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Factors influencing the acceptance of pesticide-free farming systems by farmers

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Summary

The application of pesticides has been linked with environmental and health hazards. The reduction of pesticides in agriculture constitutes a major policy issue in Europe. The implementation of pesticide free farming systems can make an important contribution to this issue and to the protection of sensitive natural resources. However, under existing conditions, the uptake of this type of system is often associated with major barriers. It is therefore important to understand which barriers inhibit the introduction of this system and how the acceptance of pesticide-free farming can be increased among farmers. To this end, we use qualitative interviews with conventional and partially pesticide-free farmers in south-west Germany to investigate which factors are decisive for farmers to abandon the use of chemical pesticides. The results show that, in addition to local factors such as soil, weather and farm and marketing structures, personal experience with pesticide-free cultivation and personal expectations regarding yield losses are particularly important acceptance factors. Furthermore, in addition to financial incentives, marketing structures are also needed to achieve cost-covering price increases. Our results provide important insights into the many factors influencing the transition to pesticide-free agriculture and thus contribute to the design of sustainable production systems.

Keywords

Pesticide-free, Sustainable agriculture, Adoption, Farmer behavior

Introduction

Pesticides have been an integral part of modern agriculture, aiding farmers in their fight against pests and increasing crop yields (Damalas, 2009). However, the widespread use of pesticides has resulted in numerous negative consequences, including environmental degradation, health hazards and increased resistance among pest populations (Godfray et al., 2010; Hawkins et al., 2019; Powles & Yu, 2010; Riyaz et al., 2022). In particular, pesticide residues in food are becoming an increasingly critical issue for consumers (Nitzko et al., 2022). As a result, there has been a growing interest in pesticide-free farming practices that focus on natural methods of pest control as for instance established in organic farming approaches (Stehle & Schulz, 2015).

Agriculture without synthetic chemical pesticides is a new concept in plant cultivation with the aim of achieving the highest possible yields through the use of mineral fertilisers while at the same time reducing environmental impacts by avoiding the use of chemical plant products (Zimmermann et al., 2021). By avoiding pesticides entirely, this concept has the potential to make a significant contribution to the reduction of pesticides targeted by the EU and to avoid the problems of pesticide residues in food and loss of biodiversity. However, the adoption of pesticide-free farming is still limited (Christensen et al., 2011; Finger & El Benni, 2013; Möhring & Finger, 2022). In this context, pesticide-free agriculture is understood as more than the mere substitution of chemical plant protection measures by non-chemical (e.g. technical) measures. Rather, pesticide-free agriculture is a system-level approach that aims to redesign the farming system to incorporate both new technologies and agroecological practices (Jacquet et al., 2022; Zimmermann et al., 2021). Comprehensive information on the drivers, barriers and challenges faced by farmers is needed for the widespread uptake of pesticide-free farming systems.

In this paper, we examine the acceptance of pesticide-free farming from the farmers' perspective. Specifically, we investigate the factors that influence farmers' decision-making regarding the adoption of pesticide-free farming practices and the challenges they face. We also explore the role of knowledge and experience in shaping farmers' acceptance of pesticide-free farming. In addition, we are evaluating possible scenarios for the implementation of pesticide-free farming systems. To do this, we use a qualitative approach, interviewing both conventional farmers and farmers who already farm partially without pesticides.

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The research paper is part of the research project Agriculture 4.0 without chemically synthetic pesticides. Through our research, we aim to provide insights into the factors that influence the acceptance of pesticide-free farming practices among farmers. We hope that our findings will inform policy decisions and promote the adoption of sustainable farming practices that benefit both farmers and the environment.

Background

Social science and behavioural research shows that social and psychological dimensions of farmers' decision-making behaviour have a decisive influence on changes in agricultural practice (Knowler & Bradshaw, 2007; Zimmermann & Britz, 2016). There is a wide range of literature on the adoption and implementation of more sustainable and environmentally friendly farming systems such as organic farming or the adoption of agri-environmental measures in general (Dessart et al., 2019; Meemken & Qaim, 2018; Zimmermann & Britz, 2016). However, the factors influencing the acceptance and implementation of different production systems and agri-environmental measures can rarely be transferred or generalised, as these factors must always be considered in the context of the farming systems and local conditions (Knowler & Bradshaw, 2007). Research on the factors relevant to pesticide-free agriculture, as well as their complex interconnections and modes of action, is still rare (Finger & El Benni, 2013; Finger & Möhring, 2022; Möhring & Finger, 2022). The adoption of pesticide-free agriculture goes beyond the requirements of individual agri-environmental measures. However, the barriers are lower than for conversion to organic farming as there are no restrictions on the use of fertilisers and there are no requirements for livestock farming (Zimmermann et al., 2021). Yield expectations are also higher than with organic farming (Pergner & Lippert, 2023), which has an impact on the profitability of the farming system. At the same time, pesticide-free farming does not yet have an institutionalised structure in Germany like organic farming. Thus, pesticide-free agriculture faces different challenges, involving both farmer motivation and attitudes towards more sustainable measures, as well as barriers to adoption at farm level.

The existing literature shows the numerous influencing factors that need to be taken into account when implementing farming practices that aim at strengthening environmental aspects. These will be reviewed in the following section. As no comprehensive studies on pesticide-free agriculture are available to date, aspects of the adoption of AEM, Integrated Pest Management (IPM), partially pesticide-free farming or conversion to organic farming that might be relevant to the adoption of pesticide-free agriculture are considered. In this respect, the following section only provides an overview of possible relevant factors for the adoption of pesticide-free farming. The interaction of different factors, depending on the characteristics of the farming system, can lead to considerable differences. In particular, the divergence between farmers' attitudes and actual behaviour poses a challenge for a targeted analysis of acceptance factors.

To frame and broadly structure our field of enquiry, we draw on the Campell Paradigm (Campbell, 1963). According to this, actual behaviour is determined by two main influencing factors: the subjective (environmental) attitude of the person and the objective behavioural costs for the person (Kaiser et al., 2010; Kaiser & Byrka, 2015). Only if the personal attitude outweighs the behavioural costs is it likely that the behaviour will be implemented.

Attitudes and Motivations

Behavioural factors such as personal attitudes, preferences, perceptions, motivation and social factors are seen as decisive for the adoption of sustainable agricultural practices (Dessart et al., 2019; Knapp et al., 2021).

In their meta-analysis of the literature on the importance of agri-environment schemes (AES), Batáry et al. (2015) found that in addition to financial incentives such as payment levels and ease of on-farm implementation, other factors such as farmers' attitudes and circumstances are important. Wilson (1997), in his study of Welsh farmers' motivation to participate AES, suggested that while financial incentives have an impact, individual differences such as age, education and length of residence are important factors in explaining variation in the uptake of AES. In their meta-analysis of socio-psychological factors in the adoption of sustainable agricultural practices by European farmers, Swart et al. (2023) find that general attitudes, intentions and perceived usefulness are the most important factors, while economic outcomes and environmental awareness have the least influence.

Schmitzberger et al. (2005) identified a strong correlation between the mentality of farmers and on-farm biodiversity among Austrian farmers, according to which more production-oriented farmers have lower biodiversity on their farms. Snoo et al. (2010), on the other hand, concluded that intrinsic motivation rarely leads to actual behaviour and that socio-psychological differences between Dutch farmers do not correlate with the ecological effects of conservation measures. Jahrl et al. (2012) also observed only a weak correlation between farmer motivation and implementation of agri-environmental measures, suggesting that the barriers to implementation are greater than the benefits to farmers.

Another relevant factor is farmers' expectations about the outcome of the production system. For example, higher production risks are perceived in organic farming due to the absence of pesticides and mineral fertilisers (Serra et al., 2008), which means that farmers' personal perceptions of risk and risk preferences are more important (Acs et al., 2009; Kallas et al., 2010; Meemken & Qaim, 2018). The importance of farmers' risk expectations is also evident with regard to the introduction of Integrated Pest Management (IPM). The abandonment of pesticides is perceived as a risk, on the one hand with regard to yields and on the other hand with regard to yield qualities (Lefebvre et al., 2015; Pergner & Lippert, 2023). As a result, the reduction of pesticides is not considered profitable and inhibits the adoption of IPM (Deguine et al., 2021).

Behavioural Costs

As shown earlier, underlying attitudes play an essential role in the adoption of agricultural practices. It also shows that although positive attitudes towards a particular practice exist, they do not necessarily lead to actual behaviour. On the other hand, there are numerous behavioural costs, whereby behavioural costs include all factors that influence behaviour both negatively and positively. The cost of a specific behaviour depends on the circumstances under which the behaviour takes place (Kaiser & Byrka, 2015).

Besides personal preferences, attitudes and social norms towards the system, other factors such as technical and economic issues play an important role (Home et al., 2019). Farm characteristics include the type of production, cultivated crops, and livestock. It also contains resource endowment and possible adjustment costs.

When converting to organic farming, technical problems are perceived, especially in relation to crop production (Läpple & Kelley, 2013). In this context, farmers considering conversion perceive an additional workload in organic farming (Ferjani et al., 2010). The risk of weed infestation and its control is one of the biggest concerns of farmers when converting (Ferjani et al., 2010). Adjustment costs include the costs that arise from a change of system (Gardebroek & Lansink, 2004). These are determined by the production orientation and economics of the farm. In the case of pesticide-free farming, this mainly includes the cost of machinery for mechanical crop protection and tillage.

In a study of Swiss farmers converting to organic farming, Home et al. (2019) found that a lack of supply and delivery points and a lack of informal support networks were the biggest barriers in areas with a low density of organic farms. Schmidtner et al. (2012) point out that there are off-farm economies of scale that can lead to an increase in organically farmed land such as low livestock density, poor soil quality and a high proportion of nature reserves. The density of organic farmers can also have a positive influence on the conversion decisions of other farmers, due to social networks and professional exchange and support among organic farmers (Schmidtner et al., 2012). The importance of knowledge in the context of pesticide reduction is also evident in IPM. Therefore, limited knowledge is a major barrier to the adoption of IPM (Deguine et al., 2021).

Also, access to organic markets is an important adoption factor for farmers (Läpple & Cullinan, 2012). Distance to markets and to customers (Karki et al., 2011) as well as the length of travel distances and associated transport costs, can also be barriers to switching in this context (Home et al., 2019). Market access is also a major challenge in the adoption of IPM (Lefebvre et al., 2015).

Material and Methods

As no comprehensive explanatory theory is currently available, there is still a need to better understand the importance and interplay of the various factors that are crucial for the adoption of pesticide-free agriculture. Therefore, we chose a qualitative approach to explore the knowledge base on farmers' decision-making regarding the adoption and implementation of pesticide-free agriculture.

The target group of interviewees included both conventional farmers and farmers who already partially abstain from the use of pesticides. The sampling was carried out in the course of a snowball system of conventional and partially pesticide-free farmers. The last are all members of the Kraichgau Korn market association. This association produces and processes bread grain without pesticides. The participating farmers only forego pesticides for bread grain intended for Kraichgau Korn. Other crops can still be cultivated conventionally. The cultivation of grain without pesticides is also not tied to a specific area, which means that the areas on which Kraichgau Korn grain is cultivated can change annually within the framework of crop rotation. The bread grain is processed by the brand's own mills and sold to bakers in the region. The certification of the pesticide-free grain is carried out by an external certification firm.

Since structural and regional aspects always need to be taken into account in agricultural farming systems, the interviews were limited to the Kraichgau Korn area of operation, which is located in the northern region of the federal state of Baden-Württemberg in Southwestern Germany. This area is characterised by a high level of arable farming. On the one hand, this limits the study. This means that the results cannot be extrapolated to the whole of Germany. On the other hand, this approach made it possible to take a deeper look at perceived and actual barriers, which may result from regional factors such as soil quality, weather influences and market structures.

When selecting the interview partners, the aim was to achieve maximum contrast within the framework of the regional conditions (Patton, 1990). Thus, not only farm managers of arable farms were interviewed, but also mixed farms and livestock farms (Table).

The other seven farmers are conventional farmers, with one farm currently in the process of conversion to organic farming and one farm cultivating a small (>10 %) share of land according to organic farming standards. The aim of the selection of farm managers was firstly to interview farmers who were partially pesticide-free about their personal attitudes, values and experiences. Following this, farm managers from conventional farms were interviewed in order to compare their attitudes and values with those of partly pesticide-free operating farmers and to identify similarities and differences. Although Kraichgau Korn farmers are only partially pesticide-free, their experiences, attitudes and perspectives are transferred to the concept of pesticide-free agriculture as far as possible. The findings from the differences between conventional farmers and partly pesticide-free farmers provide insights into acceptance factors and barriers to the adoption of pesticide-free agriculture.

There are considerable differences between the farms in terms of size. The average farm size in Germany is 63 ha, in Baden-Württemberg the farm size of 37 ha is well below the national average. The average in the region where interviews were conducted is about 49 ha. However, this must also be

Table. Interviewed farmers and farm characteristics

Type (Kraichgau Korn (KK)/ Conventional)	Sex	Age	Education (Agricultural/Higher Education [a])	Soil Quality [b]	Farm size	Full Time (FT)/ Part Time (PT)	Livestock
KK	m	52	AE	60-80	120 ha	FT	yes
KK	m	42	AE	20-60	60 ha	FT	no
KK	m	57	AE	20-80	270 ha	FT	no
KK	m	32	AE	40-60	10 ha	PT	yes
KK	m	42	HE	30-40	110 ha	PT	no
KK	m	52	HE	50-60	120 ha	FT	yes
KK	m	53	-	40-60	30 ha	PT	no
Conventional	m	55	HE	30-80	1400 ha	FT	no
Conventional	m	66	HE	30-80	68 ha	FT	no
Conventional	m	39	HE	20-90	200 ha	FT	no
Conventional	m	55	AE	30-80	100 ha	FT	no
Conventional	m	37	AE	50-60	120 ha	FT	Yes
Conventional	m	52	AE	60-70	50 ha	PT	yes

[a] Higher Education: at least a “Meister” degree at an agricultural school
[b] Valuation index of farmland

considered in the context of the distribution of land. More than half of the farms in Baden-Württemberg manage less than 20 ha. The share of these farms in the total agricultural area is relatively low at only 13%. Similarly, 57% of the farms are part-time farms. Only a quarter of the farms are larger than 50 ha. However, these farms manage two-thirds of the agricultural land in Baden-Württemberg. The selected farms have an average area of 204 ha (median 110 ha), with a considerable range between the smallest farm with 10 ha (part-time farmer) and the largest farm 1400 ha (farm cooperation).

In the interviews, data was collected on the farm manager himself and on the farm. The interview guide was based on existing literature the adoption of sustainable farming practices with regard to farmer attitudes and expectations and behavioural costs and included questions on the following topics:

- The farmer, age, education level,
- The farm, farm size, farm type, cultivated crops, livestock, farm succession, future plans, soil quality,
- Attitudes towards sustainability in agriculture,
- Attitudes and understanding of biodiversity,
- Attitudes towards AES, such as what AES they use,
- Attitudes towards organic farming, have they ever thought about conversion, what may be barriers,
- Importance of chemical plant protection; benefits and risks of chemical plant protection,
- Information and knowledge transfer, how they gain knowledge, how they share information.

During the interviews, the farm managers were asked about pathways for the implementation of pesticide-free agriculture, including three possible financing scenarios:

1. Funding exclusively through subsidies. The subsidies cover at least the yield deficits and variations. Marketing of the pesticide free products at higher sales prices is not required.
2. In addition to the existing subsidies, higher market prices are obtained for the pesticide-free products to compensate for the yield losses. The products are marketed and distributed by regional marketing cooperatives, similar to Kraichgau Korn.
3. In addition to existing subsidies, higher market prices are achieved. Marketing takes place nationwide through a standard label, similar to organic products.

The farm managers were provided with detailed information about the research project in advance by giving them information material. The research project and the research objectives were explained again in a conversation before the interview. All interviews were recorded using a digital recorder. The farm managers were asked in advance for their consent to be recorded. After the interviews, the material was transcribed. The interviews were conducted on farm, via video conference or by telephone between May and November 2022. The length varied between 25 minutes and 76 minutes with an average length of 52 minutes. No compensation was provided for participation in the interviews.

The interviews were analysed by means of a qualitative content analysis according to (Mayring, 2010) with the help of MAXQDA software. A deductive-inductive coding procedure was chosen in which both existing categories resulting from the given framework of the guideline and new categories were created from the material itself. If topics could not be assigned to the deductively formed categories, a new category was created. This led to a constant revision of the category scheme. After 12 interviews, no new categories or insights were gained and saturation was achieved.

Results

Farmers' attitudes and motivations

All farmers consider the preservation of soil fertility and the related preservation of the economic basis to be an essential factor of sustainability. Kraichgau Korn farmers also recognise the importance of reduced substance inputs, particularly pesticides. This group places particular importance on sustainability in the context of biodiversity. By partially dispensing with pesticides, they aim to promote more sustainable agriculture and greater biodiversity. The partial abandonment of chemical pesticides is a form of management that corresponds to their idea of a sustainable agriculture: *"In the end, it's the best of both worlds for me. I like the regional aspect, the environmental protection aspect, the nature conservation aspect and then I said, well, I'm behind that, I'm going to keep doing that."* The farmers' attitudes towards AEM vary. On one hand, they view it as beneficial due to its ability to make sustainable farming practices economically feasible. However, they are critical of its inability to differentiate among regional factors, its inflexibility in terms of long commitment periods and, in some cases, its limited impact on sustainability. Regarding pesticide-free agriculture, the existing subsidies are considered by all farmers to be too low to enable implementation on the whole farm.

An essential factor for the acceptance of pesticide-free agriculture is the personal experience of the farm manager in dispensing with pesticides. Farm managers who are already involved in Kraichgau Korn are less critical of not using pesticides and could imagine extending the model to other crops. Based on their own experience with Kraichgau Korn, they see marketing at profitable prices as a bigger challenge than plant cultivation aspects: *„So if there were marketing channels, we would go that way. It would be a dream to run the farm according to Kraichgau Korn guidelines (...). I could well imagine that, but you need a marketing channel."*

For conventional farmers who have no experience with pesticide-free farming, crop risks such as higher weed density and the associated yield risk are of greater concern. One farmer explained: *„And when I see what seed potential is building up there, I'm curious to see how it will develop over the next few years. That is also the next problem. It also builds up if you are sloppy with mechanical soil cultivation (...) And when it really gets out of hand, the blackgrass already suppresses it. And how do you get rid of that."* A complete conversion to pesticide-free agriculture at farm level is not conceivable for conventional farmers. Partial implementation on individual areas or for individual crops is more likely to be considered by most.

Another important factor is the perception of the benefits of not using chemical plant protection products. Farmers who partially farm without pesticides consider the effects on the environment and biodiversity to be higher than conventional farmers. This is due, among other things, to more weeds in the field and the increased presence of certain management indicator species. One partly pesticide-free Farmer explained: "*I would say that the large number of wild herbs in the fields means that I believe that more insects feel at home here, and that useful insects can of course be attracted, so that the cereal leaf beetle is not a problem and other insect species also find a home in our fields. In this respect, I believe that on the subject of insects, small flora and fauna are a bit more sustainable. That is of course one of the reasons why I do this, because it also interests me."*

Behavioural costs

Acceptance depends strongly on the crops grown by the farmers. These, for their part, are judged by two factors. Firstly, how suitable a crop is for avoiding pesticides. So how suitable is a crop to (1) mechanical weed control (2) sensitive to pests, (3) sensitive to fungal diseases. Secondly, crops are assessed in relation to their marketing potential. Very capital-intensive or high-priced crops, especially special crops, where it is difficult to achieve additional prices due to the high price level, are seen as less suitable under the given support schemes and market conditions, as is expressed by one farmer: *"The fact is that it is hardly valued in direct marketing. At least not in the case of asparagus, because asparagus is a high-priced product where the consumer values freshness and quality of origin. An added value of organic would hardly be enforceable. Even in food retailing, the current organic asparagus producers can hardly enforce additional revenues there."* In addition to marketing aspects, the Kraichgau Korn farmers also mention the challenge of a separate value chain. In addition to separate marketing, separate processing of the products is also needed to prevent contamination by conventional products.

Besides the crops grown, the production system of the farm plays an essential role. Fodder cultivation is not considered very suitable for the avoidance of chemical plant protection products, as it is considered unlikely that additional prices can be achieved to compensate for yield losses. At the same time, livestock farms consider pesticides to be of great importance in ensuring feed quality: *„So from my point of view, I only grow feed grain. I secure the yield for my animals and also the quality of my fodder. If I were to grow bread grain for Kraichgau Korn with a higher selling price, I could imagine it, but for us it is not an option so far."* Therefore, market crops are considered to be much more suitable for pesticide-free cultivation than those used for fodder.

Another factor influencing the adoption of pesticide-free agriculture is the adaptation costs associated with conversion. These reflect current tillage practices and on-farm machinery equipment. In this context, mechanical weed control equipment such as hoes and harrows are considered necessary. Especially for small farms, these costs can be a barrier to adoption: *„Of course, it is now a financial feat, especially if you want better machines. (...) That is already extreme. And whether it's worth it for small farms, despite the subsidies you get, but it's still a huge effort."* Although farm cooperatives or machinery rings can be alternatives to buying their own equipment, this depends strongly on the availability in the region or in the local area. The joint use of machines for mechanical weed control by multiple farms also poses challenges. The time windows for the use of such machines are described as much smaller than for the use of crop protection sprayers. Multiple use is therefore limited and carries the risk that the efficiency of weed control is reduced if the time of use cannot be optimally chosen:

„There's no point in always borrowing one. The time involved is too great. If you really have to drive past the field, look, walk through and see what is there or what is not, then you can start working and not wait to see if the harrow is free tomorrow or the day after. That's just bad."

Most of the farmers surveyed, both partly pesticide-free and conventional, had already considered converting to organic farming. However, there were several on-farm reasons for not converting. For livestock farms, extensive investments in barn conversions were an obstacle for converting to organic farming. The non-livestock farms saw the nutrient supply as not sufficiently ensured. *„The fact that we have a pigsty with fully slatted floors and that it doesn't fit into any organic-label spoke against it. (...). And if we close the barn, which is quite conceivable, then there is the issue of nutrients. How do I get nutrients to the field? How can that work? I can still generate nitrogen with legumes, but I can't produce phosphorus or potash at all. And that's where we actually failed."* Other reasons were the amount of land available or labour-related barriers, such as the use of external workforce. The use of biological pesticides such as copper was seen critically in organic farming by both groups. For the Kraichgau Korn farmers, it offers the possibility to farm more sustainably and without chemical pesticides and thus offers an alternative for organic farming.

The acceptance of pesticide-free agriculture depends strongly on the personal assessment of feasibility. Whether successful implementation is considered possible from the farmers' perspective is seen in a strong regional context. Soil quality and weather are regarded as major determinants. Since pesticide-free cultivation methods must be accompanied by substitution with mechanical procedures in the context of weed control, the assessment of soil quality represents an acceptance factor: "*It is difficult to farm without chemical pesticides in these poor fields. The soil is correspondingly decomposed. You can't exactly use a harrow there either. I imagine that would be difficult. On good fields it might work without chemical plant protection. But on sites like we have now, where it is relatively hilly, some of the fields are steep. That's where all the mechanical things reach their limits."* Particularly heavy or stony soils, which are poorly suitable for mechanical weed control or more intensive tillage, are seen by conventional farm managers as less suitable for pesticide-free cultivation. Likewise, slopes and areas with an increased risk of erosion are considered less suitable.

The renunciation of pesticides goes together with specific knowledge. This relates, among other things, to the application of mechanical plant protection measures, adaptation of crop rotation and sowing dates and variety selection. In addition to conferences and field days, public authorities (agricultural offices and agricultural chambers) as well as articles and internet sources are an important source of information on pesticide-free cultivation methods. For Kraichgau Korn farmers, the professional exchange with other farmers on cultivation methods and their experiences played an important role in the conversion. Networks of farmers that allow for a professional exchange of information make a positive contribution to the transfer of knowledge and can help to minimise concerns about yield risks.

Interplay between attitudes and behavioural costs

The acceptance and implementation of pesticide-free farming depends on the interplay between farmers' attitudes and motivations on the one hand and behavioural costs on the other. The fundamental environmental attitude of farmers can be considered as a key driver. The more positive the attitude, the more likely a farmer is to adopt pesticide-free farming, even in the face of enormous behavioural costs. On the contrary, gaining access to the market (and thus selling the products at higher prices) is the biggest barrier in terms of behavioural costs. This is illustrated by a Kraichgau Korn farmer as follows: *"I have more work with it, also more effort and it also costs nerves. But I see it as very important. But it is also only made possible by Kraichgau Korn that I am able to farm like this at all. Otherwise it would not be economically feasible."*

The following Figure shows an example of the interaction of the various factors. It should be noted that this is mere-

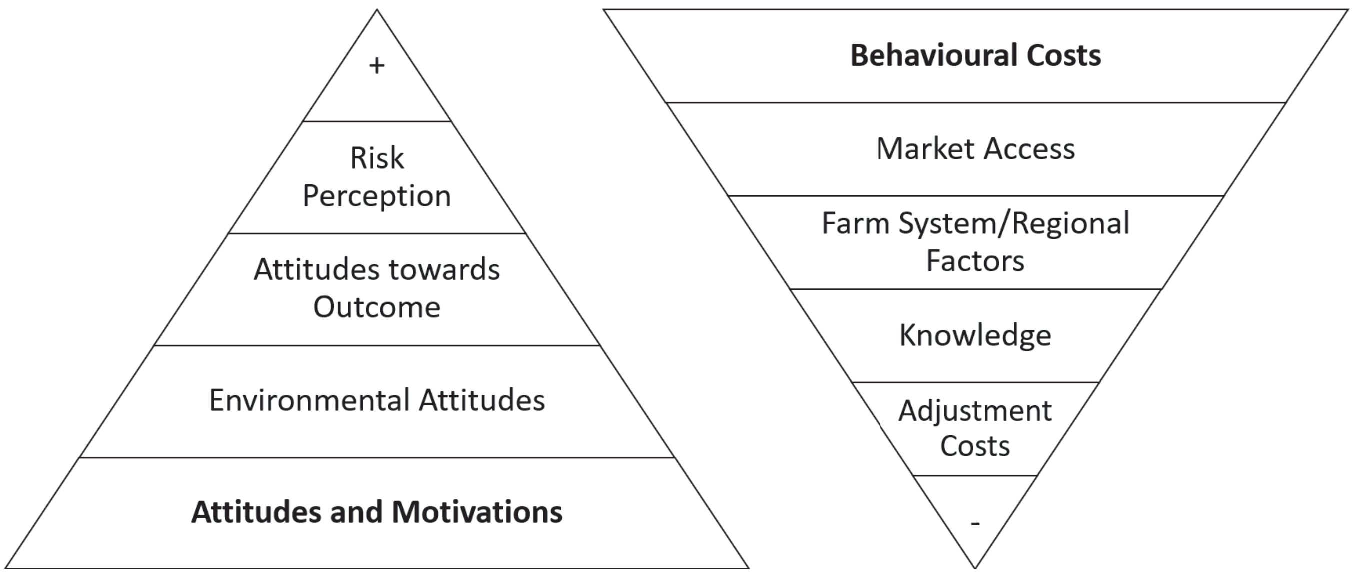

Fig. Interaction of motivational factors and behavioural costs in pesticide-free agriculture as an exemplary representation.

ly a simplified and exemplary representation of the numerous factors and that the way how they play out on a farm depends on contextual factors. Therefore, the weighting of motivational factors and behavioural costs may also differ between farms.

Scenarios for pesticide-free farming systems

The preferences of the farm managers for the three scenarios were ambiguous. However, some advantages and disadvantages were stated which are seen with the different scenarios.

One advantage in the first scenario (funding solely through subsidies) is that it does not require any extra processing and marketing, thus avoiding the effort and costs involved. Kraichgau Korn farmers named additional costs for certification and external processing as a factor to be considered for higher prices, on top of yield reductions. This scenario would therefore be the least demanding for farmers. The disadvantages mentioned were the dependence on political decisions within the framework of the CAP. For example, funding purely through subsidies is not seen as sustainable or long-term viable and is subject to political constraints. Likewise, the products produced as sustainable or more environmentally friendly are not sufficiently valued by the consumer in the course of a higher price: "*For me, there is only the market. That means the consumer has to honour it accordingly and if the consumer doesn't honour it, then he has no right to interfere and then he should let me inject or something else and that's it.*" Overall, the approach is seen as unrealistic. The current level of subsidies for pesticide abandonment is not considered sufficient. Also, the new subsidies within the eco-schemes are not seen as sufficient. A change in this is not expected in the near future, at least for the next CAP period.

Advantages within the second scenario (marketing and distribution through regional marketing cooperatives) are the closer connection to consumers due to the regionality of the products. On one hand, it is argued that production on a regional level is more sustainable, whilst on the other hand, it could enhance trust between farmers and consumers: *"I think regional would be better, more targeted. The farmer would be more satisfied, (…) and the local population in the region would perhaps have greater confidence because it comes from here and not from somewhere else."* A disadvantage is the high effort for farmers in the implementation of regional market communities. In addition, no economies of scale can be exploited in terms of political lobby work, external processing of the products and the cost-intensive certification of the products. The lack of market power due to the small size of the individual communities compared to food retailers is also perceived as a disadvantage. This can be a significant weakness, especially in price negotiations to achieve the necessary higher prices.

In the case of marketing through a standardised label (scenario 3), critics argue that the previously mentioned aspect of regionality is lost and that producers (i.e. farmers) become anonymous: *"If this is countrywide under one label, then I practically become a mass producer. I make something, take it to the collection centre and the job is done. (…) I think it's better if it's regional, also for consumer transparency."* For Kraichgau Korn farmers in particular, regional production is a strong motivator. The advantages of this scenario are perceived to be economies of scale in processing and marketing, as well as greater opportunities to influence policy decisions. This is seen as particularly important when it comes to setting prices for food retailers. Organic farming associations are cited as a positive example, as they can represent the interests of their members to retailers and politicians. In principle, however, marketing through a standardised label does not contradict regional producer groups.

Discussion

The main acceptance factors for a conversion to pesticide-free agriculture can be determined from the results. This includes both attitude-related factors and behavioural costs. The results of the interviews revealed that a large number of factors also interact to influence the acceptance of pesticide-free farming.

Our results show the importance of farmers' attitudes towards outcome as a major factor influencing acceptance, which are particularly reflected in the experiences, perceived yield expectations and risks of farmers who abandoned pesticide use. This is in line with the findings of Vanslembrouck et al. (2002) that positive experiences with environmental programmes are likely to lead to a positive attitude towards this practice. On the other hand, higher experience with a particular farming practice can lead to a lower probability of changing the existing production type (Läpple, 2010; Siebert et al., 2006). Farmers who partially abandon pesticides can in principle imagine an expansion of pesticide-free cultivation. This can also be explained by their greater knowledge of the special features of cultivation without pesticides, such as adapting crop rotation or sowing dates and altered soil cultivation. Findings on the adoption of pesticide-free wheat production and organic farming show that risk-averse actors in the field of crop protection, are less likely to adopt a conversion (Möhring & Finger, 2022). A complete conversion to pesticide-free farming is a much higher barrier for conventional farmers than the abandonment of pesticides for individual crops and fields. At the same time, it is important to communicate the crop-dependent yield risks in order to minimise uncertainties on the farmers' side. The exchange of experience with farmers who have already dispensed with pesticide free farming and a broad transfer of knowledge are of particular importance here. Here, too, it has been shown that an institutional framework can facilitate the exchange of experience and knowledge, as in the case of IP-Suisse's pesticide-free wheat programme or with organic farming associations (Finger & Möhring, 2022). Therefore, it can make sense to allow farmers to start on single fields in order to gain their own experience in dispensing with pesticides with as little risk as possible.

Our results show that the current subsidies for pesticide-free farming are considered by all participants to be too low to cover the additional costs incurred. Under these conditions, additional prices for agricultural products are necessary to make pesticide-free agriculture cost-covering for farmers. The additional prices vary depending on the crop cultivated and the associated yield reductions and risks, as well as the additional effort required for cultivation. In addition, other factors must be considered, such as the adaptation of crop rotation and, in particular, costs for external processing, certification and marketing. Results from Switzerland on pesticide-free wheat cultivation programmes show that a combination of direct payments and price premiums is a suitable combination and leads to a high level of acceptance by farmers (Möhring & Finger, 2022).

Creating market structures that enable farmers to cover their costs is one of the major challenges in implementing pesticide-free agriculture. Market access and marketing at higher prices is also a core challenge in the reduction of pesticides in integrated pest management (Lefebvre et al., 2015). This depends in particular on consumers' willingness to pay for pesticide-free products and the development of a comprehensible marketing strategy for these products (Wendt & Weinrich, 2023). However, it is not sufficient to simply market pesticide-free agricultural products at higher market prices; a separate value chain is also needed for the further processing of the products. Since neither processing in conventional nor organic value chains are possible due to the different standards and the associated contamination in the processing chain, storage, transport, and further processing of the initial products must be carried out separately in addition to separate certification. This poses enormous financial challenges, especially for small and regional production cooperatives. Implementing pesticide-free cropping systems therefore requires a separate infrastructure, which is a specific challenge for farmers. The widespread adoption of this concept is heavily reliant on consumers acceptance of the products. At the same time, the use of pesticides in sensitive areas (e.g. nature reserves) is to be banned in the EU as part of the Sustainable Use Regulation (SUR) (EUROPEAN COMMISSION, 2022). As a result, pesticide-free agriculture is now more pertinent than ever.

The results show the importance of adjustment costs as a barrier to adoption. This is also shown by Möhring & Finger (2022), who found that the availability of machinery for mechanical weed control has a direct influence on the adoption rate for pesticide-free wheat cultivation. Especially for smaller farms, these adaptation costs represent a high burden. A wide availability of machinery for mechanical weed control is therefore needed for a large-scale implementation of pesticide-free farming. Machinery rings and contractors who provide these machines can play a supporting role, especially for small farms. At the same time, targeted investment promotion for this technology is needed.

An essential factor in the assessment of pesticide-free farming systems was seen in the location factors. In particular, soil quality was mentioned as a factor. Heavy and stony soils, soils at risk of erosion and slopes were considered by the conventional farmers to be less suitable for a pesticide-free system, as increased tillage is made more difficult here or is to be avoided. At the same time, farmers at Kraichgau Korn have dispensed with pesticides in cereal cultivation under similar locational conditions. However, since the farmers did not completely abandon the use of pesticides, the suitability of the soils on the farm could be taken into account in the course of the land selection. Although soil quality can have a limiting influence on the implementation of pesticide-free cultivation, there is a difference in the assessment of the two farm manager groups. Here, too, the influence of the farmers' individual experience is evident.

This study has certain limitations due to the qualitative approach and the resulting small sample size. It is therefore difficult to generalise the results. Findings relate to small group of farmers under specific environmental conditions. The multitude of factors influencing adoption and their importance are therefore linked to the specific conditions of farms and regional circumstances. Similarly, other crops such as vegetables and other specialised crops could not be examined in detail. It was also not possible to take a closer look at the challenges in the value chain for a holistic pesticide-free farming system. Despite these limitations, the outcome of this research is a deeper understanding of the drivers and barriers to pesticide-free agriculture from the farmer's perspective. In particular, the results contribute to an understanding of the complex interrelationships between these factors and their influence on the uptake of pesticide-free agriculture.

Conclusion

This paper investigates the acceptance of crop production systems without chemical pesticides in Germany. We analyse influencing factors, barriers, and challenges for the introduction of a farming system that completely avoids the use of pesticides and does not only target individual crops. Whether the introduction of pesticide-free agriculture is successful depends to a large extent on whether it is possible to create functioning marketing structures for these products. Under the current framework conditions, marketing at higher prices compared to conventional products is a basic precondition for successful implementation in order to guarantee sufficient profitability for farmers.

Although the barriers to entry for pesticide-free farming systems are lower than for organic farming, adaptation costs are a barrier to adoption. Targeted investment promotion for machinery for mechanical crop protection and for the use of these machines across farms can help to reduce this adoption barrier.

Uncertainties about yield risks are a stronger factor for conventional farmers due to lack of experience with pesticide-free cultivation than for farmers who already partially avoid pesticides. Communication on the advantages of pesticide-free cultivation and on yield risks, as well as the dissemination of information on pesticide-free farming, can help to reduce uncertainties and are essential for acceptance.

Further research should explore which measures can be used to promote the implementation of pesticide-free farming systems in a targeted way. Furthermore, with a focus on possible implementation scenarios, it should be investigated how pesticide-free farming systems can be implemented in practice. In particular, the challenges of certification, processing and marketing must be taken into account.

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Conflicts of interest

The authors declare that they do not have any conflicts of interest.

Data availability

Data is not publicly available due to privacy restrictions.

References

Acs, S., Berentsen, P., Huirne, R., van Asseldonk, M., 2009: Effect of yield and price risk on conversion from conventional to organic farming. Australian Journal of Agricultural and Resource Economics 53 (3), 393–411, DOI: 10.1111/j.1467-8489.2009.00458.x.

Batáry, P., Dicks, L.V., Kleijn, D., Sutherland, W.J., 2015: The role of agri-environment schemes in conservation and environmental management. Conservation biology: the journal of the Society for Conservation Biology 29 (4), 1006–1016, DOI: 10.1111/cobi.12536.

Campbell, D.T., 1963: Social Attitudes and Other Acquired Behavioral Dispositions, URL: https://api.semanticscholar.org/CorpusID:143151327.

Christensen, T., Pedersen, A.B., Nielsen, H.O., Mørkbak, M.R., Hasler, B., Denver, S., 2011: Determinants of farmers' willingness to participate in subsidy schemes for pesticide-free buffer zones—A choice experiment study. Ecological Economics 70 (8), 1558–1564, DOI: 10.1016/j.ecolecon.2011.03.021.

Damalas, C.A., 2009: Understanding benefits and risks of pesticide use. Scientific Research and Essays 4 (10), 945–949.

Deguine, J.-P., Aubertot, J.-N., Flor, R.J., Lescourret, F., Wyckhuys, K.A., Ratnadass, A., 2021: Integrated pest management: good intentions, hard realities. A review. Agronomy for Sustainable Development 41 (3), DOI: 10.1007/s13593-021-00689-w.

Dessart, F.J., Barreiro-Hurlé, J., van Bavel, R., 2019: Behavioural factors affecting the adoption of sustainable farming practices: a policy-oriented review. European Review of Agricultural Economics 46 (3), 417–471, DOI: 10.1093/erae/jbz019.

EUROPEAN COMMISSION, 2022: Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the sustainable use of plant protection products and amending Regulation (EU) 2021/2115.

Ferjani, A., Zimmermann, A., Reissig, L., Station de recherche Agroscope Reckenholz-Taenikon ART, 2010: Organic Agriculture: Why so Few Farms Convert. Agrarforschung (Switzerland).

Finger, R., El Benni, N., 2013: Farmers' adoption of extensive wheat production – Determinants and implications. Land Use Policy 30 (1), 206–213, DOI: 10.1016/j.landusepol.2012.03.014.

Finger, R., Möhring, N., 2022: The adoption of pesticide-free wheat production and farmers' perceptions of its environmental and health effects. Ecological Economics 198, 107463, DOI: 10.1016/j.ecolecon.2022.107463.

Gardebroek, C., Lansink, A.G.O., 2004: Farm-specific Adjustment Costs in Dutch Pig Farming. Journal of Agricultural Economics 55 (1), 3–24, DOI: 10.1111/j.1477-9552.2004.tb00076.x.

Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C., 2010: Food security: the challenge of feeding 9 billion people. Science 327 (5967), 812–818, DOI: 10.1126/science.1185383.

Hawkins, N.J., Bass, C., Dixon, A., Neve, P., 2019: The evolutionary origins of pesticide resistance. Biological reviews of the Cambridge Philosophical Society 94 (1), 135–155, DOI: 10.1111/brv.12440.

Home, R., Indermuehle, A., Tschanz, A., Ries, E., Stolze, M., 2019: Factors in the decision by Swiss farmers to convert to organic farming. Renewable Agriculture and Food Systems 34 (6), 571–581, DOI: 10.1017/S1742170518000121.

Jacquet, F., Jeuffroy, M.-H., Jouan, J., Le Cadre, E., Litrico, I., Malausa, T., Reboud, X., Huyghe, C., 2022: Pesticide-free agriculture as a new paradigm for research. Agronomy for Sustainable Development 42 (1), DOI: 10.1007/s13593-021-00742-8.

Jahrl, I., Rudmann, C., Pfiffner, L., Balmer, O., 2012: Motivations for the implementation of ecological compensation areas. Agrarforschung Schweiz 19 (4), 208–215.

Kaiser, F.G., Byrka, K., 2015: The Campbell paradigm as a conceptual alternative to the expectation of hypocrisy in contemporary attitude research. The Journal of social psychology 155 (1), 12–29, DOI: 10.1080/00224545.2014.959884.

Kaiser, F.G., Byrka, K., Hartig, T., 2010: Reviving Campbell's paradigm for attitude research. Personality and social psychology review: an official journal of the Society for Personality and Social Psychology, Inc 14 (4), 351–367, DOI: 10.1177/1088868310366452.

Kallas, Z., Serra, T., Gil, J.M., 2010: Farmers' objectives as determinants of organic farming adoption: the case of Catalonian vineyard production. Agricultural Economics 41 (5), 409–423, DOI: 10.1111/j.1574-0862.2010.00454.x.

Karki, L., Schleenbecker, R., Hamm, U., 2011: Factors influencing a conversion to organic farming in Nepalese tea farms. 1612-9830.

Knapp, L., Wuepper, D., Finger, R., 2021: Preferences, personality, aspirations, and farmer behavior. Agricultural Economics 52 (6), 901–913, DOI: 10.1111/agec.12669.

Knowler, D., Bradshaw, B., 2007: Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food Policy 32 (1), 25–48, DOI: 10.1016/j.foodpol.2006.01.003.

Läpple, D., 2010: Adoption and Abandonment of Organic Farming: An Empirical Investigation of the Irish Drystock Sector. Journal of Agricultural Economics 61 (3), 697–714, DOI: 10.1111/j.1477-9552.2010.00260.x.

Läpple, D., Cullinan, J., 2012: The development and geographic distribution of organic farming in Ireland. Irish Geography 45 (1), 67–85, DOI: 10.1080/00750778.2012.698585.

Läpple, D., Kelley, H., 2013: Understanding the uptake of organic farming: Accounting for heterogeneities among Irish farmers. Ecological Economics 88, 11–19, DOI: 10.1016/j.ecolecon.2012.12.025.

Lefebvre, M., Langrell, S.R.H., Gomez-y-Paloma, S., 2015: Incentives and policies for integrated pest management in Europe: a review. Agronomy for Sustainable Development 35 (1), 27–45, DOI: 10.1007/s13593-014-0237-2.

Mayring, P., 2010: Qualitative Inhaltsanalyse. *Handbuch Qualitative Forschung in der Psychologie*, VS Verlag für Sozialwissenschaften, 601–613, DOI: 10.1007/978-3-531-92052-8_42.

Meemken, E.-M., Qaim, M., 2018: Organic Agriculture, Food Security, and the Environment. Annual Review of Resource Economics 10 (1), 39–63, DOI: 10.1146/annurev-resource-100517-023252.

Möhring, N., Finger, R., 2022: Pesticide-free but not organic: Adoption of a large-scale wheat production standard in Switzerland. Food Policy 106, 102188, DOI: 10.1016/j.foodpol.2021.102188.

Nitzko, S., Bahrs, E., Spiller, A., 2022: Pesticide residues in food and drinking water from the consumer's perspective: The relevance of maximum residue levels and product-specific differences. Sustainable Production and Consumption 30, 787–798, DOI: 10.1016/j.spc.2022.01.016.

Patton, M.Q., 1990: Qualitative evaluation and research methods. Newbury Park, Sage, 532 s.;, ISBN: 0803937792.

Pergner, I., Lippert, C., 2023: On the effects that motivate pesticide use in perspective of designing a cropping system without pesticides but with mineral fertilizer—a review. Agronomy for Sustainable Development 43 (2), DOI: 10.1007/s13593-023-00877-w.

Powles, S.B., Yu, Q., 2010: Evolution in action: plants resistant to herbicides. Annual review of plant biology 61, 317–347, DOI: 10.1146/annurev-arplant-042809-112119.

Riyaz, M., Ahmad Shah, R., Sivasankaran, K., 2022: Pesticide Residues: Impacts on Fauna and the Environment. *Biodegradation Technology of Organic and Inorganic Pollutants*, IntechOpen, DOI: 10.5772/intechopen.98379.

Schmidtner, E., Lippert, C., Engler, B., Häring, A.M., Aurbacher, J., Dabbert, S., 2012: Spatial distribution of organic farming in Germany: does neighbourhood matter? European Review of Agricultural Economics 39 (4), 661–683, DOI: 10.1093/erae/jbr047.

Schmitzberger, I., Wrbka, T., Steurer, B., Aschenbrenner, G., Peterseil, J., Zechmeister, H., 2005: How farming styles influence biodiversity maintenance in Austrian agricultural landscapes. Agriculture, Ecosystems & Environment 108, 274–290, DOI: 10.1016/j.agee.2005.02.009.

Serra, T., Zilberman, D., Gil, J.M., 2008: Differential uncertainties and risk attitudes between conventional and organic producers: the case of Spanish arable crop farmers. Agricultural Economics 39 (2), 219–229, DOI: 10.1111/j.1574-0862.2008.00329.x.

Siebert, R., Toogood, M., Knierim, A., 2006: Factors Affecting European Farmers' Participation in Biodiversity Policies. Sociologia Ruralis 46 (4), 318–340, DOI: 10.1111/j.1467-9523.2006.00420.x.

Snoo, G.R. de, Lokhorst, A.M., van Dijk, J., Staats, H., Musters, C., 2010: Benchmarking biodiversity performances of farmers. Aspects of Applied Biology 100, 311–318.

Stehle, S., Schulz, R., 2015: Agricultural insecticides threaten surface waters at the global scale. Proceedings of the National Academy of Sciences 112 (18), 5750–5755, DOI: 10.1073/pnas.1500232112.

Swart, R., Levers, C., Davis, J.T., Verburg, P.H., 2023: Meta-analyses reveal the importance of socio-psychological factors for farmers' adoption of sustainable agricultural practices. One Earth, DOI: 10.1016/j.oneear.2023.10.028.

Vanslembrouck, I., Huylenbroeck, G., Verbeke, W., 2002: Determinants of the Willingness of Belgian Farmers to Participate in Agri-environmental Measures. Journal of Agricultural Economics 53 (3), 489–511, DOI: 10.1111/j.1477-9552.2002.tb00034.x.

Wendt, M.-C., Weinrich, R., 2023: Consumer Segmentation for Pesticide-free Food Products in Germany. Sustainable Production and Consumption 42, 309–321, DOI: 10.1016/j.spc.2023.10.005.

Wilson, G.A., 1997: Factors Influencing Farmer Participation in the Environmentally Sensitive Areas Scheme. Journal of Environmental Management 50 (1), 67–93, DOI: 10.1006/jema.1996.0095.

Zimmermann, A., Britz, W., 2016: European farms' participation in agri-environmental measures. Land Use Policy 50, 214–228, DOI: 10.1016/j.landusepol.2015.09.019.

Zimmermann, B., Claß-Mahler, I., Cossel, M. von, Lewandowski, I., Weik, J., Spiller, A., Nitzko, S., Lippert, C., Krimly, T., Pergner, I., Zörb, C., Wimmer, M.A., Dier, M., Schurr, F.M., Pagel, J., Riemenschneider, A., Kehlenbeck, H., Feike, T., Klocke, B., Lieb, R. et al., 2021: Mineral-Ecological Cropping Systems—A New Approach to Improve Ecosystem Services by Farming without Chemical Synthetic Plant Protection. Agronomy 11 (9), 1710, DOI: 10.3390/agronomy11091710.