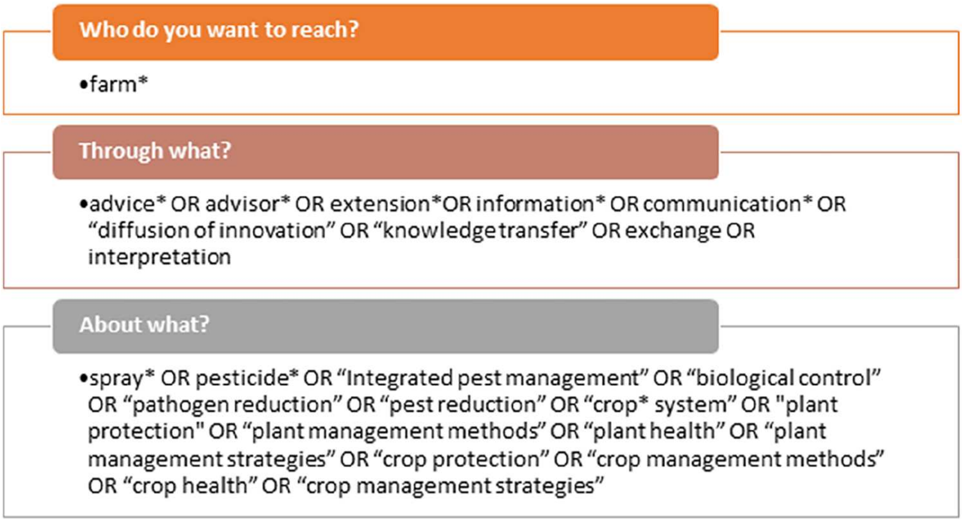

Figure 1. Categories and search words for the qualitative systematic review.

do you (the authors of the manuscripts) want to reach? (2) Through what? And (3) About what? After an extensive process in finding search words, including numerous test search, under each category we utilized with following final search words in each category (see Figure 1).

For this study we have used the same search words in comparable searches in the academic databases Web of Sciences Core Collection (http://webofknowledge.com/) and in Scopus (https://www.scopus.com/). We further narrowed down this search to articles in English published between 1990 and 2018 resulting in 4004 total articles (excluding duplicates). These articles were then further reduced by a set of inclusion criteria as outlined in Table 2 through three stages. First by performing a preliminary evaluation based on the articles' titles and first impressions of the abstract. In the second stage, the abstracts were read thoroughly for the inclusion criteria and finally, the remaining full articles were examined to determine if they fit the scope of the study. The inclusion criteria included reference to specific crops and climate zones to allow alignment with a wider project using these limitations for mapping crop protection practices (see Berlin et al. 2018). By applying the inclusion and exclusion criteria in the three steps described above, we narrowed down the articles to 1231 articles after the first step, 223 after the

Table 2. Literature inclusion criteria.

Type of publication	Peer-reviewed journal articles
Crops	Articles relating to crops within the scope of this study (wheat, barley, oat, potato, sugar beet and rapeseed) Articles having a general discussion concerning crops
Temperate zone	Articles relating to climate zones within the scope of this study (Köppen-Geiger climate classification zones Cfb, Dfb, Dfc, and Cfa) Articles having no geographical focal point related to their discussion
Range	Articles describing any mode/method of disseminating research on crop protection to practitioners

second, and 65 after the third. The full list of the articles and how they are coded to each knowledge-implementation process is included in Appendix 1.

When reading the full article in the third step, we also began analyzing the articles by how the authors viewed knowledge production and communication, focusing on the types of 'knowledge-implementation processes' that were recommended or described, these processes are outlined in the results below. Many of the publications suggested references to multiple knowledge-implementation processes. In these cases, the publication was included in the analysis of all of the relevant processes. Figure 2 shows the way that the number of articles coded to each knowledge-implementation process as well as the overlap between the processes.

	ICTs	Management models and approaches	Education platforms and events	Advisory and extension services	Networks	Collaborative Approaches
ICTs	28	1	3	2	2	5
Management models and approaches	1	9	2	1	1	6
Education platforms and events	3	2	19	12	3	7
Advisory and extension services	2	1	12	20	4	6
Networks	2	1	3	4	11	7
Collaborative Approaches	5	6	7	6	7	22

Figure 2. Matrix of overlapping knowledge-implementation processes.

Results: knowledge-implementation processes for crop protection

While the subject matter of the 65 articles analyzed is quite diverse, the majority of them focus on technical solutions to crop protection challenges. The articles suggested a variety of potential best practices in crop protection, including addressing a wide range of crop protection solutions focusing on agricultural practices, farm management regimes and decision-making processes, with knowledge-implementation practices taking a secondary role. The knowledge-implementation practices described by the articles were broadly categorized within the six knowledge-implementation processes: *information and communication technologies* (*ICTs*), *management models and approaches*, *education platforms and events*, *advisory and extension services*, *networks*, and *collaborative approaches*.

For a list of the articles and the knowledge-implementation processes they discuss see Appendix A.

As Figure 3 shows, the number of articles relating to the different knowledge-implementation processes has changed over time. However, it is difficult to state a clear historical development. Worth mentioning is that the *ICT*s approach has been part of a large share of the publications discussing knowledge-implementation within crop protection from 1990 until 2009, but that this share has decreased since 2010. There is also a trend in increased mention of *networks* and *collaborative approaches* in the later years of the study.

The following sections details our understanding of the six knowledge-implementation processes by elaborating on the way these are discussed in the articles assigned to each process.

ICT – Information and Communication Technologies

The term *Information and Communication Technology (ICT)* is commonly used to refer to forms of communication that use the internet as a medium. Twenty-eight of the

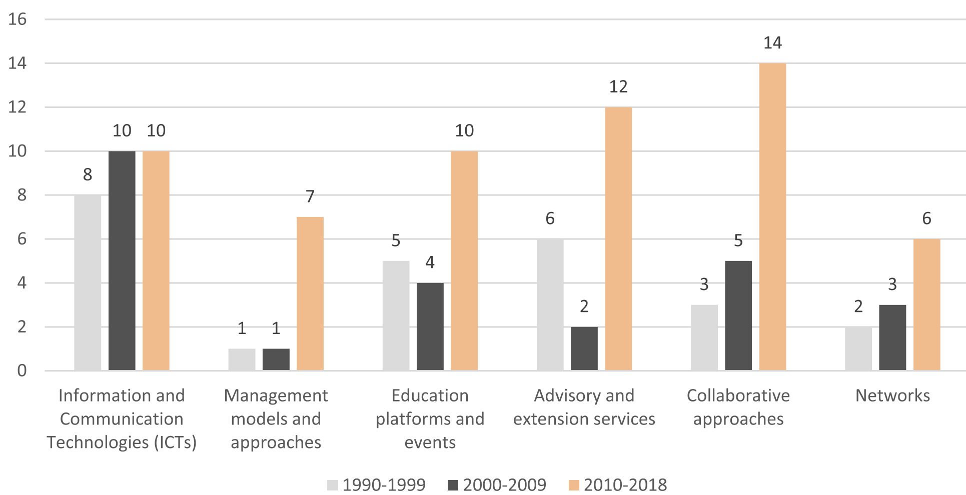

Figure 3. Historical overview of the number of articles relating to the knowledge-implementation processes.

publications relate to and discuss different types of ICTs making this the most frequently mentioned knowledge-implementation process. Specific types of ICTs referenced include Geographic Information System (GIS), Variable Rate Technology (VRT), online systems for information and knowledge sharing and e-learning tools. More than half of the publications within this process focus on so-called Decision Support Systems (DSS), which are types of ICTs that collect data from the practitioners and then make recommendations based on this data. One type of DSS can be used to determine what pesticides to use, the appropriate dosage, and when to apply as these software tools are meant to provide decision-makers with accessible and useful science-based information to make better decisions (Evans, Terhorst, and Kang 2017; Lomotey et al. 2013).

The publications generally frame ICTs as one-way communication tools, providing scientific information to end users. These publications often point out farmers' need for up to date, rapid and convenient information to be able to make good crop protection decisions, in the form of remote sensing (Brisco et al. 1998), weather forecasts (Strand 2000), or warning services (Rossi, Caffi, and Salinari 2012) to name a few examples. Other publications see ICTs as a means to recommend solutions and give guidance for stakeholders by offering predictions and interpretation of data, relating the discussion to programs or software meant to support practitioners' decision-making (see for example Stevenson et al. 1995; Sadok et al. 2009).

In some cases, the publications recommend ICTs as more constructional forms of communication including knowledge sharing. For example, ICT tools can be used to create networks, such as a web-based knowledge exchange between stakeholders (Bruce 2016; Rantanen et al. 1993). As one author explains, 'There are huge opportunities to facilitate knowledge exchange through online systems for farmers and people who advise farmers' (Bruce 2016, 89). This quote provides an important perspective that indicates the potential of technology and particularly ICTs to facilitate wider communication between actors in the AKIS, including opening up for two-way information exchange.

Management models and approaches

The second type of knowledge-implementation process that emerged from the crop protection literature are *management models and approaches* which cover different methods and tools for farm management and decision making. The nine publications that describe this form of communication include analog methods of knowledge-implementation, such as checklists, guides and models meant to help farmers improve their crop protection practices. These models and approaches typically provide frameworks to help practitioners make decisions about their crop management relating to topics such as risk mitigation and comprehension, damage reduction, weed management, and integration of sustainable systems (Ayouba 2016; Bereswill, Streloke, and Schulz 2014). As such, these management models and approaches include a certain practice that the authors wish farmers adopt. Essentially, these models are meant to help farmers assess certain scenarios and make appropriate decisions related to crop protection.

These management models and approaches are meant to adapt research into practical application using a subjective model of communication by attempting to adjust research findings to fit the farmer's situation. Some publications argue that the management models provide practitioners with useful insights (Ayouba 2016) as well as showing practical implementation (Bereswill, Streloke, and Schulz 2014; Wijnands 1992). However, many of these publications have a theoretical approach, not emphasizing how the models can be applied in practical and local situations. Doohan et al. (2010) argue that a better understanding of farmers' decision process is needed for models to be properly developed and suited for practice. Participatory approaches, such as effective knowledge sharing and co-development of models, are also mentioned as increasing the implementation rate of manuals describing best-practices (Alix et al. 2015; Hewett, Quinn, and Wilkinson 2016; Hughes and Burnett 2015).

Education platforms and events

Under the third knowledge-implementation process of *education platforms and events*, we included crop protection literature that recommended educational tools and methods to increase practitioners' knowledge and understanding of crop protection. Nineteen publications were coded to this process. The suggested educational platforms and events were often combined with or related to recommendations about what type of measures or behaviors that would be beneficial to create a better crop protection practice. As such, these education platforms and events underlying assumption is that knowledge or understandings of a certain practice is lacking and that an increase in knowledge for a farmer, through educational platforms or events, would result in adoption of that practice. The most frequently mentioned educational processes were practical training programs, as well as experiential learning (see for example Wezel et al. 2018; Korani 2012; or Ozcatalbas and Brumfield 2010). Two publications discuss tools to ensure farmers participation in educational practices, for example by incorporating new educational material within already established educational programs such as pesticide certificate programs (Stahl et al. 2016; Wyatt, Herzfeld, and Haugen-Brown 2015).

Often the articles address education by relating to extension programs (both governmental and NGO), seeing advisory and extension services as the educator, and sometimes seeing these actors in need of additional training to increase their potential in affecting farmer practices (such as Doruchowski 2008). However, some publications also consider educational approaches through other sources including social learning and farmer-to-farmer training (Rebaudo and Dangles 2013) or educational programs based on collaborative learning approaches with stakeholders (Rajendran et al. 2016). The publications discussing education platforms and events, therefore, relate to different communication models, ranging from the subjective model of transferring knowledge in an educational setting to the construction model of interactive knowledge creation. However, the common denominator of the articles is the belief that knowledge is missing, and that this is the central barrier to implementation of new methods and practices of crop protection.

Advisory and extension services

The fourth knowledge-implementation process discussed the role of agricultural advisory and extension services in knowledge-implementation of crop protection. There were 20 publications under the umbrella of *advisory and extension services*, and they suggest that these services are meant to change agricultural practices by sharing scientific knowledge and informing, advising, and teaching farmers new techniques. About half of the publications within this process discuss advisory services and their direct contact with farmers as consultants. The other half discuss more widely about extension services, transferring research into practice and running education programs.

An underlying assumption within the process of advisory and extension services is that these services act as the bridge between knowledge creators (academia) and practice (farmers). Advisory and extension services are often seen as beneficial when reaching out to practitioners because of their pre-established contacts and large networks (such as Roberts and Rao 2012). In general, advisory and extension services are considered as a trusted source of information for farmers (such as Bradshaw et al. 1996). However, many publications within this process focus on how advisory and extension services should best be utilized to change farmer practices. For example, some publications point out the need for advisory and extension services to incorporate farmers' knowledge and experience with scientific and technical knowledge, addressing farmers' individual situation, trajectory of change, or belief structure (see for example Chantre and Cardona 2014 or Moss 2010). Furthermore, advisors and the extension personnel are meant to have large influence on farmers and farming practices due to interpersonal reasons. For example, intermediation skills and the relationship between advisory service and farmer are seen as important for affecting farmers' practices as well as understanding the local setting the farmers operate within (Cerf et al. 2017; Ilbery, Maye, and Little 2012).

Networks

The fifth knowledge-implementation process we identified relates to *networks* and their ability to implement and create new knowledge. These ten publications described different constellations of actors and discussed the ability of networks to enhance other processes such as extension services, collaboration between stakeholders, and the development of new technical practices.

The publications revolve around the idea that a network is a tool to share information and connect practitioners and stakeholders (Rantanen et al. 1993). Networks can be platforms for discussing, creating, and exchanging knowledge (Alix et al. 2015; Brinks and de Kool 2006), thereby creating an environment for practitioners to pose questions and get support in redesigning their practices (Cerf et al. 2017). The basis for these publications is the idea that changing practices is a social process. Cullen et al. (2008) elaborates on this understanding by describing how farmers need to trust information sources in order to incorporate and implement new knowledge, identifying other farmers as the actors who have the highest credibility for this. As such, implementing new or changed practices requires 'a supportive network of other growers, not merely the transfer of technology' and that this furthermore 'requires an alternative set of social relationships among farmers, extension agents, and scientists: a supportive network or partnership' (Cullen et al. 2008, 278).

Collaborative approaches

The sixth and final knowledge-implementation process we identified describes *collaborative approaches* where stakeholders are involved in the knowledge creation process. The twenty-two articles discuss collaborative approaches when developing toolboxes, policies, best practices, change processes and technology, as well as within planning, executing, and interpreting experiments such as cropping systems or creating strategies for herbicide use reduction. The publications mainly focus on collaborations involving researchers, and extension services, however some take a broader scope including stakeholders such as farmer groups, industry, consumers, or environmental organizations (Francis et al. 1990; Zoschke and Quadranti 2002).

According to publications within this knowledge-implementation process, knowledge creation incorporates different stakeholder's knowledge and expertise (for example, local knowledge), contributing to a better understanding of what crop protection solutions are most applicable in real world situations (such as Nazarko, Van Acker, and Entz 2005). This assures that the suggested practices correspond to the needs of the user (Stigter, Sivakumar, and Rijks 2000). As a result, using a collaborative approach, such as stakeholder participation, when developing best practices or technological devices results in end products that are better adapted to distribution and implementation (Alix et al. 2015; Brinks and de Kool 2006; Rossi, Caffi, and Salinari 2012). An underlying assumption of collaborative approaches is that they increase the potential for knowledge-implementation because the knowledge creation happens closer to practice, thereby reducing the knowledge-to-action gap.

Discussion: communication processes in crop protection literature

While the analysis of the knowledge-implementation processes shows some variety in the proposed methods of bridging the knowledge-to-action gap, they tend to rely on traditional forms and methods of knowledge dissemination. The following section outlines some of the trends and gaps that emerge from this analysis, including how these relate to the communication models introduced in the section *Conceptual models of communication*. Finally, as the literature indicates an increasing interest in two-way communication processes in the agricultural sector, we delved deeper into the way that the articles described networks and collaborative processes.

Relationship to traditional communication models

Our knowledge-implementation processes correspond with the conceptual models of communication in the way that they incorporate different levels of interaction between the sender (usually researchers) and the receiver (farmers and landowners). *ICTs* and *management models and approaches* can be viewed as utilizing the transmission model as they tend to emphasize one-way communication where farmers are being informed of new research developments through different means. Within the processes of *educational platforms and events* and *advisory and extension services* articles discussed initiatives that could be considered within multiple of the communication models. While some articles recommended processes that utilized the transmission model, others incorporated the subjective or constitutive models of communication. One commonality is that these tend to focus on sharing expert knowledge within these initiatives. Thus, even in articles where the role of the farmers is considered, this is primarily as the audience for trainings or educational activities. While they might be invited to give feedback or participate in educational trainings (asking questions, etc.) they are primarily recipients of 'expert' generated knowledge. *Networks* and *collaborative approaches* can be viewed as relating to the constitutive model of communication since these processes include dialogical interactions between the different stakeholders including researchers and farmers. Furthermore, these approaches often call for more emphasis on types of knowledge provided by diverse stakeholders.

Although the knowledge-implementation processes engage with different communication models, they tend to build on traditional forms of agricultural communication, such as advisory and extension services. Despite increased interest in collaboration and participation along the lines of the constitutive model, the actors and systems of the traditional AKIS still govern the suggested processes for knowledge dissemination in the agricultural system. Transmission style communication processes are dominant with actor groups maintaining traditional roles. Even in instances that advocate for collaboration and network processes, the role of extension and advisory services is emphasized with these actors coordinating or participating in many of these processes.

In the articles coded for *networks* and *collaborative approaches*, focus on extension and advisory services and education was still strong, although the literature made concrete recommendations on how these forms of knowledge-implementation processes can be improved by the inclusion of additional stakeholders. Barzman and Dachbrodt-Saaydeh (2011), for example, suggest that a collective approach that combines traditional extension services with the involvement of other stakeholders including farmers could lead to more successful implementation. Meanwhile, Rajendran et al. (2016), emphasize that collaboration with multiple stakeholders including farmers in developing educational programs can do important work for facilitating the shift to sustainable agricultural practices.

Focus on the sender of information

Another trend we noticed among the articles, including the articles on *networks* and *collaborative approaches*, is the way they emphasize the role of the sender in communicating crop protection practices. In many cases, the aim of the articles seems to be primarily to advocate for new or better crop protection techniques. The publications thus, tend to focus on methods for spreading information about these techniques. As a result, the agency of the researchers and knowledge producers is highlighted, with limited information on supporting or enabling the end-stage users in implementation. As one article suggests, 'these important technological progresses need to be transferred to the field and to users, so that users gain experience and confidence in these tools' (Alix et al. 2015, 155). This quote seems to align with the transmission model of communication by suggesting that by sending these technologies to the field, they will be properly used and result in better crop protection. In another example, Bianchi et al. (2013) suggest the development of toolkits for functional agrobiodiversity as a method for turning knowledge into implementation. To us, this similarly implies that if farmers are provided with the right information (in this case through a toolkit) that they will implement functional agrobiodiversity.

While these recommendations are perfectly valid, it is noteworthy that they tend to overlook the complexity of knowledge-implementation processes by implying that this step (packaging and sharing new information) is the central aim of these processes. The drawback as we see it is that this emphasis tends to 'black box' the step of implementation and reduce the agency of practitioners (Callon and Latour 2014). By this, we mean that what happens beyond communicating the information to practitioners 'no longer needs to be reconsidered' and becomes 'a matter of indifference' (Callon and Latour 2014, 285). Essentially, the publications take for granted what will happen once the information is sent to farmers, implying an expectation that the shared information on crop protection will be simply adapted and put in practice without question. This suggests that even while calling for processes more in line with the constitutive model the actual understanding of communication processes is more in line with the transmission model, which suggests that failures of implementation result from poorly packaged information. This interpretation ignores the possibility of other types of barriers that could be considered with a true constitutive model, such as the possibility that the information itself does not actually work in the use case. Cullen et al. (2008) suggest one such barrier, highlighting the way that the economic consequences of changing practices might be one motive for farmers not implementing new recommendations or toolkits. In the same article, they go so far as to emphasize the benefits of cooperative process by suggesting that farmers are also more likely to take the recommended steps if they have been involved in the process of developing the technology or practice.

The focus on the sender as the main actor within the communication act leads to also seeing the sender as the solution when issues of implementation arise. In other words, when end users fail to adopt the new knowledge the solution is viewed as the result of a weakness in the packaging or sending of the new information. Improvements can be even more 'ready-to-use' or 'easy-to-apply' for the farmer. This type of framing is problematic, because faulty packaging of information is only one possible reason for the failure of implementation for new practices. In reality, this failure may also be in the actual implementation step, for example if the farmer disagrees with this information or finds it incompatible with other aspects of their practice.

Lack of clarity around the practice of collaboration and participation

The rise in articles advocating knowledge-implementation methods such as *networks* and *collaborative approaches*, indicates that there has been an increasing interest in these processes, as also noted in Šūmane et al. (2018). Despite this trend the literature we reviewed provided limited concrete information on how these communication practices could or should look. In many cases, articles were coded as including *collaborative approaches* based on a brief mention that advocated for these approaches. We found that the 22 articles that discussed *collaborative approaches* and the 11 relating to *networks* often used terminology such as collaboration, participation, experiential, dialogue, cooperation, or others that we connect with the constitutive model of communication. This interpretation is confirmed by Barzman and Dachbrodt-Saaydeh (2011) who write that 'The classical diffusion model of research and extension – where knowledge is generated by research, then handed over to advisory services which then "transfer" it to farmers – is increasingly being replaced by more collective and participatory approaches' (1483). Nevertheless, in many cases (ten of the collaborative approaches articles and six of the network articles) the discussion of these kinds of topics were quite brief, in some cases earning these codes for limited statements in support of these communication processes. As the search criteria for the study turned up many articles that included only limited focus on knowledge-implementation terms generally, this fits the trend from the literature. One potential interpretation for this gap is that while there is recognition that participation and collaboration are beneficial, there is limited understanding of how these processes can be achieved.

Some of the literature emphasizes how collaborative and participatory approaches are attractive alternatives as they are more likely to generate crop protection measures that are applicable to real world farming situations since they incorporate multiple forms of knowledge. Cerf et al. (2017), for example, point out the multitude of actors and institutional factors that influence innovation processes, describing a political perspective on the debate around the phase out of chemical pesticides, an experiential perspective on the way that farmers are represented, and an interactive perspective one that considers how farmers and other stakeholders are represented in participatory processes. This type of deeper participation is not universal, however, Nazarko, Van Acker, and Entz (2005) note that 'research that is termed participatory ranges widely in scope, from simply locating research sites on farmers' land, to having farmers control the research agenda and share in the interpretation of results' (471). Building on this literature, we suggest that the use of participatory or collaborative approaches should align with a constitutive model of communication encouraging open exchange and knowledge sharing between the different parties. Researchers utilizing these processes can draw inspiration from other fields of participatory and co-productive research (see, for example, Malmborg et al. 2022) to better understand how these can bridge the KTA gap.

Conclusions

Crop protection is a complex practice where knowledge and understanding of how to optimize crop production while minimizing chemical use is under constant development. To better understand how this new information can be transferred to and implemented by end stage users, this literature review explores the knowledge-implementation processes proposed as methods for overcoming the KTA gap around crop protection information. In the majority of the articles analyzed, the main focus was on the crop protection practices, with the processes for knowledge-implementation described as a lesser aim of the articles.

We found that the majority of the articles focused on one-way processes of (knowledge) communication, drawing on the transmission communication model. The articles also often focused on the activities of the sender, meaning the discussion of the KTA gap emphasized how researchers and advisors could better communicate their results to farmers. As such, what happened on the implementation side of these processes is often black-boxed by the literature and farmers were framed exclusively as recipients of information. A long history of communication research shows that this is a faulty model since it does not engage the end user (in this case farmers) actively in the communication process making it unclear how they have understood and valued new information. Furthermore, the knowledge-implementation processes often built on the traditional roles of the AKIS, with advisors and extension agents acting as the intermediaries of new information.

As a second aim of this article, we focused on the discussion of collaborative processes are discussed in the literature, examining which gaps and trends emerge from the articles that discuss networks or collaborative processes. We found that while many of the articles mentioned participation, cooperation, or collaboration, there was little guidance of how these processes should look. Future research could explore this gap through a more extensive study on the literature around collaborative processes concerning crop protection and advisory communication more generally. Furthermore, as previous studies indicate, farmers trust and value the experience of other farmers as experts (Rust et al. 2022), future research could include a more observational approach to improve understanding of how farmers communicate best practices with each other and how these processes can be applied to communication between researchers and practitioners. Finally, future research could focus on how farmers utilize and interpret knowledge once they learn of it, exploring the gap found in this article by removing the black box from the implementation side of the knowledge-implementation processes. Such research could provide more concrete recommendations on how communication along the lines of the constitutive model can be used in crop protection research, providing an important compliment to the transmission and subjective forms of communication dominant in the traditional AKIS.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by SLU Future Foods through project *Mind the gap: Plant protection* and the Swedish Board of Agriculture through project *Fact-based advice for sustainable and effective plant protection* [grant number 4.1.18-16803/2019].

Notes on contributors

Helena Nordström Källström is a researcher at the division for environmental communication, the Department of Urban and Rural development, Swedish University of Agricultural Sciences. She received her Doctor of Agriculture (AgrD) at Department of Urban and Rural development at the Swedish University of Agricultural Sciences in 2008. Her research interests includes: social sustainability such as identity, practice, motivation and decision making within food production.

Amelia Mutter is a researcher at the division for environmental communication, the Department of Urban and Rural development, Swedish University of Agricultural Sciences. She has a PhD in Technology and Social Change from Linköping University and has a background in environmental social science and science and technology studies research. Her research interests include imaginaries of a sustainable future, deliberative and participatory processes, knowledge production and truth-claims.

Sara Westerdahl is a lecturer at the Department of Urban and Rural development at the Swedish University of Agricultural Sciences. She received a bachelor's degree in economics and a master's degree in sustainable development at Uppsala University and Swedish University of Agricultural Sciences. Her research interests includes: sustainability, food policy and rural and regional development.

Anna Berlin is an Associate Professor of Biology, specializing in plant pathology, and is currently active at the Department of Forest Mycology and Plant Pathology. She received a Doctor of Agriculture (AgrD) at Department Forest Mycology and Plant Pathology at the Swedish University of

Agricultural Sciences in 2012. Her primary area of work is plant disease epidemiology, with a focus on plant health and sustainable crop production.

ORCID

Amelia Mutter http://orcid.org/0000-0001-5306-0283

References

Alix, A., K. Knauer, M. Streloke, and V. Poulsen. 2015. "Development of a Harmonized Risk Mitigation Toolbox Dedicated to Environmental Risks of Pesticides in Farmland in Europe: Outcome of the MAgPIE Workshop." In *Fifth European Workshop on Standardised Procedure for the Inspection of Sprayers in Europe - Spise 5 -*, edited by P. Balsari and H. J. Wehmann, In Julius-Kuhn-Archiv, 148-155.

Anderson, J. R., and G. Feder. 2004. "Agricultural Extension: Good Intentions and Hard Realities." *World Bank Research Observer* 19 (1): 41–60. doi:10.1093/wbro/lkh013. <Go to ISI>://WOS:000221550600002.

Ayouba, K. 2016. "On the Estimation of Damage Reducing Functions." *Economics Bulletin* 36 (4): 2394-+. <Go to ISI>://WOS:000389983500049.

Barzman, M., and S. Dachbrodt-Saaydeh. 2011. "Comparative Analysis of Pesticide Action Plans in Five European Countries." *Pest Management Science* 67 (12): 1481–1485. doi:10.1002/ps.2283.<Go to ISI>://WOS:000297511700001.

Bereswill, R., M. Streloke, and R. Schulz. 2014. "Risk Mitigation Measures for Diffuse Pesticide Entry Into Aquatic Ecosystems: Proposal of a Guide to Identify Appropriate Measures on a Catchment Scale." *Integrated Environmental Assessment and Management* 10 (2): 286–298. doi:10.1002/ieam.1517.<Go to ISI>://WOS:000333241900014.

Berlin, Anna, Helena Nordstrom Kallstrom, Anders Lindgren, and Ake Olson. 2018. "Scientific Evidence for Sustainable Plant Disease Protection Strategies for the Main Arable Crops in Sweden. A Systematic Map Protocol." *Environmental Evidence* 7 (1): 1–8. doi:10.1186/s13750-018-0141-3.

Bianchi, Fjja, V. Mikos, L. Brussaard, B. Delbaere, and M. M. Pulleman. 2013. "Opportunities and Limitations for Functional Agrobiodiversity in the European Context." *Environmental Science & Policy* 27: 223–231. doi:10.1016/j.envsci.2012.12.014.<Go to ISI>://WOS:000316843500021.

Birner, Regina, Kristin Davis, John Pender, Ephraim Nkonya, Ponniah Anandajayasekeram, Javier Ekboir, Adiel Mbabu, et al. 2009. "From Best Practice to Best Fit: A Framework for Designing and Analyzing Pluralistic Agricultural Advisory Services Worldwide." *Journal of Agricultural Education and Extension* 15 (4): 341–355. doi:10.1080/13892240903309595.

Bradshaw, N. J., C. J. Parham, A. C. Croxford, and Council Brit Crop Protect. 1996. *The Awareness, Use and Promotion of Integrated Control Techniques of Pests, Diseases & Weeds in British Agriculture and Horticulture. Brighton Crop Protection Conference: Pests & Diseases – 1996, Vols 1–3.*

Brinks, H., and S. de Kool. 2006. *Farming with Future: Implementation of Sustainable Agriculture Through a Network of Stakeholders*. Edited by H. Langeveld and N. Roling. *Changing European Farming Systems for a Better Future: New Visions for Rural Areas.*

Brisco, B., R. J. Brown, T. Hirose, H. Mc Naim, and K. Staenz. 1998. "Precision Agriculture and the Role of Remote Sensing: A Review." https://www.scopus.com/inward/record.uri?eid=2-s2.0-0032153751&doi=10.1080%2f07038992.1998.10855254&partnerID=40&md5=94a46b70375067d43b3c2686e95d0bab.

Bruce, T. J. A. 2016. "The CROPROTECT Project and Wider Opportunities to Improve Farm Productivity Through Web-Based Knowledge Exchange." *Food and Energy Security* 5 (2): 89–96. doi:10.1002/fes3.80. <Go to ISI>://WOS:000383592200003.

Callon, Michel, and Bruno Latour. 2014. "Unscrewing the Big Leviathan: How Actors Macro-Structure Reality and how Sociologists Help Them To Do So." In *Advances in Social Theory* *and Methodology*, edited by Karin Knorr Cetina and A. V. Cicourel, 277–303. London: Routledge.

Cerf, M., L. Bail, J. M. Lusson, and B. Omon. 2017. "Contrasting Intermediation Practices in Various Advisory Service Networks in the Case of the French Ecophyto Plan." https://www.scopus.com/inward/record.uri?eid=2-s2.0-85019567067&doi=10.1080%2f1389224X.2017.1320641&partnerID=40&md5=a74d374f5f7ee157152d83104166b596.

Chantre, E., and A. Cardona. 2014. "Trajectories of French Field Crop Farmers Moving Toward Sustainable Farming Practices: Change, Learning, and Links with the Advisory Services." *Agroecology and Sustainable Food Systems* 38 (5): 573–602. doi:10.1080/21683565.2013.876483.

Chowdhury, Ataharul, and Khondokar H. Kabir. 2024. "How Do Agricultural Advisory Services Meet the Needs of Farmers? Applying Q-Methodology to Assessing Multi-Stakeholders' Perspectives on the Pluralistic Advisory System in Ontario, Canada." *Journal of Rural Studies* 105: 1–13. doi:10.1016/j.rurstud.2023.103186.

Corey, A. M. 2019. "Introducing Communication." In *The Evolution of Human Communication: From Theory to Practice*, edited by T. Pierce. Oshawa, Canada: EtrePress.

Corkley, Isabel, Bart Fraaije, and Nichola Hawkins. 2021. "Fungicide Resistance Management: Maximizing the Effective Life of Plant Protection Products." *Plant Pathology* 71 (1): 150–169. doi:10.1111/ppa.13467.

Cullen, R., K. D. Warner, M. Jonsson, and S. D. Wratten. 2008. "Economics and Adoption of Conservation Biological Control." *Biological Control* 45 (2): 272–280. doi:10.1016/j.biocontrol.2008.01.016.<Go to ISI>://WOS:000255522700010.

Doohan, D., R. Wilson, E. Canales, and J. Parker. 2010. "Investigating the Human Dimension of Weed Management: New Tools of the Trade." https://www.scopus.com/inward/record.uri?eid=2-s2.0-78049328071&doi=10.1614%2fWS-D-09-00086.1&partnerID=40&md5=05b579c201aaca0150ec676a1b33d969.

Doruchowski, G. 2008. "Status of Spray Application in Poland Meeting EU Regulations." https://www.scopus.com/inward/record.uri?eid=2-s2.0-54349096186&doi=10.1564%2f19oct02&partnerID=40&md5=935edbd7848d85abb6e71fd9f53804a9.

Evans, K. J., A. Terhorst, and B. H. Kang. 2017. "From Data to Decisions: Helping Crop Producers Build Their Actionable Knowledge." *Critical Reviews in Plant Sciences* 36 (2): 71–88. doi:10.1080/07352689.2017.1336047.<Go to ISI>://WOS:000408407800001.

Francis, C., J. King, J. Dewitt, J. Bushnell, and L. Lucas. 1990. "Participatory Strategies for Information Exchange." https://www.scopus.com/inward/record.uri?eid=2-s2.0-0025553342&doi=10.1017%2fS0889189300003581&partnerID=40&md5=1409a38973540ce19e14fe41d08ac927.

Graham, I. D., J. Logan, M. B. Harrison, S. E. Straus, J. Tetroe, W. Caswell, and N. Robinson. 2006. "Lost in Knowledge Translation: Time for a Map?" *Journal of Continuing Education in the Health Professions* 26 (1): 13–24. doi:10.1002/chp.47.<Go to ISI>://WOS:000236855300003.

Hewett, C. J. M., P. F. Quinn, and M. E. Wilkinson. 2016. "The Decision Support Matrix (DSM) Approach to Reducing Environmental Risk in Farmed Landscapes." *Agricultural Water Management* 172: 74–82. doi:10.1016/j.agwat.2016.03.008.<Go to ISI>://WOS:000377740100008.

Hughes, G., and F. J. Burnett. 2015. "Integrating Experience, Evidence and Expertise in the Crop Protection Decision Process." https://www.scopus.com/inward/record.uri?eid=2-s2.0-84940371014&doi=10.1094%2fPDIS-02-15-0197-FE&partnerID=40&md5=b5d470b5e43cad4baa2de841fca449d5.

Ilbery, B., D. Maye, and R. Little. 2012. "Plant Disease Risk and Grower-Agronomist Perceptions and Relationships: An Analysis of the UK Potato and Wheat Sectors." *Applied Geography* 34: 306–315. doi:10.1016/j.apgeog.2011.12.003.<Go to ISI>://WOS:000306199400031.

Jones, G. E., and C. Garforth. 1997. "Chapter 1 – The History, Development, and Future of Agricultural Extension." In *Improved Agricultural Extension. A Reference Manual*, edited by Burton E. Swanson, Robert P. Bentz, and Andrew J. Sofranko, 8–22. Rome: Food and Agriculture Organisation.

Karlsson Green, Kristina, Johan A. Stenberg, and Åsa Lankinen. 2020. "Making Sense of Integrated Pest Management (IPM) in the Light of Evolution." *Evolutionary Applications* 13 (8): 1791–1805. doi:10.1111/eva.13067.

Kaup, Brent Z. 2008. "The Reflexive Producer: The Influence of Farmer Knowledge Upon the Use of Bt Corn." *Rural Sociology* 73 (1): 62–81. https://doi.org/10.1526/003601108783575871

Korani, Z. 2012. "Application of teaching methods, promoting integrated pest management on the farm school in order to achieve sustainable agriculture." In *Cyprus International Conference on Educational Research*, edited by H. Uzunboylu, 2187–2191. In Procedia Social and Behavioral Sciences.

Lavis, J. N., D. Robertson, J. M. Woodside, C. B. McLeod, J. Abelson, and Grp Knowledge Transfer Study. 2003. "How Can Research Organizations More Effectively Transfer Research Knowledge to Decision Makers?" *Milbank Quarterly* 81 (2): 221-+. doi:10.1111/1468-0009.t01-1-00052.<Go to ISI>://WOS:000183519400002.

Leeuwis, Cees. 2013. *Communication for Rural Innovation: Rethinking Agricultural Extension*. Oxford: John Wiley & Sons.

Leeuwis, Cees, and Noelle Aarts. 2011. "Rethinking Communication in Innovation Processes: Creating Space for Change in Complex Systems." *Journal of Agricultural Education and Extension* 17 (1): 21–36. https://doi.org/10.1080/1389224X.2011.536344

Lomotey, R. K., Y. D. Chai, S. Jamal, R. Deters, and IEEE. 2013. "MobiCrop: Supporting Crop Farmers with a Cloud-Enabled Mobile App." 2013 *IEEE Sixth International Conference on Service-Oriented Computing and Applications*.

Malmborg, Katja, Ida Wallin, Vilis Brukas, Thao Do, Isak Lodin, Tina-Simone Neset, Albert V. Norström, Niel Powell, and Karin Tonderski. 2022. "Knowledge Co-Production in the Helge å Catchment: A Comparative Analysis." *Ecosystems and People* 18 (1): 565–582. doi:10.1080/26395916.2022.2125583.

Moss, S. R. 2010. "Integrated weed management (IWM): will it reduce herbicide use?." *Communications in agricultural and applied biological sciences* 75 (2): 9–17.

Nazarko, O. M., R. C. Van Acker, and M. H. Entz. 2005. "Strategies and Tactics for Herbicide Use Reduction in Field Crops in Canada: A Review." *Canadian Journal of Plant Science* 85 (2): 457–479. https://doi.org/10.4141/P04-158.<Go to ISI>://WOS:000228942700022.

Nitsch, U. 2000. "The art of Environmental Communication." In *Knowing and Doing: On Knowledge and Action in Environmental Protection*, edited by Lars J Lundgren, 193–225. Stockholm: Swedish Environmental Protection Agency (Naturvårdsverket).

Ozcatalbas, O., and R. Brumfield. 2010. "Allelopathy as an agricultural innovation and improving allelopathy extension." *Journal of Food Agriculture and Environment* 8 (2): 908–913.

Rajendran, N., Y. S. Tey, M. Brindal, S. F. A. Sidique, M. N. Shamsudin, A. Radam, and Ahia Hadi. 2016. "Factors Influencing the Adoption of Bundled Sustainable Agricultural Practices: A Systematic Literature Review." *International Food Research Journal* 23 (5): 2271–2279. <Go to ISI>://WOS:000427099100059.

Rantanen, O., R. Merkkiniemi, J. Salonen, and T. Kaukoranta. 1993. "Development of the Real-Time Information Network AGRONET in Finland." https://www.scopus.com/inward/record.uri?eid=2-s2.0-84982617549&doi=10.1111%2fj.1365-2338.1993.tb00562.x&partnerID=40&md5=9cfca4fde02474305ff3f6e17f4d6667.

Rebaudo, F., and O. Dangles. 2013. "An Agent-based Modeling Framework for Integrated Pest Management Dissemination Programs." *Environmental Modelling & Software* 45: 141–149. doi:10.1016/j.envsoft.2012.06.014.<Go to ISI>://WOS:000320685400012.

Roberts, D., and S. Rao. 2012. "Extension Leads Multi-Agency Team in Suppressing a Pest in the West." https://www.scopus.com/inward/record.uri?eid=2-s2.0-84861740981&partnerID=40&md5=59dcdb8a4bd6ab98e42ea9a254ff022a.

Rossi, V., T. Caffi, and F. Salinari. 2012. "Helping Farmers Face the Increasing Complexity of Decision-Making for Crop Protection." *Phytopathologia Mediterranea* 51 (3): 457–479. <Go to ISI>://WOS:000313502900001.

Rust, Niki A, Petra Stankovics, Rebecca M Jarvis, Zara Morris-Trainor, Jasper R de Vries, Julie Ingram, Jane Mills, Jenny A Glikman, Joy Parkinson, and Zoltan Toth. 2022. "Have Farmers Had Enough of Experts?" *Environmental Management* 69: 1–14.

Sadok, W., F. Angevin, J. E. Bergez, C. Bockstaller, B. Colomb, L. Guichard, R. Reau, A. Messean, and T. Dore. 2009. "MASC, a qualitative multi-attribute decision model for ex ante assessment of the sustainability of cropping systems." *Agronomy for Sustainable Development* 29 (3): 447–461. doi:10.1051/agro/2009006.

Savary, Serge, Laetitia Willocquet, Sarah Jane Pethybridge, Paul Esker, Neil McRoberts, and Andy Nelson. 2019. "The Global Burden of Pathogens and Pests on Major Food Crops." *Nature Ecology & Evolution* 3: 430–439. doi:10.1038/s41559-018-0793-y

Shannon, C. E., and W. Weaver. 1949. *The Mathematical Theory of Communication*. Urbana, IL: University of Illinois Press.

Siebrecht, Norman. 2020. "Sustainable Agriculture and Its Implementation Gap-Overcoming Obstacles to Implementation." *Sustainability* 12 (9): 1–27. doi:10.3390/su12093853.

Stahl, L. A. B., L. M. Behnken, F. R. Breitenbach, R. P. Miller, D. Nicolai, and J. L. Gunsolus. 2016. "Use of an Integrated Pest Management Assessment Administered Through Turning point as an Educational, Needs Assessment, and Evaluation Tool." https://www.scopus.com/inward/record.uri?eid=2-s2.0-84995422271&partnerID=40&md5=92027373e776bf39cb9b729434c2f230.

Stevenson, W. R., J. A. Wyman, K. A. Kelling, L. K. Binning, D. Curwen, T. R. Connell, and D. J. Heider. 1995. Prescriptive crop and pest management software for farming systems involving potatoes. In *Potato Ecology And modelling of crops under conditions limiting growth*, 291–303.

Stigter, C. J., M. V. K. Sivakumar, and D. A. Rijks. 2000. "Agrometeorology in the 21st Century: Workshop Summary and Recommendations on Needs and Perspectives." https://www.scopus.com/inward/record.uri?eid=2-s2.0-0034213996&doi=10.1016%2fS0168-1923%2800%2900113-1&partnerID=40&md5=ea416b874b6980edb896da8e6a9850db.

Strand, J. F. 2000. "Some Agrometeorological Aspects of Pest and Disease Management for the 21st Century." *Agricultural and Forest Meteorology* 103 (1-2): 73–82. https://doi.org/10.1016/S0168-1923(00)00119-2. <Go to ISI>://WOS:000087530200008.

Šūmane, Sandra, Ilona Kunda, Karlheinz Knickel, Agnes Strauss, Talis Tisenkopfs, Ignacio des Ios Rios, Maria Rivera, Tzruya Chebach, and Amit Ashkenazy. 2018. "Local and Farmers' Knowledge Matters! How Integrating Informal and Formal Knowledge Enhances Sustainable and Resilient Agriculture." *Journal of Rural Studies* 59: 232–241. doi:10.1016/j.jrurstud.2017.01.020.

Wezel, A., M. Goris, J. Bruil, G. F. Félix, A. Peeters, P. Bàrberi, S. Bellon, and P. Migliorini. 2018. "Challenges and action points to amplify agroecology in Europe." *Sustainability* 10 (5): 1598.

Wijnands, F. G. 1992. "Evaluation and Introduction of Integrated Arable Farming in Practice." *Netherlands Journal of Agricultural Science* 40 (3): 239–249. <Go to ISI>://WOS:A1992KD65600003. https://doi.org/10.18174/njas.v40i3.16509

Wyatt, G. J., D. Herzfeld, and T. Haugen-Brown. 2015. "Teaching Farmers and Commercial Pesticide Applicators about Invasive Species in Pesticide Training Workshops." https://www.scopus.com/inward/record.uri?eid=2-s2.0-84946422629&partnerID=40&md5=cab5af552dc1b1b76c168b3f36153ed9.

Yngwe, Kristina. 2013. *Agricultural Knowledge and Information Systems in Sweden.* Hushållningssällskapet HIR Malmöhus (Prospects for Farmers' Support: Advisory Services in European AKIS (PRO AKIS)).

Zoschke, A., and M. Quadranti. 2002. "Integrated Weed Management: Quo Vadis?". https://www.scopus.com/inward/record.uri?eid=2-s2.0-0036241841&doi=10.1046%2fj.1445-6664.2002.00039.x&partnerID=40&md5=20c169401904ae6fa8154fb081c3c656.