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Diversified Farming Systems – An evaluation of ecological benefits, economic costs & risks farmers face

Dissertation

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In memory of my best friend Svenja Schmidtke

"Diversity creates harmony, and harmony creates beauty, balance, bounty and peace in nature and society, in agriculture and culture, in science and in politics."

Vandana Shiva

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SUMMARY

Biodiversity and associated ecosystem services in cultural landscapes are declining due to increasing agricultural production. Human population growth and changing consumption patterns cause higher demands on agricultural products and accelerates the intensification of agricultural practices. Intensification of agricultural management is a major reason of ecological problems such as homogeneity of landscapes, rising greenhouse gas emissions, eutrophication, loss of soil fertility and productivity. These negative externalities of intensive agricultural production result in high loss of biodiversity and associated ecosystem services, such as the loss of species, pollination, and biological pest control as well as reduced carbon sequestration, enhanced nutrient leaching and higher soil erosion. To mitigate these ecological problems, a new model called "Diversified farming system" has been proposed. Diversified farming systems include a range of agricultural management practices that promote ecosystem functioning and related ecosystem services at different spatial and temporal scales and contribute to the promotion of critical ecosystem services. Further diversified farming practices may replace agricultural production inputs such as fertilizer or chemical plant protection measures, which is economically advantageous.

This thesis focuses on a better understanding of the ecological and economic consequences of diversified farming systems. The ecological-economic expectations of farmers regarding benefits and costs of diversified farming practices were analyzed, including the discrepancy between scientific evidence and farmers' arguments for low adoption of diversified farming practices. The thesis ends with recommendations on how and which political incentives may lead to higher implementation rates of diversified farming practices.

For such purpose, the thesis is divided into four chapters: A first introductory chapter gives a general overview, summarizing and discussing current scientific knowledge and research gaps of diversified farming systems. Furthermore, the first chapter gives an outline of the thesis.

In the second chapter, we systematically reviewed and synthesized scientific evidence of the ecological and economic performance of diversified farming practices. We found that diversified farming practices provide substantially greater biodiversity and associated ecosystem services than non-diversified systems. The ecological benefits for the farmer were partly insufficient to outbalance economic costs in the short term, even though many examples showed that diversified farming practices can lead to higher and more stable yields, increase profitability, and reduce risks in the long-term.

In the third and fourth chapter of this thesis, we present results from face-to-face interviews of farmers on the perception of ecological-economic performance and risk change by potential implementations of diversified farming practices in Germany. The results of the third chapter show that gross margin increased for diversified crop rotation, while reduced tillage and direct seeding resulted in lower gross margin, because of expected yield reduction and higher variable costs. High soil quality leads to higher gross margin expected. The fourth chapter expands on the perception of risk change by implementation of diversified farming practices. We found that farmers expected a risk reduction by cover crops and diversified crop rotation, due to the portfolio effect, but a risk increase by reduced tillage and direct seeding, due to greater weed pressure. Large farm sizes and less fertile soils are related to the perception of reduced yield risk, presumably because of additional opportunities to increase profits through the implementation of diversification.

In conclusion, diversified farming systems can substantially contribute to maintain biodiversity and to support the provision of ecosystem services. In order to increase the implementation rate of diversified farming practices, incentives are needed to reward for ecological benefits on the farm level. However, consideration of farm features and farmers' experience and expectations may help to adjust incentives by agri-environmental policies.

ZUSAMMENFASSUNG

Die biologische Vielfalt und die mit ihr assoziierten Ökosystemleistungen in Kulturlandschaften nehmen aufgrund der zunehmenden Intensivierung der landwirtschaftlichen Produktion ab. Das Bevölkerungswachstum und die sich ändernden Konsummuster führen zu einer höheren Nachfrage nach landwirtschaftlichen Erzeugnissen und beschleunigen die Intensivierung in der Landwirtschaft. Die Intensivierung der landwirtschaftlichen Bewirtschaftung ist eine der Hauptursachen für ökologische Probleme, wie Homogenisierung der Kulturlandschaften, steigende Treibhausgasemissionen, Eutrophierung, Verlust der Bodenfruchtbarkeit und Produktivität. Diese negativen externen Effekte der Intensivierung von landwirtschaftlichen Produktionsmethoden führen zu einem hohen Verlust an biologischer Vielfalt und den mit ihr assoziierten Ökosystemleistungen, wie dem Verlust von Arten, der Bestäubung und der biologischen Schädlingsbekämpfung, sowie zu einer geringeren Kohlenstoffbindung, einer verstärkten Nährstoffauswaschung und einer höheren Bodenerosion. Die Diversifizierung landwirtschaftlicher Systeme wird als ein Modell verstanden, dass dazu beiträgt diese ökologischen Probleme abzumildern. Diversifizierte Anbausysteme umfassen eine Reihe von landwirtschaftlichen Bewirtschaftungsmethoden, die Ökosystemfunktionen und die damit verbundenen Ökosystemleistungen auf verschiedenen räumlichen und zeitlichen Ebenen fördern. Diversifizierte Anbaumethoden können landwirtschaftliche Produktionsmittel wie Düngemittel oder chemische Pflanzenschutzmaßnahmen substituieren, was zu wirtschaftlichen Vorteilen führt.

Diese Arbeit konzentriert sich auf ein besseres Verständnis der ökologischen und ökonomischen Folgen diversifizierter Anbausysteme. Die ökologisch-ökonomischen Erwartungen der Landwirt*innen hinsichtlich der Vorteile und Kosten diversifizierter Anbaumethoden wurden analysiert, einschließlich der Diskrepanz zwischen den wissenschaftlichen Erkenntnissen und den Argumenten der Landwirte für die geringe Akzeptanz diversifizierter Anbaumethoden. Die Arbeit endet mit Empfehlungen, wie und welche politischen Anreize zu einer höheren Umsetzungsrate diversifizierter landwirtschaftlicher Praktiken führen können.

Zu diesem Zweck ist die Arbeit in vier Kapitel unterteilt: Das Einführungskapitel gibt einen allgemeinen Überblick und fasst den aktuellen wissenschaftlichen Kenntnisstand und die Forschungslücken zu diversifizierten Anbausystemen zusammen und diskutiert diese. Außerdem gibt das erste Kapitel einen Überblick über den Aufbau der Arbeit und die nachfolgenden Kapitel.

Im zweiten Kapitel haben wir die wissenschaftlichen Belege für die ökologische und ökonomische Leistungsfähigkeit diversifizierter Anbaumethoden systematisch überprüft und zusammengefasst. Wir fanden heraus, dass diversifizierte Anbaumethoden eine wesentlich größere biologische Vielfalt und Ökosystemleistungen bieten als nicht-diversifizierte Systeme. Die ökologischen Vorteile für die Landwirt*innen reichten teilweise nicht aus, um die wirtschaftlichen Kosten kurzfristig aufzuwiegen, obwohl viele Beispiele zeigten, dass diversifizierte Anbaumethoden langfristig zu höheren und stabileren Erträgen, höherer Rentabilität und geringeren Risiken führen können.

Im dritten und vierten Kapitel dieser Arbeit werden Ergebnisse aus persönlichen Befragungen von Landwirt*innen über die Wahrnehmung von Gewinn- und Risikoveränderungen durch die potenzielle Einführung diversifizierter landwirtschaftlicher Praktiken in Deutschland vorgestellt. Die Ergebnisse des dritten Kapitels zeigen, dass der Deckungsbeitrag bei einer diversifizierten Fruchtfolge und dem Zwischenfruchtanbau anstieg, während reduzierte Bodenbearbeitung und Direktsaat zu einem geringeren Deckungsbeitrag führten, was auf die erwarteten Ertragseinbußen und höheren variablen Kosten zurückzuführen ist. Landwirt*innen die über gute Böden verfügen, erwarteten höhere Deckungsbeiträge durch Einführung von diversifizierten Anbaumethoden, im Gegensatz zu Landwirt*innen die auf qualitativ schlechteren Böden wirtschaften.

Das vierte Kapitel befasst sich mit der Risikowahrnehmung durch die Einführung diversifizierter Anbaumethoden. Dabei wurde deutlich, dass die Landwirt*innen aufgrund des Portfolioeffekts eine Risikominderung durch Zwischenfrüchte und eine diversifizierte Fruchtfolge erwarteten, aber eine Risikoerhöhung durch Nutzung reduzierter Bodenbearbeitung und der Direktsaat aufgrund des höheren Unkrautdrucks. Große Betriebe und weniger fruchtbare Böden stehen im Zusammenhang mit der Wahrnehmung eines geringeren Ertragsrisikos, vermutlich aufgrund zusätzlicher Möglichkeiten zur Gewinnsteigerung durch die Umsetzung der diversifizierten Anbaumethoden.

Zusammenfassend lässt sich sagen, dass diversifizierte Anbausysteme wesentlich zum Erhalt der biologischen Vielfalt und zur Bereitstellung von Ökosystemleistungen beitragen können. Es sind Anreize erforderlich, um die Umsetzungsrate diversifizierter landwirtschaftlicher Praktiken zu erhöhen und den ökologischen Nutzen auf Betriebsebene zu entlohnen. Die Berücksichtigung von betrieblichen Gegebenheiten sowie der Erfahrungen und Erwartungen der Landwirt*innen kann jedoch dazu beitragen, die Anreize durch die Agrarumweltpolitik anzupassen.

CHAPTER 1

GENERAL INTRODUCTION AND OVERVIEW OF THIS THESIS

Diversified landscape nearby Cassel (July 2022, © Julia Rosa-Schleich)

General introduction

Since the Green Revolution, the impact of agriculture on our planet has dramatically increased. Croplands and pastures together occupy more than 40% of the ice-free land (Tilman et al., 2011), and 5.1 million hectares of croplands are added globally every year (Potapov et al., 2022). To fulfill global food security, the current agricultural model relies on converting natural ecosystems to cropland and the intensive use of fertilizers and pesticides. Such intensive agriculture, however, is unsustainable and causes ecological, economic and social problems (Godfray et al., 2010). Intensive agriculture is among the main cause of terrestrial habitat loss, climate change, and the ongoing biodiversity decline (Sala et al., 2000), and it can threaten essential ecosystem services, with potentially tremendous consequences for future generations (Ponisio et al., 2015; MEA, 2005). Moreover, ecological deteriorations caused by intensive agriculture leads to high external costs for the society, and the loss of resistant and resilient agro-ecosystems directly influence the livelihood of farmers (IPES-Food, 2016). The world population has been, expected to rise tremendously by 2050, resulting in an increasing demand for food and environmental pressure (Foley et al., 2011). The survival of our species will likely depend also on our ability to develop sustainable agricultural systems that maintain food production without depauperating natural ecosystems and the global climate.

One major challenge for sustainable agricultural management is to combine economically efficient strategies with the conservation and provision of biodiversity and associated ecosystem services (Zhang et al., 2007, Tscharntke et al., 2012). Diversified Farming (DF) systems are an ecological alternative to conventional agricultural intensification (Barghouti et al., 1992) and can supply and support ecosystem services while simultaneously achieving acceptable amounts of yield (Kremen & Miles, 2012; Kremen et al., 2012; Duru et al., 2015). DF systems seek to reduce external costs by saving on chemical and physical inputs without decreasing yields, thereby improving farmers income and livelihoods (Dore et al., 2011; Bommarco et al., 2012; IPES-Food, 2016). DF systems include several practices such as intercropping, cover crops, diversified crop rotation, reduced tillage, or direct seeding and maintenance of structural elements (e.g., hedges and flower strips). These practices support agrobiodiversity at different spatial and temporal scales (Kremen & Miles, 2012; Bowman & Zilberman, 2013) and aim to promote ecological interactions that facilitate soil fertility, productivity and resilience against external disturbances (Hill 1998; Duru et al., 2015). Thus, DF practices can be implemented in several agricultural production systems (e.g., organic, integrated, conventional and extensive agriculture) to handle natural resources efficiently both at the business management and societal level.

Theoretically, DF practices may enhance biodiversity and ecosystem services, but they could also exacerbate costs by reducing the productive land or decreasing yields. Yet, decreased costs or economic benefits are also possible. For example, polycultures can enhance biological pest control and increase yields (Iverson et al., 2014). Cultivation of rice variety mixtures showed yield increases of up to 89% (Zhu et al., 2000). Diversified crop rotations that include legumes increase yields without fertilizer applications, saving up to 60 kg N/ha and 60-70 €/ha in Europe (Preissel et al., 2015). The provision of ecosystem services through DF practices offers a high potential for sustainable development. Although DF practices can potentially be the foundations for a sustainable agriculture, the trade-offs between ecological benefits and economic costs have been rarely examined (Bommarco et al., 2012). Bowman & Zilberman (2013) described factors that can help to make individual DF practices economically more attractive, e.g., reducing risks, providing complementary outputs, or optimizing production. Yet, a comprehensive assessment of the effects of multiple DF practices on economic and ecological factors that could help reducing costs and risks for the farmers do not exist (Dore et al., 2011; Bommarco et al., 2013; Iverson et al., 2014; Ponisio et al., 2015; Preissel et al., 2015). Additionally, a deeper understanding of the expectations that drive farmers decisions is needed to evaluate the feasibility and acceptability of DF practices.

Chapters outline

This thesis aims to assess the trade-offs between ecological benefits and economic costs through DF practices as well as to evaluate the feasibility, effectiveness and acceptability of DF systems as a strategy for sustainable farming. We assume that DF practices result in higher ecological benefits and lower economic costs. We expected that if several DF practices are used extensively, ecological benefits will increase, while the costs decrease through the delivery of ecosystem services. DF practices may lower pesticides, fertilizers, and machinery use, reducing inputs and variable costs (Mäder et al., 2008; Gurr et al., 2016). In Chapter 2, we review ecological and economic research on DF practices in agricultural landscapes and synthesize the effectiveness of DF practices in terms of biodiversity and ecosystem services as well as in economic returns for the farmers (Figure 1 Part 1). In Chapter 3 & 4, we investigated why farmers hesitate in applying DF practices. We present the results from face-to-face surveys designed to assess whether there is a discrepancy between farmers' perception and the actual conditions linked to DF practices including changes in ecological-economic performance and risks farmers face (Figure 1 Part 2 & 4).

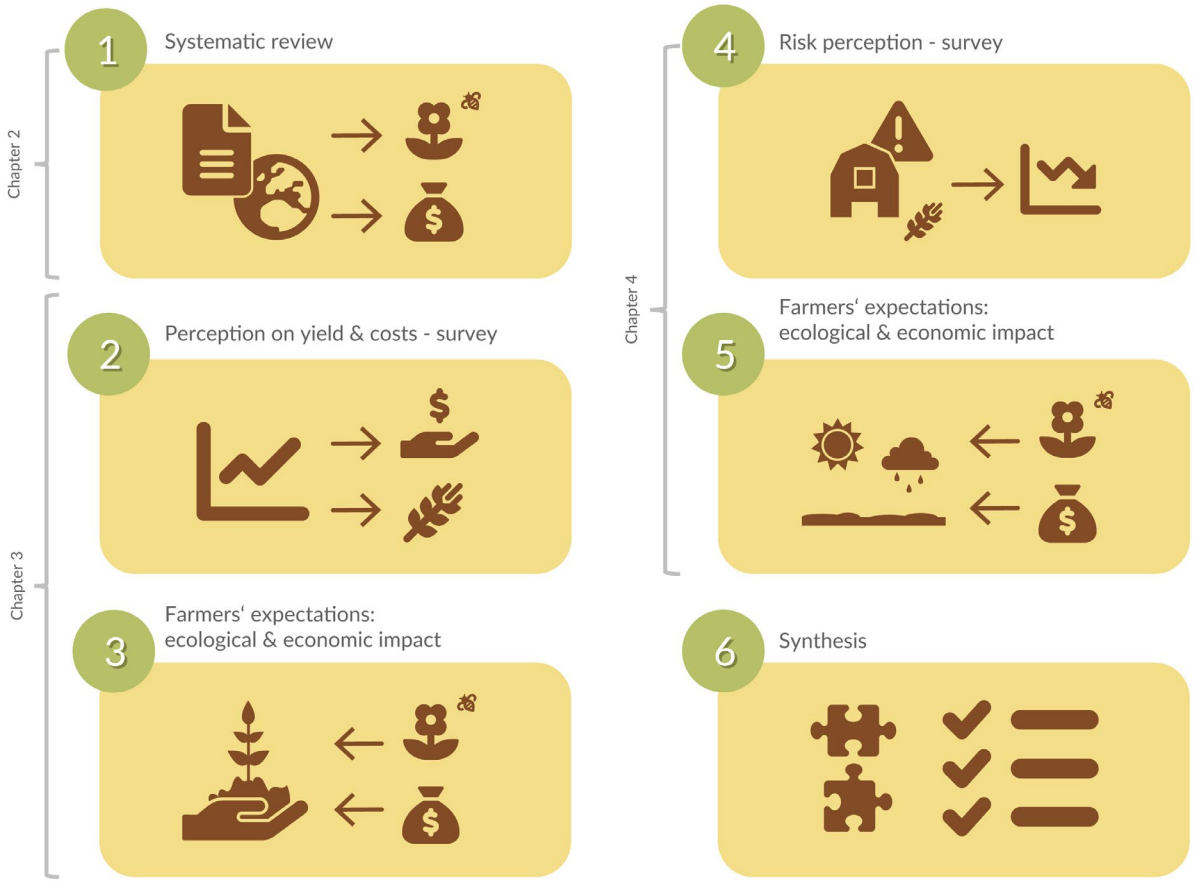

Figure 1 Outline of the thesis through a schematic illustration of the key approaches within each chapter. First of all, we conducted a systematic review (worldwide). Secondly, the findings of the systematic review were translated into a face-to-face survey, including the perception of the farmers on (2) ecological-economic performance (yield, variable costs & gross margin) and (4) risk under to scenarios by implementation of DF practices. Consequently, farmers' expectations were then analyzed considering the ecological and economical influencing factors (3) & (5). Ending with a synthesis (6) and overall conclusion of the thesis.

Chapter 2: *Ecological-economic trade-offs of Diversified Farming Systems – A review*

In this review, we synthetized the evidence for ecological and economic benefits provided by DF systems to evaluate which diversification practices supply higher ecological benefits at lower economic costs (or even increasing economic benefits). Here, we aim at answering the question:

- Which diversification practices supply high ecological benefits at low economic costs or even increase economic benefits?

Using a systematic review approach (Tranfield et al., 2003; Pullin & Stewart, 2006; Harrison, 2011), we i) assessed the benefits and costs of each DF practice; and ii) identified and compared factors (such as region, climate, soil conditions, farm size, etc.) influencing the benefits and costs of different DF practices. Our results indicated that DF practices provide substantially

greater ecosystem services, whereas ecological benefits did not always outbalance economic costs. These findings indicated that financial instruments are needed to increase the implementation of DF practices and to reward farmers for the ecosystem services provided at the farm level.

Chapter 3: *Mixed farmers' perception of the ecological-economic performance of diversified farming*

For a deeper understanding of farmers' perception on the ecological-economic performance of DF practices, we investigated farmers' perceived change of yield, variable costs, and gross margin by implementation of DF practices through a face-to-face survey. Therefore, we formulated the following research questions:

- How does the potential implementation of five DF practices affects the perception on yield, variable costs, and gross margin?
- Which farm characteristics and risk attitude can explain these perceived changes in yield, variable costs, and gross margin?
- How can farmers' expectations be incorporated into policy decision-making to increase the implementation of DF practices?

Our results indicated that farmers expected higher ecological-economic performance from diversified crop rotation, whereas reduced tillage and direct seeding decreased the expected ecological-economic performance. Soil fertility was positively related to the perceived gross margin. These findings provide insights to which extent farmers perceive the ecological-economic performance of DF practices and which farm characteristics may lever the adoption of a DF practice.

Chapter 4: *Diversified farming perceived as yield risk reduction*

As the perception of risks influences farmers decisions on the adoption of sustainable management practices, we evaluated, in this chapter, whether DF practices can be considered a risk-mitigating strategy in two climatic scenarios, severe droughts and above-average precipitations. Therefore, we formulated the following research questions:

- How does the implementation of six DF practices under the two climatic scenarios affect the perceived yield risk?
- Which socio-economic factors are accountable for these perceived yield risk changes?

- Which ecological factors are important components of the perceived yield risk under both climatic scenarios?

Our results show that farmers expected a risk reduction by cover crops and diversified crop rotation due to the portfolio effect, but a risk increase by reduced tillage and no-tillage due to increased weed pressure. Further, large farm sizes and less fertile soils are positively related to the perceived reduced yield risk. This study shows that consideration of farm features and farmers' experience may help adjust incentives for the implementation of DF practices by agri-environmental policies.

Original articles

Chapter 2

Ecological-economic trade-offs of Diversified Farming Systems – A review

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Author contribution: JRS, JL, OM, and TT conceived and designed the synthesis, JRS performed the systematic review, collected the scientific evidence, and wrote the first draft of the manuscript. JL, OM, and TT were substantially involved in discussion and editing.

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Chapter 3

Mixed farmers' perception of the ecological-economic performance of diversified farming

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Author contribution: JRS, JL, OM, and TT conceived and designed the survey, JRS performed the face-to-face interviews, performed statistical analysis, and wrote the first draft of the manuscript. MF helped with the statistical analyses and the writing of the manuscript. JL, MF, OM, and TT were substantially involved in discussion and editing.

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Chapter 4

Diversified farming perceived as yield risk reduction

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Author contribution: JRS carried out the face-to-face survey, performed the statistical analysis, and performed writing – original draft and conceptualization. JL helped with statistical analysis, to draft the manuscript, review, and editing. TT and OM conceived of the study, participated in its design, and helped with review and editing. All authors read and approved the final manuscript.

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CHAPTER 2

ECOLOGICAL-ECONOMIC TRADE-OFFS OF DIVERSIFIED FARMING SYSTEMS – A REVIEW

Diversified Farming practices (2022, © Julia Rosa-Schleich)

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Abstract

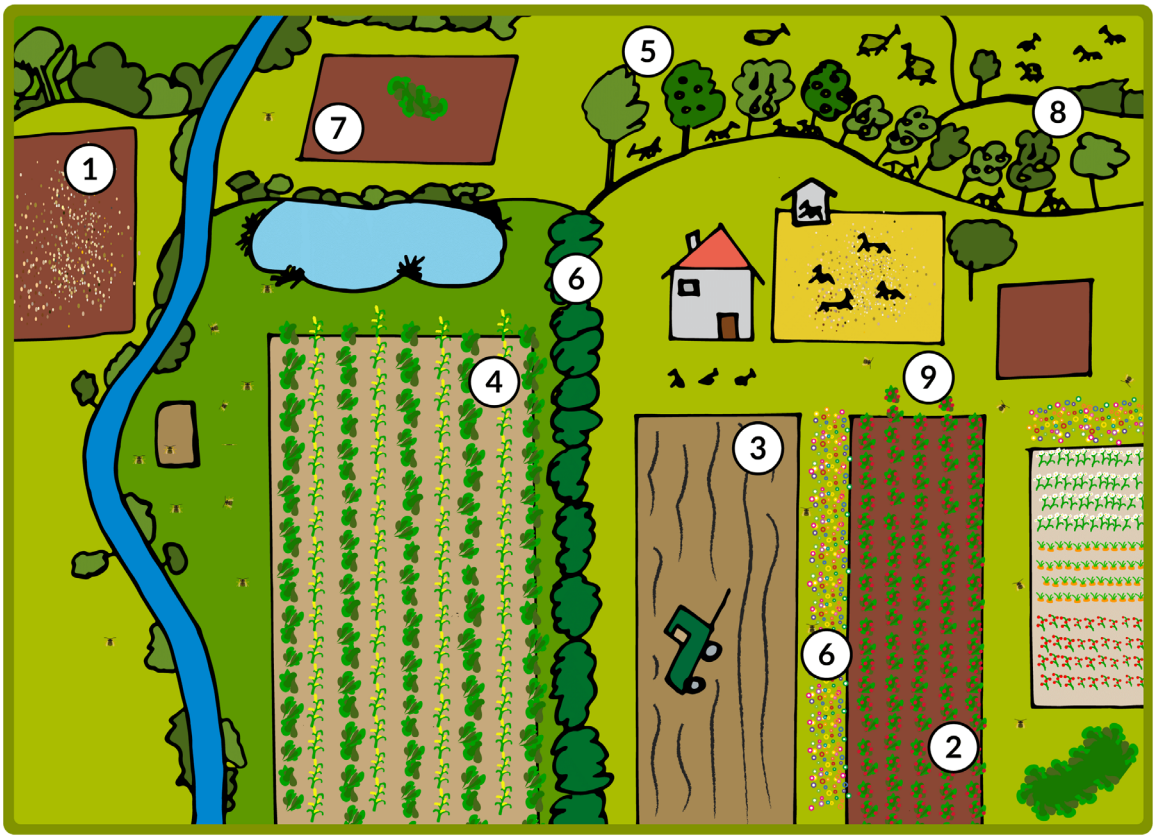
Diversified Farming (DF) Systems aim to integrate ecological and economic benefits for sustainable agriculture. DF systems can enhance ecological benefits at the farm level and therewith reduce negative environmental externalities. However, diversification may cause economic costs for the farmer. Although considering ecological-economic trade-offs is crucial for integrating biodiversity into agricultural production, ecological and economic benefits of DF practices have rarely been analyzed conjointly. Here, we synthesize published evidence provided by reviews and meta-analyses that evaluate the ecological and economic performance of single DF practices and more complex diversification bundles. Compared to non-diversified farming, DF practices provide substantially greater biodiversity and associated ecosystem services, such as pest and weed control, soil health, nutrient and water management and carbon sequestration. Overall, the ecological benefits for the farmer were partly insufficient to outbalance economic costs in the short term, even though many examples showed that DF practices have the potential to lead to higher and more stable yields, increase profitability and reduce risks in the long-term. Combined DF practices deliver highest ecological and economic benefits on the farm level. Financial instruments are needed to increase the implementation of combined DF practices to adequately reward for the ecological benefits on the farm level.

Keywords: management practices, biodiversity, ecosystem services, land-sharing, sustainable agriculture, wildlife-friendly farming

Introduction

A major challenge of the 21st century is to cope with the increasing demand for agricultural products from a growing world population with changing consumption patterns while maintaining biodiversity and securing ecosystem services in agroecosystems (Godfray et al., 2010). Production increases through agricultural intensification are characterized by high rates of fossil fuel energy consumption and high levels of agrochemical use. This intensification often causes environmental problems (Pittelkow et al., 2015), such as degradation of soil and water resources and loss of biodiversity and associated ecosystem services. Thus, modern agricultural management faces the challenge to deliver constant high-quality yield without harming the environment (Reganold & Wachter, 2016).

Diversified Farming (DF) Systems potentially offer one way to combine high ecological and high economic benefits for the farmer. DF Systems include a wide range of agricultural management practices that promote ecosystem functioning and related ecosystem services at different spatial and temporal scales including soil fertility, productivity and resilience against external disturbances (Kremen & Miles, 2012; Kremen et al., 2012). Diversification is applicable to different agricultural production systems, e.g., integrated, conventional and extensive agriculture. The resulting ecological effects may provide economic benefits at the farm-level and the societal level. A comprehensive synthesis on interactions between, ecological consequences, economic parameters at the farm level and individual DF practices does not exist (Garibaldi et al., 2017). Economically, DF practices may lead to increased opportunity costs if some lands are temporarily or permanently retired from production, or if yields decrease. In contrast, reduced costs or enhanced economic benefits at the farm level can be expected through reduced rates of fossil fuel energy consumption, low levels of chemical nutrient use, decreased workloads or overall higher productivity, for example through increased pollination rates or biological pest control (Kremen & Miles, 2012). However, it is difficult to provide a universal conclusion of the benefits of the individual DF practices, because the performance is highly context specific (Kremen et al., 2012). Nonetheless, we find much evidence in favor of DF practices.



Single measures		*Combined practices*
1. Cover crop & green manure	4. Intercropping	7. Conservation agriculture
2. Diversified crop rotation	5. Agroforestry	8. Mixed crop-livestock
3. Reduced tillage	6. Structural elements	9. Organic agriculture

Figure 1 Schematic illustration of a Diversified Farming System. Numbers represent the DF practices considered within this review.

This paper expands the work of Kremen & Miles (2012) by adding studies published since 2012 and by integrating economic variables. In this paper, we compare DF practices through a systematic literature synthesis. We analyze agricultural management practices that are used in DF Systems (Figure 1) to answer the question: Which diversification practices supply high ecological benefits at low economic costs or even increase economic benefits? We identify practices with win-win relationships and those with the fewest trade-offs between ecological and economic goods. DF practices may generate ecological benefits at the cost of economic benefits, i.e., high-low relationships, whereas high-high relationships describe parallel increases of ecological benefits and economic benefits for the farmer. Low-low relationships indicate low ecological as well as low economic benefits at the farm scale, whereas low-high relationships are characterized by few ecological benefits but high economic benefits at the farm. Our synthesis contributes to the available body of scientific literature by showing that

there remains a lack of evidence for many of the benefits of DF practices across different agroecosystems, thus showing a critical need for more targeted research on ecological and economic benefits of DF practices provided for farmers.

Methods

We synthesized published literature available through ISI Web of Science and Google Scholar. For each DF practice, we used a search string protocol (Table S1). We then selected relevant articles that compare DF practices with resource-intensive agricultural practices regarding their related benefits and costs (Table S2). We included meta-analyses, reviews, and studies, based on global or long-term datasets, that: 1) relate ecological and economic benefits to individual DF practices at the farm scale and 2) compare the DF practice with controls, e.g., no-tillage vs. intensive tillage, with or without cover crops, intercropping vs. monoculture. We categorized DF practices as: (i) single measures (cover crops, diversified crop rotation, reduced tillage, intercropping, agroforestry, structural elements) and (ii) combinations of single measures (systems) (conservation agriculture, mixed crop-livestock and organic agriculture) (Table 1). If we found no review, meta-analysis, or long-term study, we additionally searched for original papers indicating benefits of DF practices (illustrated by white boxes in Table 3 and Appendix B). These studies were not used for the ranking, because they are based on single observations or are missing an appropriate control.

Table 1 Details of DF practices considered in this review, an overview of the ecological and economic benefits at the farm level found and a few key references.

Single measures:	Ecological and economic benefits at the farm level	Key references
1. Cover crops & green manure Crops that are planted between the main food crops during the winter or summer fallow period to provide a constant soil cover.	**Ecological:** higher biodiversity, improved pest control, higher weed control and soil health, reduced soil erosion, improved water and nutrient management, higher carbon sequestration and increased resilience **Economic:** long-term yield improvement, reduced fertilizer and machinery input, higher profitability, and less risk	Dabney et al., 2001 Vukicevich et al., 2016 Snapp et al., 2005 Valkama et al., 2015
2. Diversified crop rotation Temporal sequence of different crops grown on the same piece of land (temporal diversification).	**Ecological**: increased biodiversity, improved pest control, higher weed control and soil health, reduced soil erosion, increased nutrient availability and higher carbon sequestration **Economic:** long-term yield improvement, reduced fertilizer input, higher profitability	Doltra & Olsen, 2013 Venter et al., 2016
3. Reduced tillage Reduced tillage includes no-till, direct seeding and/or minimal mechanical soil disturbance through non-turning soil cultivation.	**Ecological**: increased belowground biodiversity, improved pest control and soil health, reduced soil erosion, increased nutrient availability and higher carbon sequestration, improved water management, increased resilience **Economic:** increased long-term yield, fewer machinery costs and reduced labor input	Derpsch et al., 2010 Knowler & Bradshaw, 2007 Snapp et al., 2005
4. Intercropping Characterized by growing multiple cultivars or crop species simultaneously on the same field (spatial diversification).	**Ecological**: improved biodiversity and pest control, higher nutrient management, better soil health and weed control **Economic:** increased yields and reduced agrochemical input, higher profitability, and less risks	Duchene et al., 2017 Himmelstein et al., 2017 Letourneau et al., 2011 Nie et al., 2016
5. Agroforestry Defined as the integration of trees and crops on the same land. Agroforestry is a type of	**Ecological**: increased biodiversity, enhanced pest and weed control, higher soil health, better nutrient management, greater carbon sequestration and erosion control	Carsan et al., 2014 Malézieux et al., 2009 Pumariño et al., 2015 Torralba et al., 2016

intercropping but integrates woody and herbaceous layers.	**Economic:** higher yield and yield stability, reduced agrochemicals, higher profitability	
6. Structural elements Linear features in the landscape that had to be implemented or managed by the farmer.	**Ecological**: increased biodiversity, enhanced pollination and pest control, reduced soil erosion **Economic:** input savings (seeds, fertilizer, pesticides), marginal operation costs (labor savings and energy, machinery depreciation)	Griffiths et al., 2008 Haaland et al., 2011 Holland et al., 2016
<u>Systems (combined measures):</u> **7. Conservation Agriculture** Based on a combination of three principles applied on the field: 1. Minimal mechanical soil disturbance by reduced tillage and direct seeding, 2. Permanent soil cover through the retention of crop residues on the soil surface by cover crops and mulching and 3. A diversified crop rotation or mixture.	**Ecological**: increased biodiversity, enhanced soil health, higher control of pests and diseases and better nutrient and water management **Economic:** improved long-term yields, lower machinery input and higher fuel, time, and labor savings	Knowler & Bradshaw, 2007 Mafongoya et al., 2016 Thierfelder et al., 2014 Rusinamhodzi et al., 2011
8. Diversified crop-livestock systems The integration of crops with livestock (spatial and temporal diversification).	**Ecological**: higher biodiversity, enhanced pest and weed control, lower diseases and improved soil health and less erosion **Economic:** high yields, input savings (herbicides, pesticides and fertilizer), increased profitability and reduced risk	Bell et al., 2016 Bonaudo et al., 2013 Nie et al., 2016 Sulc & Tracy, 2007
9. Organic agriculture Farming without the use of agrochemical inputs such as mineral fertilizer and pesticides, thereby relying on ecological processes and biodiversity adapted to local conditions.	**Ecological**: increased biodiversity and pollination, enhanced diseases incidence, better soil health and erosion control, better nutrient and water management, higher carbon sequestration and resilience of the agro-ecosystem **Economic:** higher yield stability and increased long-term advantages, savings through non-use of agrochemicals, higher profitability on the market and lower risk	Seufert & Ramankutty, 2017 Kremen & Miles, 2012 Reganold & Wachter, 2016

We compared farm level benefits of DF practices with resource-intensive practices, across different agro-climatic regions and agricultural systems by considering a broad set of ecological indicators and economic parameters. For the purpose of this paper, we refer to ecological benefits based on physical indicators instead of an assessment as economic benefits to the society (e.g., pollination or carbon sequestration). For the ecological performance on the farm, we assessed 11 ecological variables: biodiversity, pollination, pest control, disease incidence, weed control, soil health, erosion control, nutrient and water management, carbon sequestration, and resilience of the agroecosystem. For the economic performance we used 11 economic variables at farm level: yield, yield stability, long-term yield effects, herbicide input, pesticide input, fertilizer input, machinery input, labor input, other kinds of input costs (e.g., seed costs, forage), profitability, and risk (Table 2). For the ranking we coded the positive output as 1 and a negative output as -1; if both effects or no effect were reported in the literature, we coded this result as zero. We then summed the number of ecological and economic benefits of each practice and ranked their performance accordingly (Figure 3).

Table 2 Definitions of the farm level ecological and economic benefits as used in this paper.

Benefit	**Definition**
Biodiversity	Increased abundance and richness of plant and animal species including above- and belowground communities.
Carbon sequestration	Increased soil organic carbon content.
Disease incidence	Lower disease and pathogen infestation.
Erosion control	Reduction of soil loss by water or wind.
Nutrient availability	Higher nutrient efficiency (faster mineralization rates, reduced N leaching, better nutrient cycling and nitrogen fixation).
Pest control	Enhanced biological regulation of pests, pest resistance or tolerance.
Pollination	Enhanced pollinator richness and abundance for improved crop pollination quality and quantity.
Resilience	Improved resistance to climatic events such as droughts and/or heavy rains.
Soil health	Improved soil fertility, soil physical properties such as reduced soil compaction, and higher soil microbial biomass.
Water regulation	Better water-holding capacity, water-use efficiency and water infiltration into the soil.
Weed control	Less crop competition with weeds, increased allelopathic interactions, enhancement of weed seed decay.
Fertilizer savings	Fertilizer costs (amount) can be reduced.
Herbicide savings	Herbicide costs (amount) can be reduced.
Labor savings	Less expenditure for labor expressed in man-hours and power available per worker.
Long-term effect on yield	Increase in yield after several years.

Machinery savings	Reduction of depreciation and interest and power or energy supplied to a machine (e.g., fuel).
Other savings	Establishment costs such as costs for forage or operation costs can be reduced.
Pesticide savings	Costs (amount) for pesticides are reduced.
Profitability	System and farm profitability, indicating success of the economic performance.
Risk	Potential of fluctuating profitability over time due to damage, injury, liability, loss, or any other negative occurrence that is caused by external or internal vulnerabilities.
Yield	Gains in physical yield (biomass) obtained in the short-term.
Yield stability	Reduced yield fluctuations or higher yield stability over several years.

We checked all articles in our assessment of the benefits for double counting (Figure 2). If the studies used for the review were not clearly stated, we used the reference list. The aim of this synthesis is to update the evidence that DF systems provide ecological and economic benefits at the farm level by using available quantitative and semi-quantitative studies. Some of the studies used within this synthesis deal with both the ecological and producer dimension (we focus on) with a perspective on ecological and economic benefits, including a consumer perspective (e.g., Kremen et al., 2012, Garbach et al., 2016; Reganold & Wachter, 2016; Seufert & Ramankutty, 2017). In contrast to Garbach et al., (2016), we also consider single DF practices and expand our ecological-economic evaluation on a wider range of economic benefits for the farmer.

Results and discussion

We identified 1,926 articles by using nine search strings, one for each DF practice. We then screened the title and the abstract of each article and extracted 348 papers for full-text analysis. Of these, we further analyzed 159 articles, which are based on 10,031 primary studies. Of these articles, 52 meta-analyses, 13 quantitative syntheses, 72 reviews and 21 studies dealt with ecological and economic benefits at the farm level of DF practices. Figure 2 shows the number of total articles found for each practice and the proportion of primary studies used within these articles.

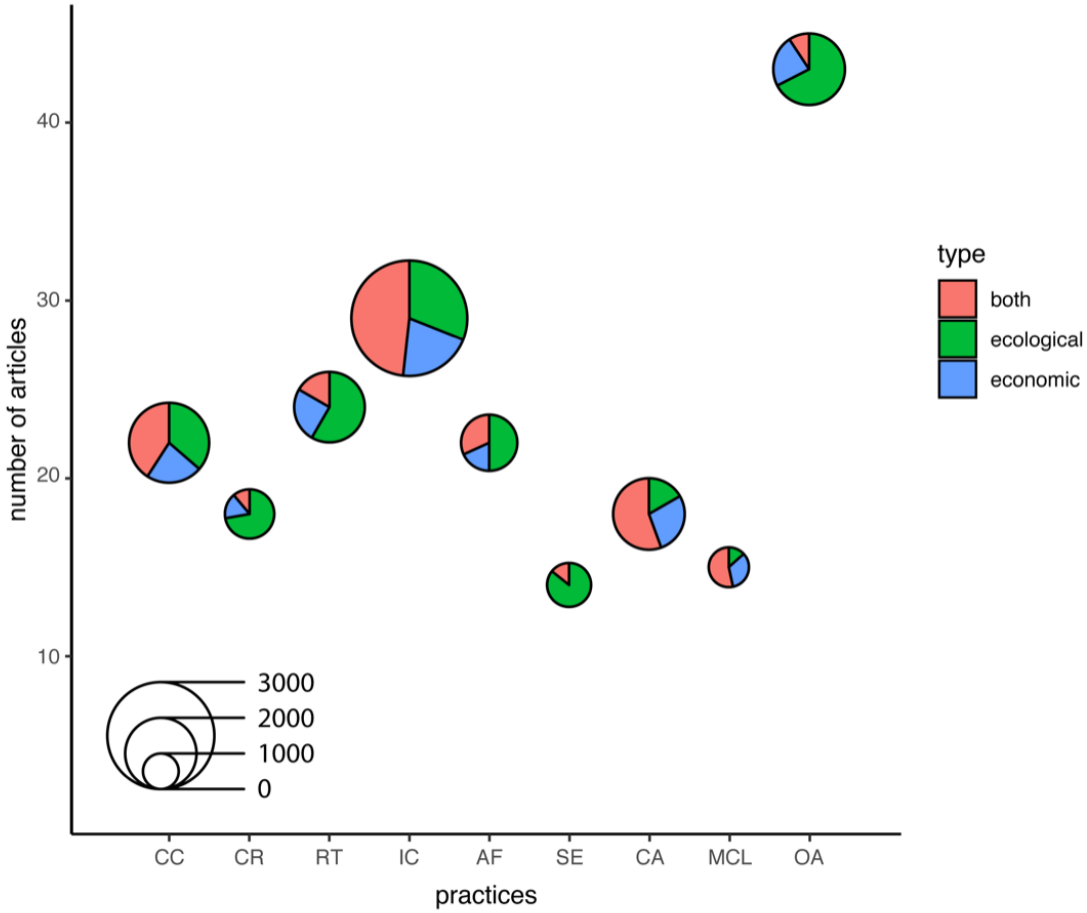


Figure 2 Number of articles used for the synthesis. Size of the pie indicates proportions and amount of primary studies used within the reviews considered. Practices: CC=cover crops, CR= crop rotation, RT=reduced tillage, IC=intercropping, SE=structural elements, CA=conservation agriculture, MCL=mixed-crop livestock and OA = organic agriculture. Type describes the proportion of articles considering ecological, economic or both aspects. Overall, we found much evidence for ecological benefits at the farm level, such as biodiversity, nutrient availability and carbon sequestration and farm-scale economic benefits such as yield, yield stability and profitability. For all other potential farm-level benefits, we found little evidence.

Table 3 Assessment of the ecological and economic benefits at the farm level of DF practices (arrows show the direction of the effect: ↑ (increase), ↓ (decrease), ↑↓ both effects found in comparison to the control. Different color shades indicate the number of articles found: light grey = less than three reviews found, middle grey =less than six reviews and meta-analysis found, and dark grey = more than six reviews and several meta-analysis found). White boxes indicate that no reviews and meta-analyses have been found, while the effects shown are based on an additional specific search for original papers. These white boxes are excluded from the ranking (in Fig. 3; for more details see Appendix B).

	Single measures					**Combined measures**			
DF Practices	Cover crop & green manure	Crop rotation	Reduced tillage	Intercropping	Agroforestry	Structural elements	Conservation agriculture	Mixed crop-livestock	Organic agriculture
Ecological benefits (for the farmer)									
Biodiversity	↑	↑	↑	↑	↑	↑	↑	↑	↑
Pollination	↑	↑↓	↑	↑	↑	↑	↑	↑↓	↑
Pest control	↑	↑	↑	↑	↑	↑↓	↑	↑	↑↓
Disease incidence	↑↓	↑	↑	↑	↑	↑↓	↑	↑	↑
Weed control	↑	↑	↓	↑	↑	↑↓	↓	↑	↑↓
Soil health	↑	↑	↑	↑	↑	↑	↑	↑	↑
Erosion control	↑	↑	↑	↑	↑	↑	↑	↑	↑
Nutrient availability	↑	↑	↑↓	↑	↑	↑	↑	↑	↑
Water regulation	↑	↑↓	↑	↑	↑	↑	↑	↑	↑
Carbon sequestration	↑	↑	↑		↑	↑	↑	↑	↑
Resilience	↑	↑	↑	↑	↑	↑	↑	↑	↑
Economic benefits (at the farm scale)									
Yield	↓	↑↓	↓	↑	↑↓	↑	↑	↑	↓
Yield stability	↓	↑	↑	↑	↑	↑	↑		↑
Long-term effect on yield	↑	↑	↑		↑↓		↑		↑

Herbicide savings	↑↓		↓	↑		↑	↓	↑	↑
Pesticide savings	↑↓		↑↓	↑	↑	↑		↑	↑
Fertilizer savings	↑	↑	↑↓		↑	↑	↑↓	↑	↑
Machinery savings	↑	↑↓	↑	↓	↑↓	↑	↑		↑↓
Labor savings		↑	↑	↓	↑↓	↑↓	↑	↓	↑↓
Other savings	↑↓	↑			↓	↑	↑↓	↑	↑
Profitability	↑	↑	↑↓	↑	↑		↑	↑	↑
Risk	↓	↑↓	↓	↓	↓	↓	↓	↓	↓

We are aware that no single DF practice performs best in all situations. For example, agricultural practices are typically less intensive in developing countries (Badgley et al., 2006). Smallholder farmers in developing countries often do not have access to chemical or machinery inputs, which means that agricultural practices used often resemble DF practices. Place-specific conditions such as precipitation and soil type may favor the implementation of different DF practices. For example, intercropping in Asia composes two grain crops (strip-based) that are harvested for either human or animal consumption, whereas intercrops in Europe consist of cereal-legume mixtures which are harvested as fodder (Yu et al., 2015). Thus, comparisons of DF practices for regions differing in agro-climate or cultural traditions are often difficult, in particular with respect to conclusions on the global level (e.g., De Beenhouwer et al., 2013; Ponisio et al., 2015; Pittelkow et al., 2015). On a case-by-case basis, several external factors have to be considered (e.g., farm size, climate, infrastructure, political and institutional constraints). In some cases, benefits derived through the DF practices are closely related to other benefits, while only few studies account for the important role of the landscape scale. Nevertheless, we summarized the effects of each practice on farm level ecological and economic benefits (Table 2). In the following sections, we first sum up evidence on ecological benefits and then expand on farm-level economics. We close each section with an overview of the combined effects (Figure 3).

Cover crops

Cover crops provide a continuous cover of the soil between two main food crops and can be planted during the winter or summer fallow period. Two different types of cover crop use can be distinguished: 1) if cover crops are not harvested but plowed into the soil, their biomass serves as green manure, and 2) if the cover crops are harvested, biomass serves as fodder for livestock. The investigated literature suggests an association between the cultivation of cover crops and ecological benefits for the farmer. Short-term effects of cover crops used as green manure on yield and yield stability are often negative, whereas long-term effects can be positive. We found evidence that the main economic benefit at the farm level is reduced fertilizer application, whereas investigations of other inputs such as herbicides and pesticides did not provide consistent results.

Cover crops are associated with increased diversity in habitats, nesting and feeding resources, which improves above- and belowground biodiversity (Dabney et al., 2001). Cover crops with high plant functional group richness, e.g., a mixture of legumes or grasses, increase the diversity of beneficial soil microbes while minimizing the proliferation of soil-borne pathogens (Vukicevich et al., 2016). Cover crops control weeds through competition, soil allelopathy, enhancement of weed seed decay and the maintenance of crop residues (Lu et al., 2000). 15% of surveyed vegetable growers in New York, and less than 5% of surveyed potato growers in Michigan report weed reduction as a benefit by cover crops (Snapp et al., 2005). However, effects on pollination, pest and disease control are less clear. Phacelia or legumes such as lupine as cover crops promote pollinators (Suso et al., 2016) but evidence from other cover crops is lacking. Cover crops may increase pest resistance by breaking down pest cycles, for example, through reducing parasitic nematodes (Snapp et al., 2005). Thus, cover crops must be carefully selected, considering the common crop pests (Lu et al., 2000). For example, planting alfalfa prior to potato reduces Rhizoctonia solani infection by 50% (Snapp et al., 2005).

In general, cover crops reduce yield, probably through waterlogging (Rusinamhodzi et al., 2011). However, including cover crops in crop cycles enables constant yield over several years, especially in dry years (Snapp et al., 2005). Furthermore, cover crops tend to increase yields in the long-term, mainly in grains (Doltra & Oelsen, 2013). The overall profitability of farming increases through cover crops by cultivating legumes (Lu et al., 2000), as they reduce fertilizer costs, establishment costs and increase energy efficiency. Nitrogen fertilization can be reduced by 23-31 kg ha-1 after grain legumes, and cereal yields were 0.5-1.6 Mg ha-1 higher than after cereal pre-crop (Tonitto et al., 2005). Establishment costs depend on the seed costs and the required amount of seeds of the cover crop type (Lu et al., 2000). Establishment costs

for legumes can be 10 times higher than for grasses (Snapp et al., 2005). However, cover crops lead to equal or higher profitability and less risk compared to monoculture-fallow cultivation. Long-term increased profitability may more than compensate the immediate establishment costs of cover crops (Snapp et al., 2005). Reduced energy requirements result from improved soil health and water-holding capacity as well as reduced fertilizer application. Because of their robustness towards inclement weather (Preissel et al., 2015), planting grain legume cover crops acts as a risk diversification strategy under increasing climatic fluctuations.

We found evidence that farm level ecological benefits of cover crops outweigh the economic benefits at farm level. Economic benefits for the farmer can increase through selecting cover crops that are locally adapted. Small-scale farmers may particularly benefit from reduced risk of production losses that are predicted to accelerate by climatic variation in the future.

Diversified crop rotation

Diversified crop rotation can be defined as a temporal sequence of different crops grown on the same piece of land (temporal diversification). Throughout the literature search we found several articles on ecological benefits but few articles on farm level economic benefits. We found evidence that a diversified crop rotation is economically beneficial for farmers mainly through increased long-term yield, lower input costs and risk reduction.

In comparison to a simple rotation, diverse crop rotations provide 15% higher microbial richness and a 3.4% increase in microbial diversity (Venter et al., 2016). Pollination-dependent crops in the rotation system may increase pollinator diversity and richness (Bommarco et al., 2012). A well-planned crop rotation can reduce the infestation of fungi, bacteria, virus, and insect pests. Switching crops in the rotation is, moreover, an effective way to control weed density (Nichols et al., 2015). One way to preserve soil health is the incorporation of 2–5 years phases of perennial pastures in grain-dominated crop rotations (Bell et al., 2013). Crops that are well adapted to specific regions, e.g., salty or acidic soils may deliver additional benefits for the farmer. In temperate and tropical regions, the perennial herb chicory as well as grass mixtures with annual or perennial legumes enhance ecosystem functioning and related ecosystem services (Bell et al., 2013). Combining a sequence of leaf crops and cereals has improved soil health in terms of nutrient availability, faster mineralization rates and less N leaching into the groundwater (Doltra & Oelsen, 2013). Gardner & Drinkwater (2009) found that compared to simplified rotation (e.g., corn/soy), a diversified crop rotation increases 15N recovery by 30% overall and in grain cash crop by 17%.

Additionally, long-term crop rotation often increases yields, as shown in a comparison to maize and wheat monoculture. The highest diversified crop rotation (maize-spring barley-peas-wheat) showed the greatest yield effect (Berzsenyi et al., 2000). Crop rotation has the potential to improve energy efficiency, because synergistic relations among crops may reduce input requirements, such as fertilizer application (Sanderson et al., 2013). Nonetheless, opportunity costs depend on the requirements of the cultivated crop types regarding machinery and labor. As an adaptation to these factors, farmers favor a more diverse crop rotation when grain prices are low, shorter rotations when grain prices are high (Zentner et al., 2002). Throughout a diverse crop rotation, economic gains by specialization on the best performing crops can be lost, for example, if a more profitable crop is substituted by a less profitable crop (Zentner et al., 2002). However, the lower profit of some crops in the rotation can be compensated by lower risk (Zentner et al., 2002).

Despite these examples, little evidence exists for ecological and economic benefits of a diversified crop rotation at the farm scale. A lack of meta-analyses on biological pest control and the effects of pests and diseases make overall conclusions difficult. Moreover, we found no systematic studies on economic consequences for the farmer of diversification of crop rotation.

Reduced tillage

Reduced tillage includes no-till, direct seeding and/or minimal mechanical soil disturbance through non-turning soil cultivation. We found several studies showing that reduced tillage is associated to high ecological benefits for the farmer, but few studies identified economic benefits on the farm level. The core challenge under reduced tillage is the trade-off between weed control and herbicide application.

The preservation of organic matter in the soil and minimal soil disturbance under reduced tillage maintains soil health (Derpsch et al., 2010). Organic residues on the surface improve and maintain soil porosity and thus provide soil water available for the plants (Derpsch et al., 2010). Moreover, organic matter provides resources for belowground biodiversity, such as earthworm populations and fungal communities, which in turn stabilize soil health through increased infiltration rates (Spurgeon et al., 2013). The cultivation of legumes without tillage improves water regulation further, because biological nitrogen fixation provides plant nutrients and less nutrients leach into the groundwater (Derpsch et al., 2010). A meta-analysis (282 comparisons) by Mhazo et al. (2016) shows that no-till leads to 56% lower sediment concentration and 60% less soil erosion compared to conventional tillage. Minimal soil disturbance can also raise carbon sequestration: Changing from conventional tillage to no-till

can sequester 57 ± 14 g C m-2 yr-1 as shown by a global data analysis including 67 long-term experiments consisting of 276 comparisons (West & Post, 2002).

In most cases, short-term crop yield is lower under no-tillage, however, in the long term, yields improve. Based on 678 studies with 6005 paired observations for 50 crops and 63 countries, a meta-analysis by Pittelkow et al. (2015) shows that yield decreases by 5.1% compared to yields under conventional tillage. However, they also show that this yield loss depends on the crop type, as, for instance, legume, oilseed, and cotton yield were not reduced. For all crop types, yields from no-till systems resembled yields from conventional systems after 5 or more years, except for maize, for which yields did not improve over time (Pittelkow et al., 2015). The main economic driver to adopt reduced tillage are input savings, through reduced tractor hours, farm labor, and machinery costs (Knowler & Bradshaw, 2007). Notably, reduced tillage saves costs from reduced contour terracing and replanting of crops following heavy rains (Derpsch et al., 2010). Machinery savings include less input of energy per unit area and per unit output, lower fuel, repair costs and lower depreciation rates of equipment (Derpsch et al., 2010). Troccoli et al. (2015) found 53% (77 Euro/ha and year) less farming operation costs in Italy for no-till systems compared to conventional systems.

Reduced tillage leads to a trade-off between weed cover and the need for adequate weed management, e.g., by herbicide applications (Derpsch et al., 2010). The opportunity cost of switching from conventional tillage to no-till varies in the returns across different soil physical conditions, such as textural composition of the soil and climate conditions (Grace et al., 2012). We found evidence that reduced tillage supports ecosystem functioning and services, even though the number of ecological benefits for the farmer is lower than for cover crops and diversified crop rotation. In contrast, we found more evidence for economic advantages at the farm level compared to the cultivation of cover crops or diversified crop rotation. Less costs can be expected by switching from conventional tillage to reduced tillage practices.

Intercropping

Intercropping is defined by growing multiple cultivars or crop species simultaneously on the same field and can be distinguished into three main types: mixed intercropping, relay intercropping and strip intercropping. We found several articles on these three types showing that intercropping is ecologically highly beneficial, but very few studies identified economic benefits generated from this DF practice. We found evidence that the biggest challenge within intercropping systems are high labor requirements and more complex mechanization.

Intercropping incorporates a diversified plant community and thus increases above-ground biodiversity. Associated flower richness in intercropping fields upscales to high

richness of natural enemies with significantly lower pest abundances compared to monocultures (Letourneau et al., 2011). A vote-counting conducted on 50 studies on biological pest control in wheat-based intercropping systems, found lower pest abundance (92% of cases) compared to pure stands (Lopes et al., 2016). However, the type of intercropping affected enemy responses: while strip intercropping reduced pest populations in all studies, mixed intercropping reduced pests in half of the studies and never increased natural enemy populations, predation, and parasitism rates (Lopes et al., 2016). Intercropping reduces N leaching and increases soil N availability. Especially non-legumes (ryegrasses) reduce N leaching by 50% (Valkama et al., 2015). Increased N and balanced nutrient contents in cereals often occur in combination with legumes (Iverson et al., 2014; Pelzer et al., 2014). Reduced inter-specific competition and enhanced complementarity and facilitation in legume/cereal systems improve resource use efficiency, which improved soil stability, permeability, and fertility (Duchene et al., 2017). Intercropping facilitates weed control through interspecific competition for light, nutrients, and water (Verret et al., 2017). Moreover, intercropping suppresses herbivores through enemy enhancement, which reduces crop damage better than less diversified crop plantings (Letourneau et al., 2011). Niche differentiation and complementarity effects increase and stabilize yields, reduce agrochemical inputs, and consequently increase land use efficiency up to 23% (Yu et al., 2015, Himmelstein et al., 2017). However, this effect was found for cereals but not for legume yield (Ren et al., 2014). Both effects, reduced grain yield (-3%) through the cultivation of non-legumes and improved grain yields using legumes and mixed crops were found (Valkama et al., 2015). Through temporal niche differentiation, crop mixtures with different growing periods yield most benefits (Yu et al., 2015). Most meta-analyses evaluate both additive and substitutive designs (e.g., Letourneau et al., 2011; Iverson et al., 2014). Using a substitutive design and measuring yield only of the main crop results in lower yield, because crop density is simply much lower in the mixture compared to the control (Letourneau et al., 2011). Intercropping in wheat fields may allow reduced insecticide use (Lopes et al., 2016), which reduces insecticide costs. However, intercropping systems are typically more labor intensive because they are less easily mechanized (Brooker et al., 2015). As with crop rotation, profitability of intercropping systems highly depends on the crop choice. Intercropping improves profitability and reduces risks on the farm level due to the diversification of income streams (Nie et al., 2016).

We found much evidence that the implementation of intercropping practices is environmentally beneficial. Yield effects are well estimated and can incentivize intercropping in agricultural management.

Agroforestry

Agroforestry is defined as the integration of trees and crops on the same piece of land. Agroforestry systems vary widely according to the purpose of establishment and in the spatial arrangement e.g., shade trees in tropical crops and woody strips in temperate cropland. Our literature search uncovered multiple articles dealing with ecological benefits of agroforestry. Economic benefits for the farmer are similar to intercropping and diversified crop rotation.

High biodiversity is typically associated with ecosystem service facilitation, such as biological pest control (Tscharntke et al., 2011). The abundance of natural enemies reduces crop damage due to herbivory (Pumariño et al., 2015). Agroforestry favors insectivorous species (mainly birds), which significantly diminish arthropods with a cascading effect onto reduced herbivore induced crop damage (Van Bael et al., 2008). Contrastingly, conversion from agroforestry to plantations leads to 46% decrease in species at a global scale (De Beenhouwer et al., 2013). Agroforestry systems contain high soil organic carbon (Sharma et al., 2015) and thus enhance soil fertility, nutrient content, and cycling (Torralba et al., 2016). Moreover, trees shelter the ground and thereby prevent soil erosion (Torralba et al., 2016).

Agroforestry systems may provide both higher and lower crop yields compared to monocultures. Recent meta-analyses found negative effects on biomass production (Torralba et al., 2016), but optimal shade levels and habitat complexity may create a win-win situation between biodiversity and yield (Clough et al., 2011). In an example from Indonesia, shade trees increase the productive lifetime of cacao trees and promote the diversity of beneficial organisms, such as insectivorous birds that naturally control pests (Clough et al., 2011; Maas et al., 2013). We found no meta-analyses investigating yield stability or long-term yield effects. However, we found increases in product quality in agroforestry. In coffee agroforestry systems in Central America, shade promotes slower and more balanced filling and uniform ripening of coffee berries, which outperformed product quality of monocultures of unshaded plants (Weston et al., 2015). However, agroforestry requires sophisticated management skills, downsizes land for main crop production and demands higher labor. Machinery and labor input highly depend on how much staff and labor hours are needed and how much equipment can be used (Malézieux et al., 2009). High purchase costs were reported associated with tree planting and maintenance through increased opportunity costs, for instance if the product does not end up attracting a market (Carsan et al., 2014). The main driver to adopt agroforestry practices is to improve land productivity by promoting the provision of facilitation and complementarity effects of the associated crops.

We found evidence on the importance of agroforestry systems for the provision of ecosystem services, but their economic benefits for the farmer are often low. Agroforestry can substantially contribute to environmentally friendly farming practices and reduce negative externalities for the society. A challenge for the farmer consists in the mechanization and higher labor requirements needed for a successful implementation.

Structural elements

Linear features in the landscape that had to be implemented or managed by the farmer and can be either at the field edge (e.g., hedgerows or flower strips) or lie within a crop (e.g., beetle banks). On the farm gate, structural elements (SE) are the most common off-farm habitats with direct influence on the crop. SE can be grouped into three categories: annual and perennial herbaceous field margins (wildflower strips, seeded flower strips and grassy strips) and permanent woody margins like hedgerows or living fences. The literature on the integration of SE into agriculture shows fewer ecological and more farm level economic benefits than other DF practices. SE require land out of crop production to create habitat for ecosystem services. The land used for SE often contains marginal land (e.g., along field edges or small patches not easily accessible) that would not be planted and naturally leads to lower yield.

SE support biodiversity through their structural complexity and therewith provide food, nesting, and overwintering resources (Haaland et al., 2011). In particular hedges and field margins are known for their high associated biodiversity that benefits biological pest control (Pollard & Holland, 2006) and pollination through bees, butterflies and hoverflies (Scheper et al., 2013). Gurr et al. (2016) found that nectar-producing plants around rice fields in Thailand, China and Vietnam reduced populations of pests, reduced insecticide applications by 70%, increased grain yields by 5% and delivered an economic advantage of 7.5%. However, direct effects on the adjacent field are determined by several aspects, such as habitat quality, field:boundary ratio, field size and dispersal ability (Griffiths et al., 2008). Aphid specific predators, parasitoids and polyphagous predators reduced peak aphid numbers and yield loss by several studies (e.g., Schmidt et al., 2003; Holland et al., 2016). To create such win-win situations for the total field area, arthropods must be able to disperse rapidly to achieve an even field coverage before pest populations develop. However, the potential for biological pest control is often insufficient and fails to reach the economic threshold level (Griffiths et al., 2008; Tscharntke et al., 2016).

Inputs can be saved if SE deliver a sufficient degree of biological pest control and therewith prevent pests exceeding the economic threshold. In case of sufficient biological pest control, farmers face an incentive to implement SE adjacent to the crop field when the

implementation costs are lower than the costs for chemical pest control (Griffiths et al., 2008). Farmers would save the costs associated with application of the agro-chemicals, energy, machinery depreciation and possible labor costs. Thomas et al. (1991) show that the costs associated with switching land out of production were more than offset by cost savings for pesticides and aphid-induced yield loss. They estimated that establishment costs of a beetle bank in a 20 hectare wheat field were $130 in the first year, and that the associated yield loss from switching land out of production was $45 per year. Natural enemy suppression saved labor and pesticide costs of $450 per year, and the prevention of aphid-induced yield loss saved approximately $1000 per year for the 20 ha field. This is particularly interesting as pesticide efficacy declines in the long-term due to development of resistance. Currently, regulations for the use of pesticides become more stringent, and the consequent pressure for the integration and management of SE may rise.

Overall, many reviews and meta-analyses on SE focus on pollination and biological pest control. Most of them indicate positive effects of SE (but see Tscharntke et al., 2016), whereas many economic aspects were not comprehensively analyzed. However, we found that economic performance at farm level compared to other practices can be high.

Conservation agriculture

Conservation agriculture (CA) combines reduced tillage, permanent soil cover through cover crops or mulching and a diversified crop rotation or mixture. CA represents an environmentally friendly and complex way of farming, offering many ecological benefits at the farm level and for the society. The interactions between the three principles of conservation agriculture add onto the beneficial effects of each individual practice. We found evidence that the greatest challenge under CA is weed control.

CA positively affects biodiversity through increased soil fauna diversity and abundance of termites, ants, centipedes, and beetle larvae by increased spatial (cover crops) and temporal (crop rotation) heterogeneity (Mafongoya et al., 2016). Increased soil fauna activity improves soil physical conditions in terms of infiltration, porosity, aggregate stability and hydrological properties. Moreover, CA increases topsoil organic matter, greater moisture retention and increased soil fertility (Palm et al., 2014; Knowler & Bradshaw, 2007). This beneficial effect on the soil enhances also bacterial biodiversity (Knowler & Bradshaw, 2007). Diversified crop rotation is the most important strategy for farmers applying CA to break pest and disease life cycles (Thierfelder et al., 2014). For example, CA helps to overcome predominant insect pests and diseases in maize like grey leaf spot, maize streak virus, rust, ear rots and striga in Southern Africa (Thierfelder et al., 2014). CA also improves water use efficiency, soil water balance and

water productivity (Mafongoya et al., 2016). In Zambia, Thierfelder & Wall (2010) observed 209% greater infiltration under CA treatments compared to conventional tillage treatments. Higher water use efficiency and improved nutrient cycles in CA provides the basis for yield increases (Mafongoya et al., 2016). The absence of mechanical weed control under CA poses a great challenge, especially in earlier stages of adoption (Hobbs et al., 2008; Mafongoya et al., 2016). This challenge may accelerate under reduced herbicide application (Chauhan et al., 2012). In the long run, however, CA can improve weed control, while high crop residues can help to suppress weed growth (Hobbs et al., 2008). Moreover, increased weed control through herbivory rates may minimize herbicide use, risk, costs and labor demand, but further research is needed to confirm or reject this assumption.

The effects of decreased yields under reduced tillage can be minimized to only -2.5% in CA due to synergistic interactions with the use of cover crops and diversified crop rotation (Pittelkow et al., 2015). In fact, CA even enhanced yield by 7.3% under rainfed agriculture in dry climates (Pittelkow et al., 2015). The yield performance and the reduction of yield risk (decreased yield variation) under CA depends on soil structure, amount and distribution of precipitation, level of fertility and application of manure (Troccoli et al., 2015; Mafongoya et al., 2016).

The input costs of CA are difficult to estimate. Cost savings arise mainly from reduced machinery costs, fuel, time, and labor savings (Zentner et al., 2002). CA is characterized by lower farm power requirements and reduced number of field crossings. This translates into low-power tractor life and reduced working time, which in turn leads to slower depreciation rates of equipment and less fuel consumption per unit area and output (Troccoli et al., 2015). Savings in labor and machinery costs ($7 to $10 ha $^{-1}$) can more than offset higher herbicide expenditures (Zentner et al., 2002). However, synergistic effects can be enhanced, for example through the use of legumes to reduce the amount of fertilizer (Zentner et al., 2002).

Farm level benefits of CA highly depend on the local environment, socioeconomic, cultural conditions, as well as on how well CA technologies are adapted to these conditions (Mafongoya et al., 2016). Through our literature search, we perceive that often, but not always, CA can represent a profitable system, with beneficial effects on soil health and quality, as well as greater provision of other ecosystem services.

Diversified crop-livestock systems

Diversified crop-livestock systems are based on the integration of crops with livestock (spatial and temporal diversification). The integration of livestock and crop production on the same area brings high ecological and economic benefits for the farmer and leads to a win-win-situation. Throughout the literature search we found several articles addressing the ecological benefits of diversified crop-livestock systems, whereas the literature suggests that the main economic benefits for the farmer include high yields, input savings and increases in profitability.

As an element of diversified crop-livestock systems, perennial pastures increase above- and below-ground biodiversity by providing refuge for invertebrates and soil microbes (Bell et al., 2013). The integration of mixed crops and pasture grown in close proximity breaks pest cycles or slows down their dispersion into adjacent fields (Nie et al., 2016). Diversified crop-livestock systems directly and indirectly control weed and pest populations. Direct weed and pest control results from browsing by livestock. For example, poultry controls arthropod and mollusk pests by browsing weed seeds and herbs, which cleans a field before crop cultivation (Hilimire, 2011). Moreover, during crop growth, poultry may feed directly on pest species while other animals, such as cattle, may destroy pest habitats (Hilimire, 2011). Indirect weed and pest control results from dual-purpose crops, which especially control intractable weeds. One example is the cultivation of alfalfa, which is particularly valuable as it can suppress even problematic herbicide-resistant weeds (Bell et al., 2013). Dual-purpose crops moreover improve soil health, reduce soil erosion, and increase water infiltration rates by their permanent soil cover (Nie et al., 2016). Low soil compaction through grazing can preserve soil structure and therefore supports high yields (Sulc & Tracy, 2007). Where early sowing is possible, dual-purpose crops provide long vegetative phases, early soil cover and deep roots, which allows optimal water-use-efficiency (Bell et al., 2013). Switching between grazing and cropping on the same area improves the nutrient cycling and therewith increases soil fertility (Ryschawy et al., 2012). In contrast, uneven distribution of grazers may negatively affect soil fertility because concentrated manure may lead to localized eutrophication. Here, additional operation steps are needed, which in turn require increased energy, labor, and machinery input. Overall, the type of animals and the purpose of livestock keeping might impact soil fertility differently: for example, beef production leads to lower nutrient pollution than dairy production (Ryschawy et al., 2012).

In diversified crop-livestock systems, increased yields can be expected. A meta-analysis by Ren et al. (2014) shows greater yield in mixed crop-livestock systems compared to monoculture. Diversified crop-livestock systems reduce the need for mineral fertilizer due to

the manure provided by the livestock (Ren et al., 2014). However, precise estimates are lacking. Nonetheless, the overall input costs are reduced by the integration of crop and livestock on the same area (Sulc & Tracy, 2007). By the provision of high-quality feed on grazing areas for animals, additional input savings through reduced feed expenditures and increased production efficiency are possible (Bell et al., 2013; Nie et al., 2016). Diversified crop-livestock systems allow high rates of recycling of natural resources and their by-products and low amounts of external inputs (Bonaudo et al., 2013). High productivity and profitability are expected within well-managed diversified crop-livestock system at the farm scale (Nie et al., 2016; Ryschawy et al., 2012). Opportunity costs primarily include reduced grain crop areas, but increased proportions of livestock production outweigh the loss of grain crop area and overall farm profitability increases (Bell et al., 2013).

Diversified crop-livestock systems are less sensitive to input and output price fluctuations. The manifold ecological and economic benefits for farmers of integrated diversified crop-livestock systems are highly dependent on the local biophysical, socio-economic, and cultural conditions, and diversified crop-livestock systems can represent an environmentally beneficial and economically productive and profitable system for farmers.

Organic agriculture

Organic agriculture (OA) relies on ecological processes and biodiversity adapted to local conditions, rather than the use of agrochemical inputs. Recently, several syntheses investigated the ecological and economic performance of organic agriculture based on results of many meta-analyses (Kremen & Miles, 2012; Reganold & Wachter, 2016; Seufert & Ramankutty, 2017).

OA provides more plant and faunal diversity than conventional agriculture (Reganold & Wachter, 2016). Organic agriculture results in increased organism abundance (40-50%) and species richness (ranging from 1-34%) compared to conventional agriculture (Seufert & Ramankutty, 2017). Functional groups such as herbivores, pollinators, predators, and producers are more diverse in organic agriculture, but differ by taxonomic group, landscape context and intensity of production (Kremen & Miles, 2012; Reganold & Wachter, 2016). Plants and bees benefit the most from OA while other arthropods and birds benefit to a smaller degree (Seufert & Ramankutty, 2017). OA consistently results in higher soil carbon levels, better soil quality and less soil erosion compared to conventional systems (Reganold & Wachter, 2016). The use of legumes and cover crops can replace the benefits of mineral N fertilizer (Reganold & Wachter, 2016). Data from temperate and tropical agroecosystems suggest that leguminous cover crops could fix enough nitrogen to replace the amount of synthetic fertilizer currently in

use (Badgley et al., 2006). Soils under organic management show positive cascading effects through high organic matter content on water management in terms of higher water holding capacity and water infiltration rates (Reganold & Wachter, 2016). This water use efficiency could be achieved even under drought as well as excessive rainfall conditions (Reganold & Wachter, 2016).

Several studies show short-term yield decline by transition to OA. On average, yield in OA is 19 to 25% lower compared to conventional agricultural management (Seufert & Ramankutty, 2017). However, after three to five years, yield recovers and yield stability increases (Crowder & Reganold, 2015). If organic agriculture is based on DF practices, such as intercropping or a diversified crop rotation, the yield loss can be substantially diminished compared to non-diversified farming systems (Ponisio et al., 2015; Crowder & Reganold, 2015). Facilitation and complementarity effects under OA improve the resilience of the whole agroecosystem. As an example, maize yield in drought years was significantly (137%) higher under organic management, compared to conventional management (Lotter et al., 2003). However, such stabilizing effects of the system may only emerge in the long-term. OA typically is complex and labor intensive. While total management costs are similar to conventional farming, organic systems have higher labor costs but lower input costs. This is warranted by more labor-intensive management practices, such as the preparation of compost or weeding, by higher shares of labor-intensive commodities, such as vegetables and fruits, and by overall smaller farm sizes (Seufert & Ramankutty, 2017). Main factors determining the profitability of OA include crop yields, labor and total costs, price premiums for organic products, the potential for reduced income during the organic transition period (usually three years), and potential cost savings from the reduced reliance on non-renewable resources and purchased inputs. Premium prices lead to higher average profitability (Reganold & Wachter, 2016). In addition, organic price premiums can buffer against low prices and price volatility: Farming systems following agroecological and organic principles have been shown to provide more stable yields and to be more resilient to extreme weather events and therewith reduce risk and economic dependence on a single crop (Reganold & Wachter, 2016).

Trade-offs in organic agriculture exist between biodiversity benefits and provision of yield and between weed control and yield. Biodiversity per unit output may benefit most from OA in mixed and low-productivity landscapes because of a smaller yield difference between organic and conventional farms. Weed control in OA can be positively influenced using reduced tillage (Cooper et al., 2016). The use of reduced tillage practices for weed control in organic agriculture may result in machinery and labor savings. Overall, literature we found

suggest that OA seems to be the best way to achieve high ecological benefits and high net revenues on the farm. However, the current trend to intensify OA with simplified, large-scale farming may lead to a loss of the ecological benefits typical for former OA, at both the farm level and for society (e.g., Guthman, 2000).

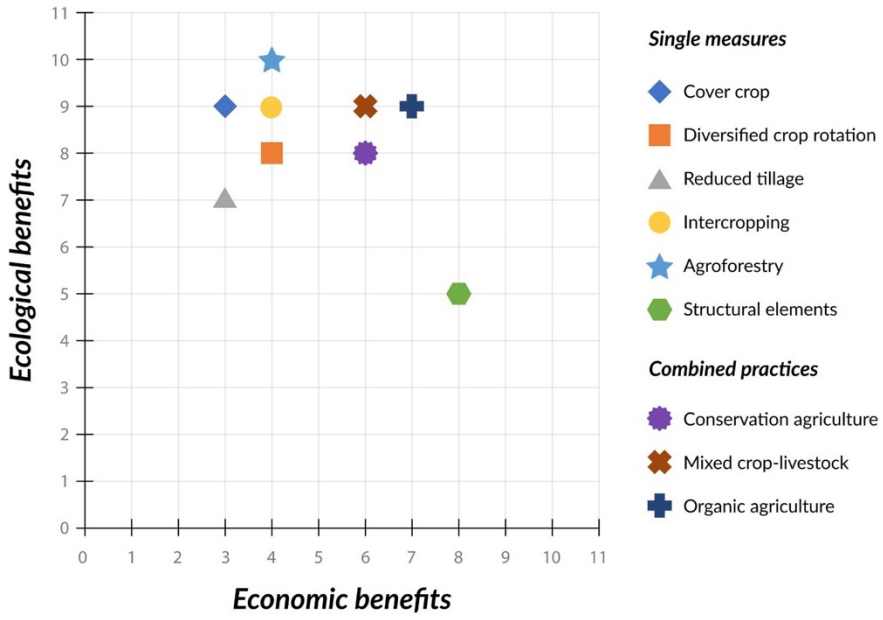


Figure 3 Frequency of farm level benefits and ranking of DF practices based on vote-counting of papers. Combined practices are characterized by parallel increases of ecological and economic benefits for the farmer. Examples for single measures: more studies have been found showing that cover crops have high ecological but less studies found economic benefits, whereas studies evaluating the benefits of structural elements appear to have lower ecological but high economic benefits at the farm level.

Conclusion

The development of environmentally friendly alternatives to resource-intensive agricultural management practices has been intensively studied for several decades. Although DF practices are a promising strategy, implementation rates of DF practices are low. A reason for this minimal application may be a knowledge gap of trade-offs and synergies between ecological and economic benefits of DF practices at the farm level. Despite efforts of some studies to investigate ecological and economic aspects of DF practices (e.g., Seufert & Ramankutty, 2017; Reganold & Wachter, 2016), better evidence for policy makers requires a wider economic, social welfare perspective (see Crowder & Reganold 2015, www.ipes-food.org). Our synthesis contributes to the scientific literature by stating that there remains a lack of evidence for many benefits of DF practices across different agro-ecosystems and shows a critical need for more targeted research on ecological and economic benefits of DF practices provided for the farmers. We identified numerous articles dealing with ecological benefits of DF practices: e.g., increased

biodiversity, improved control of pests, diseases and weeds, better and more stable soil health, reduced soil erosion, improved water and nutrient management and increased resilience of the agroecosystem. The most prominent economic benefits at the farm level include input savings related to seeds, chemicals, machinery, and to some extent labor savings. In the short term, DF practices often result in reduced physical crop yield compared to non-diversified practices. In the long term, however, the yield of DF practices can be equivalent and or even outcompete yield of non-diversified practices. Not merely crop yield, but rather labor costs, price premiums for product quality, or extra income streams and costs of inputs are main factors that influence overall profitability. Overall, ecological and economic benefits at the farm can outperform the disadvantages of small yield losses. Our synthesis suggests that the implementation of combined DF practices, such as conservation agriculture, mixed crop-livestock systems and organic agriculture is more promising than the implementation of single DF practices. In order to make DF systems an attractive and feasible long-term option for the farmers, financial instruments and clear regulations may be needed to adequately reward the implementation of combined DF practices for the ecological benefits on the farm level. However, little comprehensive evidence is available to support DF practices as a basis to design financial instruments to make DF systems an even more interesting option for farmers and the society alike.

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Supplementary material

Table S1 Overview of applied search terms for the systematic literature search.

Search term categories	Search term
DF practices	
Cover crop & crop rotation*	("cover crop*" **OR** "green manure" **OR** "crop rotation" **OR** "crop sequence*")
Reduced tillage	("reduced tillage" **OR** "no-till*" **OR** "zero-till*" **OR** "direct seeding" **OR** "low-till*")
Intercropping	("intercrop*" **OR** "crop diversification" **OR** "polyculture*" **OR** "crop mixture*" **OR** "crop varieties*")
Agroforestry	("agroforestry")
Structural elements	("structural element*" **OR** "field margin*" **OR** "flower strip*" **OR** "hedgerow*" **OR** "insect strip*" **OR** "conservation strip*")
Conservation agriculture	("conservation agriculture")
Diversified crop-livestock systems	("mixed crop-livestock*" **OR** "integrated crop-livestock*" **OR** "diversified crop-livestock*")
Organic agriculture	("organic farming*" **OR** "organic agriculture*" **OR** "organic management*")
	AND
Benefits and costs related to the individual DF ˜	("benefit*" **OR** "cost*" **OR** "benefit-cost*" **OR** "pre-crop effect" **OR** "ecological*" **OR** "economic*" **OR** "trade-off*" **OR** "win-win*" **OR** "ecosystem services")
	AND
Focus on assessment	("meta-analysis" **OR** "review")

* We combine the two DF practices within one search string, because best results were obtained with this combination.

˜ general terms in combination with the individual DF practices

Table S2 Overview of the complete reference list including all relevant articles used within the assessment of the ecological and economic benefits of DF practices (Table 2). Abbreviations: GDS=Global data set, LTS= long-term study, MA = meta-analyses, MSA = multi scale analyses, MRA = Meta regression analysis, QS = Quantitative syntheses, R = review; = vote counting. * = original study not included in the ranking.

Variable	**Effect (Code)**	**References**	**Type of study**
Cover crop			
Biodiversity	↑(1)	Dabney et al., 2001 Vukicevich et al., 2016	R R
Carbon sequestration	↑(1)	Dabney et al., 2001 Poeplau & Don, 2015 Ugarte et al., 2014 Jarecki & Lal, 2003 Fageria et al., 2005	R MA MA R R
Disease incidence	↑↓(0)	Dabney et al., 2001 Snapp et al., 2005	R R
Erosion control	↑(1)	Dabney et al., 2001 Lu et al., 2000 Altieri et al., 2015 Snapp et al., 2005 Sanderson et al., 2013 Fageria et al., 2005	R R R R R R
Nutrient availability	↑(1)	Valkama et al., 2015 Becker, 2001 Dabney et al., 2001 Lu et al., 2000 Doltra & Oelsen, 2013 Snapp et al., 2005 Tonitto et al., 2005 Sanderson et al., 2013 Wortman, 2016 Quemada et al., 2013 Jarecki & Lal, 2003 Fageria et al., 2005 Franzluebber, 2007	MA R R R LTS R MA R MA MA R R R
Pest control	↑(1)	Dabney et al., 2001 Lu et al., 2000 Snapp et al., 2005 Sanderson et al., 2013	R R R R
Pollination	↑	*Wilson et al. 2018	S

Resilience	↑(1)	Vukicevich et al., 2016	R
Soil health	↑(1)	Dabney et al., 2001 Doltra & Oelsen, 2013	R LTS
Water regulation	↑(1)	Dabney et al., 2001 Tonitto et al., 2005	R MA
Weed control	↑(1)	Dabney et al., 2001 Lu et al., 2000 Snapp et al., 2005	R R R
Fertilizer savings	↑↓(1)	Becker, 2001 Dabney et al., 2001 Snapp et al., 2005 Tonitto et al., 2005 Altieri et al., 2015 Preissel et al., 2015	R R R MA R MA
Herbicide savings	↑↓(0)	Dabney et al., 2001 Lu et al., 2000	R R
Long-term effect on yield	↑(1)	Ponisio et al., 2015 Doltra & Oelsen, 2013	MA LTS
Machinery savings	↑↓(1)	Lu et al., 2000 Altieri et al., 2015 Tonitto et al., 2005	R R MA
Other savings	↑↓(0)	Dabney et al., 2001 Lu et al., 2000 Snapp et al., 2005	R R R
Pesticide savings	↑↓(0)	Dabney et al., 2001 Snapp et al., 2005	R R
Profitability	↑(1)	Lu et al., 2000 Snapp et al., 2005	R R
Risk	↓(1)	Lu et al., 2000 Preissel et al., 2015	R MA
Yield	↓(-1)	Valkama et al., 2015 Tonitto et al., 2005 Sileshi et al., 2008 Doltra & Oelsen, 2013 Rusinamhodzi et al., 2011 Preissel et al., 2015 Franzluebbers, 2007	MA MA MA LTS VC MA R
Yield stability	↓(-1)	Sileshi et al., 2008	MA

Diversified crop rotation			
Biodiversity	↑(1)	Venter et al., 2016	MA
Carbon sequestration	↑(1)	West & Post, 2002 Powlson et al., 2016 Ugarte et al., 2014 Jarecki & Lal, 2003	R MA MA R
Disease incidence	↑(1)	Franzluebbers, 2007	R
Erosion control	↑(1)	Franzluebbers, 2007	R
Nutrient availability	↑(1)	Doltra & Olsen, 2013 Gardner & Drinkwater, 2009	LTS MA
Pest control	↑(1)	Gurr et al., 2016	LTS
Pollination	↑↓(0)	Bommarco et al., 2012	R
Resilience	↑	*Wienhold et al., 2017	S
Soil health	↑(1)	Bell et al., 2013 Qadir et al., 2008	R R
Water regulation	↑↓	*Wienhold et al., 2017	S
Weed control	↑(1)	Nichols et al., 2015 Liebman & Dyck, 1993	R R
Fertilizer savings	↑↓(1)	Sanderson et al., 2013	R
Labor savings	↑	*Wienhold et al., 2017	S
Long-term effect on yield	↑(1)	Franzluebbers, 2007	R
Machinery savings	↑↓(0)	Sanderson et al., 2013	R
Other savings	↑↓(1)	Sanderson et al., 2013	R
Profitability	↑(1)	Preissel et al., 2015	MA
Risk	↑↓(0)	Zentner et al., 2002	R
Yield	↑↓(0)	Ponisio et al., 2015 Mason et al., 2015 Franzluebbers, 2007	MA R R
Yield stability	↑	*Berzsenzyi et al., 2000	S
Reduced tillage			
Biodiversity	↑(1)	Derpsch et al., 2010	R

		Van Capelle et al., 2012 Spurgeon et al., 2013	MA MA
Carbon sequestration	↑(1)	Powlson et al., 2016 West & Post, 2002 Post et al., 2012 Ugarte et al., 2014 Jarecki & Lal, 2003 Fageria et al., 2005 Grace et al., 2012 Hutchinson et al., 2006	MA R R MA R R MA R
Disease incidence	↑(1)	Derpsch et al., 2010	R
Erosion control	↑(1)	Derpsch et al., 2010 Mhazo et al., 2016 Wang et al., 2007	R MA R
Nutrient availability	↑↓(0)	Derpsch et al., 2010 Gardner & Drinkwater, 2009	R MA
Pest control	↑(1)	Derpsch et al., 2010	R
Pollination	↑	Garibaldi et al., 2014	R
Resilience	↑(1)	Derpsch et al., 2010	R
Soil health	↑(1)	Derpsch et al., 2010	R
Water regulation	↑(1)	Derpsch et al., 2010 Spurgeon et al., 2013 Wang et al., 2007	R MA R
Weed Control	↓(-1)	Derpsch et al., 2010 Nichols et al., 2015 Armengot et al., 2016	R R MA
Fertilizer savings	↑↓(0)	Derpsch et al., 2010	R
Herbicide savings	↑↓(-1)	Derpsch et al., 2010 Knowler & Bradshaw, 2007 Zentner et al., 2002 Thierfelder et al., 2014	R R R R
Labor savings	↑↓(1)	Nichols et al., 2015 Knowler & Bradshaw, 2007 Huang et al., 2015 Wang et al., 2007	R R MA R
Long-term effect on yield	↑(1)	Derpsch et al., 2010	R
Machinery savings	↑↓(1)	Derpsch et al., 2010	R

		Wang et al., 2007	R
Pesticide savings	↑↓(0)	Derpsch et al., 2010	R
Profitability	↑↓(0)	Knowler & Bradshaw, 2007 Marra & Kaval, 2000 Derpsch et al., 2010	R MA R
Risk	↓(1)	Derpsch et al., 2010 Zentner et al., 2002	R R
Yield	↓(-1)	Huang et al., 2015 Derpsch et al., 2010 Pittelkow et al., 2015 Wang et al., 2007 Mason et al., 2015	MA R MA R R
Yield stability	↑(1)	Pittelkow et al., 2015 Derpsch et al., 2010	MA R
Intercropping			
Biodiversity	↑(1)	Hilimire, 2011 Bell et al., 2013 Duchene et al., 2017	R R R
Disease incidence	↑(1)	Altieri et al., 2015 Costanzo & Bárberi, 2014 Anil et al., 1998	R R R
Erosion control	↑(1)	Bell et al., 2013	R
Nutrient availability	↑(1)	Doltra & Oelsen, 2013 Valkama et al., 2015 Nie et al., 2016 Yu et al., 2015 Xue et al., 2016 Duchene et al., 2017 Brooker et al., 2015 Li et al., 2014 Flechter et al., 2016 Costanzo & Bárberi ,2014 Anil et al., 1998 Ren et al., 2014	LTS MA R MA R R R R R R R MA
Pest control	↑(1)	Midega et al., 2015 Himmelstein et al., 2017 Anil et al., 1998 Letourneau et al., 2011 Tanveer et al., 2017 Iverson et al., 2014	R MA R MA R MA

		Duchene et al., 2017 Costanzo & Bárberi, 2014 Poveda et al, 2008	R R R
Pollination	↑	Garibaldi et al., 2014	R
Resilience	↑(1)	Malézieux et al., 2009 Tanveer et al., 2017 Costanzo & Bárberi, 2014	R R R
Soil health	↑(1)	Duchene et al., 2017	R
Water regulation	↑(1)	Pelzer et al., 2014 Duchene et al., 2017 Brooker et al., 2015 Anil et al., 1998	MA R R R
Weed control	↑(1)	Letourneau et al., 2011 Verret et al., 2017 Tanveer et al., 2017 Duchene et al., 2017 Costanzo & Bárberi, 2014 Anil et al., 1998	MA MA R R R R
Herbicide savings	↑↓(1)	Himmelstein et al., 2017	MA
Labor savings	↓↑(-1)	Brooker et al., 2015 Flechter et al., 2016 Kahn et al., 2010	R R R
Machinery savings	↓↑(-1)	Brooker et al., 2015	R
Pesticide savings	↑↓(1)	Lopes et al., 2016	R
Profitability	↑(1)	Nie et al., 2016 Yu et al., 2015 Himmelstein et al., 2017 Anil et al., 1998	R MA MA R
Risk	↓(1)	Nie et al. 2016 Verret et al. 2017	R MA
Yield	↑(1)	Ponisio et al., 2014 Letourneau et al., 2011 Iverson et al., 2014 Aziz et al., 2015 Pelzer et al., 2014 Valkama et al., 2015 Verret et al., 2017 Yu et al., 2015 Tanveer et al., 2017 Duchene et al., 2017	MA MA MA R MA MA MA MA R MA

		Costanzo & Bárberi, 2014 Ren et al., 2014 Himmelstein et al., 2017 Anil et al., 1998	R MA MA R
Yield stability	↑(1)	Letourneau et al., 2011 Duchene et al., 2017	MA R
Agroforestry			
Biodiversity	↑(1)	Torralba et al., 2016 Chaudhary et al., 2016 De Beenhouwer et al., 2013 Bainard et al., 2011 Anderson & Zerriffi, 2012 Carsan et al., 2014 Robbins et al., 2015	MA R MA MA R R R
Carbon sequestration	↑(1)	Lorenz & Lal, 2014 Sharma et al., 2015 Anderson and Zerriffi, 2012 Ziegler et al., 2012 Udawatta & Shibu, 2012 Olbermann et al., 2004 Branca et al., 2013 Jarecki & Lal, 2003	R R R R MA R R R
Disease incidence	↑(1)	Malézieux et al., 2009 Pumariño et al., 2015	R MA
Erosion control	↑(1)	Torralba et al., 2016 Nie et al., 2016	MA R
Nutrient availability	↑(1)	Torralba et al., 2016 Carsan et al., 2014	MA R
Pest control	↑(1)	Pumariño et al., 2015 Van Bael et al., 2008 Altieri et al., 2015 Malézieux et al., 2009	MA MA R R
Pollination	↑(1)	Tscharntke et al., 2011 Carsan et al., 2014	R R
Resilience	↑(1)	Anderson & Zerriffi, 2012 Carsan et al., 2014	R R
Soil health	↑(1)	Torralba et al., 2016 Anderson & Zerriffi, 2012 Ziegler et al., 2012 Carsan et al., 2014	MA R R R

Water regulation	↑(1)	Anderson & Zerriffi, 2012 Carsan et al., 2014	R R
Weed control	↑(1)	Pumariño et al., 2015	MA
Fertilizer savings	↑↓(1)	Malézieux et al., 2009	R
Labor savings	↑↓(0)	Malézieux et al., 2009 Craswell et al., 1998	R R
Machinery savings	↑↓(0)	Malézieux et al., 2009	R
Other savings	↑↓(-1)	Cole, 2010	R
Pesticide savings	↓↑(1)	Malézieux et al., 2009	R
Profitability	↑(1)	Weston et al., 2015 Anderson & Zerriffi, 2012 Craswell et al., 1998 Robbins et al., 2015	R R R R
Risk	↓(1)	Anderson & Zerriffi, 2012 Robbins et al., 2012	R R
Yield	↑↓(0)	Malézieux et al., 2009 Torralba et al., 2016 Nie et al., 2016 Ren et al., 2014 Weston et al., 2015 Branca et al., 2013 Pumariño et a., 2015	R MA R MA R MA MA
Yield stability	↑(1)	Carsan et al., 2014	R
Structural elements			
Biodiversity	↑(1)	Cobb et al., 1999 Lovell & Sullivan, 2006 Griffiths et al., 2008 Marshall and Moon, 2002 Vickery et al., 2009 Haaland et al., 2011	R R R R R R
Carbon sequestration	↑	*Falloon et al., 2006	S
Erosion control	↑(1)	Marshall & Moon, 2002 Baudry et al., 2000 Lovell & Sullivan, 2006	R R R
Disease incidence	↑↓	*Altieri et al., 1999	S
Nutrient availability	↑	*Altieri et al., 1999	S

Pest control	↑↓(0)	Uyttenbrock et al. 2016 Rusch et al., 2013 Holland et al., 2016 Shackelford et al., 2013 Baudry et al., 2000	MA MA MA MA R
Pollination	↑(1)	Scheper et al., 2013 Shackelford et al., 2013 Uyttenbroeck et al., 2016 Marshall & Moon, 2002 Haaland et al., 2011 Nicholls & Alteri, 2013 Hinsley & Bellamy, 2000 Dover & Sparks, 2000	MA MA MA R R R R R
Resilience	↑(1)	Marshall & Moon, 2002 Griffiths et al., 2008 Lovell & Sullivan, 2006	R R R
Water regulation	↑(1)	Marshall & Moon 2002 Griffiths et al., 2008 Lovell & Sullivan, 2006	R R R
Weed control	↑↓(0)	Marshall & Moon, 2002	R
Fertilizer savings	↑↓(1)	Griffiths et al., 2008	R
Herbicide savings	↑↓(1)	Griffiths et al., 2008	R
Labor savings	↑↓(0)	Griffiths et al., 2008	R
Machinery savings	↑↓(1)	Griffiths et al., 2008	R
Other savings	↑↓(1)	Griffiths et al., 2008	R
Pesticide savings	↓↑(1)	Griffiths et al., 2008	R
Risk	↓(1)	Griffiths et al., 2008	R
Yield	↑(1)	Marshall & Moon, 2002 Griffiths et al., 2008	R R
Yield stability	↑(1)	Griffiths et al., 2008	R
Conservation agriculture			
Biodiversity	↑(1)	Knowler & Bradshaw, 2007 Mafongoya et al., 2016 Thierfelder et al., 2014 Scopel et al., 2012	R MA R R

Carbon sequestration	↑(1)	Knowler & Bradshaw, 2007 Ugarte et al., 2014 Mafongoya et al., 2016 Li et al., 2016 Thierfelder et al., 2014	R MA MA MA R
Disease incidence	↑(1)	Thierfelder et al., 2014	R
Erosion control	↑(1)	Knowler & Bradshaw, 2007 Li et al., 2016 Thierfelder et al., 2014 Hobbs et al., 2008 Scopel et al., 2012	R MA R R R
Nutrient availability	↑(1)	Mafongoya et al., 2016	MA
Pest control	↑(1)	Knowler & Bradshaw, 2007 Mafongoya et al., 2016 Thierfelder et al., 2014	R R R
Pollination	↑	*Palm et al., 2014	R
Resilience	↑(1)	Knowler & Bradshaw, 2007 Pittelkow et al., 2015	R MA
Soil health	↑(1)	Knowler & Bradshaw, 2007 Mafongoya et al., 2016 Thierfelder et al., 2014 Corbeels et al., 2014	R MA R MSA
Water regulation	↑(1)	Knowler & Bradshaw, 2007 Mafongoya et al., 2016 Thierfelder et al., 2014 Hobbs et al., 2008	R MA R R
Weed control	↓(-1)	Chauhan et al., 2012 Mafongoya et al., 2016 Mashingaidze et al., 2012 Hobbs et al., 2008	R MA LTS R
Fertilizer savings	↑↓(0)	Rusinamhodzi et al., 2011 Zentner et al., 2002	MA R
Herbicide savings	↓↑(-1)	Knowler & Bradshaw, 2007 Zentner et al., 2002 Thierfelder et al., 2014	R R R
Labor savings	↑↓(1)	Nichols et al., 2015 Knowler & Bradshaw, 2007 Zentner et al., 2002 Thierfelder et al., 2014	R R R R

Long-term effect on yield	↑(1)	Knowler & Bradshaw, 2007 Rusinamhodzi et al., 2011 Mafongoya et al., 2016 Thierfelder et al., 2014	R MA MA R
Machinery savings	↑↓(1)	Knowler & Bradshaw, 2007 Zentner et al., 2002 Troccoli et al., 2015 Hobbs et al., 2008	R R MA R
Other savings	↑↓(0)	Manley et al., 2005 Knowler & Bradshaw, 2007 Zentner et al., 2002 Hobbs et al. 2008	MA R R R
Profitability	↑(1)	Knowler & Bradshaw, 2007 Mafongoya et al., 2016 Troccoli et al., 2015 Hobbs et al., 2008 Scopel et al., 2012	R MA MA R R
Risk	↓(1)	Knowler & Bradshaw, 2007 Zentner et al., 2002	R R
Yield	↑(1)	Knowler & Bradshaw, 2007 Rusinamhodzi et al., 2011 Van den Putte et al., 2010 Mafongoya et al., 2016 Li et al., 2016 Thierfelder et al., 2014 Hobbs et al., 2008	R MA MA MA MA R R
Yield stability	↑(1)	Knowler & Bradshaw, 2007 Mafongoya et al., 2016	R MA
Diversified crop-livestock systems			
Biodiversity	↑(1)	Bell et al., 2013 Duru & Therond, 2014 Nie et al., 2016 Hilimire et al., 2011 Moraes et al., 2014	R R R R R
Carbon sequestration	↑(1)	Nie et al., 2016 Fageria et al., 2005 Moraes et al., 2014 Franzlubber, 2007	R R R R
Disease incidence	↑(1)	Nie et al., 2016	R
Erosion control	↑(1)	Bell et al., 2013	R

Nutrient availability	↑(1)	Nie et al., 2013 Sanderson et al., 2013 Moraes et al., 2014	R R R
Pests control	↑(1)	Nie et al., 2016 Hilimire et al., 2011	R R
Soil health	↑(1)	Nie et al., 2016 Bell et al., 2013 Duru & Therond, 2014 Sanderson et al., 2013 Hilimire et al., 2011 Moraes et al., 2014 Ghimire et al., 2012 Franzluebbers, 2007	R R R R R R R R
Water regulation	↑(1)	Bell et al., 2013	R
Weed control	↑(1)	Bell et al., 2013 Hilimire et al., 2011 Schuster et al., 2016	R R R
Fertilizer savings	↑↓(1)	Ghimire et al., 2012 Ren et al., 2014 Ryschawy et al., 2012 Sulc & Tracy, 2007	R MA R R
Herbicide savings	↑↓(1)	Schuster et al., 2016 Ren et al., 2014	R MA
Labor savings	↓↑(-1)	Franzluebbers, 2007	R
Other savings	↑↓(1)	Bell et al., 2013 Nie et al., 2016 Sanderson et al., 2013 Ghimire et al., 2012	R R R R
Pesticide savings	↓↑(1)	Ghimire et al., 2012	R
Profitability	↑(1)	Ryschawy et al., 2012 Hilimire et al., 2011 Moraes et al., 2014 Moraine et al., 2014 Ghimire et al., 2012 Duru & Therond, 2014	R R R R R R
Risk reduction	↓(1)	Ryschawy et al., 2012 Nie et al., 2016 Moraes et al., 2014 Duru & Therond, 2014	R R R R
Yield	↑(1)	Sulc & Tracy, 2007	R

		Nie et al., 2016 Ren et al., 2014 Moraes et al., 2014 Ghimire et al., 2012 Franzluebber, 2007	R MA R R R
Organic agriculture References for organic agriculture are mainly based on three syntheses: Seufert & Ramankutty, 2017; Kremen & Miles, 2012 & Reganold & Wachter, 2016. The articles used within these syntheses were checked for duplicates and directly assigned to the particular variable.			
Biodiversity	↑(1)	Tuck et al., 2014 Batáry et al. 2011. Bengtsson et al. 2005 Anand et al. 2010. Schneider et al., 2014 Lichtenberg et al., 2017.	MA MA MA QS MRS MA
Carbon sequestration	↑(1)	Syswerda et al. 2011 Gattinger et al., 2012 Tuomisto et al., 2012 Leifeld & Fuhrer, 2010	MA LTS MA MA
Disease incidence	↑(1)	Zhu et al. 2000 Hiddink et al. 2010	S VC
Erosion control	↑(1)	Reganold et al. 1987 Siegrist et al. 1998	LTS LTS
Nutrient availability	↑(1)	Badgley et al., 2006 Gardner et al. 2009 Mondelaers et al. 2009 Watson et al. 2003 Tuomisto et al., 2012 Dangour et al., 2009	QS MA MAR MA MA QS
Pest control	↑↓(0)	Chaplin-Kramer et al. 2011 Meehan et al. 2011 Crowder et al., 2010 Geiger et al. 2010	MA LSS MA MRS
Pollination	↑(1)	Garibaldi et al. 2011 Kennedy et al., 2013	MA MA
Resilience	↑(1)	Lotter et al. 2003 Holt-Giménez et al. 2002	LTS S

Soil health	↑(1)	Mäder et al. 2002 Reganold et al. 2010 Gomiero et al., 2011 Lynch et al. (2012) Mondelaers et al. 2009	LTS LTS LTS VC MA
Water regulation	↑(1)	Wheeler et al. (2015) Wood et al. (2006) Siegrist et al., 1998	R/S R/S LTS
Weed control	↑↓(0)	Cooper et al., 2016 Liebman and Dyck 1993	MA VC
Fertilizer savings	↑↓(1)	Seufert & Ramankutty, 2017	R/S
Herbicide savings	↑↓(1)	Zentner (2011) Seufert & Ramankutty, 2017	LTS R/S
Labor savings	↑↓(0)	Prihtanti et al., 2014 Mendoza (2004)	S
Long-term effects on-yield	↑(1)	Ponisio et al., 2015	MA
Machinery savings	↑↓(0)	Seufert & Ramankutty, 2017	R/S
Other savings	↑↓(1)	Lynch et al. 2011	LTS
Pesticide savings	↑↓(1)	Seufert & Ramankutty, 2017	R/S
Profitability	↑(1)	Crowder & Reganold, (2015)	MA
Risk	↑(1)	Seufert & Ramankutty, 2017 Lotter et al., 2003	R/S LTS
Yield	↓(-1)	Seufert et al., 2012 Ponisio et al., 2015, de Ponti et al., 2012. Badgley et al., 2007 Lotter et al., 2003 Kniss et al., (2016)	MA MA MA QS QS QS
Yield stability	↑(1)	Lotter et al., 2003 Smith et al., 2007	QS LTS

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CHAPTER 3

MIXED FARMERS` PERCEPTION OF THE ECOLOGICAL-ECONOMIC PERFORMANCE OF DIVERSIFIED FARMING

Flower strip & winter wheat nearby Göttingen (July 2022, © Julia Rosa-Schleich)

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Abstract

Understanding farmers' perception of the ecological-economic performance of Diversified Farming (DF) practices is essential to assess their willingness to adopt such practices. Based on structured face-to-face interviews with 145 farmers, we analyzed the expected ecological-economic performance of DF practices using linear mixed-effects models. We focused on the farmers' perception of changes in yield, variable costs, and gross margin of cereal production in central Germany by implementing DF practices such as cover crops, diversified crop rotation, reduced tillage, direct seeding and perennial flower strips without allowing agro-chemicals. Farmers expected a higher gross margin (20%) for diversified crop rotation because of higher soil fertility, better crop development and higher potential to suppress pests and diseases. In contrast, reduced tillage and direct seeding were perceived to increase weed pressure and the costs of weed control, decreasing the gross margin (58% and 61%) through lower crop yield and higher costs. Similarly, flower strips were expected to reduce gross margin (13%). Cover crops were expected to provide ecological benefits with only slightly reduced profit (1%), as the perceived positive yield effects of cover crops were more than neutralized by higher costs. Soil fertility was positively related to the perceived gross margin, whereas farmers' risk attitude and the number of DF practices applied did not show any major influence. Farmers working in mixed farms constantly expected lower variable costs compared to farmers working in arable farms because some production factors (such as fertilizers) are generated through the farm production cycle. Our findings make clear that DF practices were valued very differently, with positive expectations of enhanced crop rotations and negative of reduced tillage and direct seeding. Environmental policy should target incentives to effectively promote agri-environmental schemes, particularly those that are negatively perceived by farmers such as reduced tillage and direct seeding.

Keywords: diversified farming practices, profitability, gross margin, sustainable agriculture

Introduction

Sustainable agriculture aims at conserving biodiversity and ecosystem services, reducing the environmental impact of farming while keeping high yield levels (Kleijn et al., 2019). Prominent and effective approaches of sustainable agriculture are Diversified Farming (DF) practices. DF practices have proven to lower negative environmental externalities by replacing agro-chemicals, such as fertilizers and pesticides, through the provision of ecosystem services (Beillouin et al., 2021; Bommarco et al., 2013; Godfray et al., 2010; Kremen & Miles, 2012; Tamburini et al., 2020). In Europe, some DF practices (crop diversification and ecological focus areas) are promoted by the Common Agricultural Policy (2014-2020) within the first and second pillar (Hauck et al., 2014). The new common CAP 2023-2027 builds up on its predecessor providing a new "Green Architecture" based on a mandatory linkage of previous cross-compliance and greening requirements and an additional "Eco-schemes" instrument that fosters biodiversity conservation by minimizing the use of agrochemicals (Lüttringhaus et al., 2021). In addition, farmers can participate in voluntary programs called agri-environment-climate measures (AECM). AECM include extensive cereal cultivation, conservation of arable wild herbs and sowing of structurally rich flowering and shelter strips (Lakner et al., 2019) without applying synthetic pesticides and fertilizers. Furthermore, the spectrum and quantity of available substances for plant protection is expected to be strongly reduced in the future (Lüttringhaus et al., 2021), increasing the need for alternative crop production practices such as DF (Jacquet et al., 2022).

Cereal production, particularly of winter wheat (*Triticum aestivum*), is highly profitable and dominates the central European agricultural sector (FAOSTAT, 2021). Since 1975, the availability of mineral N fertilizers and chemical crop protection products allowed to increase wheat productivity and its share in the crop rotation (Bonke et al., 2021). The implementation of DF practices to reduce external inputs is particularly important in winter wheat. For instance, in a diversified crop rotation, several diseases, fungi, and pests, which would otherwise be problematic in a simplified wheat-maize crop rotation, can be mitigated (Tamburini et al., 2020). A diversified crop rotation was also found to lower the density of *Alopecurus myosuroides* (black grass), one of the most abundant grass weeds in European winter-annual crops with a high affinity to develop herbicide resistances (Zeller, 2018). Increased rotational diversity reduced weed density more under no-till (overall 65%) than under intensive tillage (41%), and this effect remained independent of the environmental context and herbicide use (Weisberger et al., 2019). Furthermore, the use of cover crops and reduced tillage increased soil quality and wheat yield, whereas direct seeding resulted in lower wheat yield (Büchi et al.,

2018). Reduced tillage is reported to be 60% more profitable because of cost savings, which more than compensate for the slightly lower yields found under German climatic conditions (Zikeli & Gruber, 2017). Typical DF practices often allow to reduce the application of agro-chemicals or even replace them by natural pest control. For example, in cereal production systems, planting flower strips can sustain enemy densities to control aphids and save the workload and costs associated with the application of insecticides (Tschumi et al., 2016; Zieger, 2017). Despite the growing evidence of the potential ecological benefits of DF practices, farmers often remain concerned about the economic costs associated with their large-scale adoption (Bergtold et al., 2017; Bowman & Zilberman, 2013; Kleijn et al., 2019).

Considering farmers' perception of the ecological-economic performance of DF practices, the farm characteristics, and the farmers' risk attitude is crucial for their successful implementation (Bergtold et al., 2017; Ramsey et al., 2016). Literature is consistent about the manifold ecological benefits, but economic performance is rarely analyzed, and the farmers' opinion of profit change remains a knowledge gap. However, this is important for designing appropriate environmental schemes for farmers, as their expectations can be the main driver for adoption (Ramsey et al., 2019). Kremen & Miles (2012) and Bowman & Zilberman (2013) discussed in their seminal work farm characteristics affecting diversification. Here, we add the farmer' perspective to identify the ecological-economic changes they expect. The aim of this study was to analyze farmers' perception on change of winter wheat yields, variable costs and profits (i.e., gross margins) through five DF practices such as the use of cover crops, diversified crop rotation, reduced tillage, direct seeding and the use of perennial flower strips to evaluate their potential ecological-economic performance and how farmers' expectations can be considered for the design of environmental schemes. Furthermore, we evaluated which farm characteristics and farmers' risk attitude best explain farmers' choices. To the best of our knowledge, no study has ever evaluated the expected change of profit by the implementation of several DF practices in winter wheat production.

Since farmers in Germany are rarely adopting DF practices, we expected that i) farmers perceive a decrease in the ecological-economic performance by adopting DF practices; ii) farmers expect higher yield, lower costs and overall higher gross margin with higher soil fertility by implementation of DF practices because they believe that the physical characteristics of the farm are important for the ecological-economic performance; iii) farmers who already used DF practices on their farms, and therefore are less reluctant to try different DF practices, expect higher ecological-economic performance; iv) farmers working on arable farms, being specialized in crop production, expect higher ecological-economic performance through DF

practices than farmers working on mixed farms; and v) risk-averse farmers expect lower profitability but reduced risk by increased provision of ecosystem services by DF practices, (Mouysset et al., 2013; Sulewski & Sosulski, 2020).

Therefore, we specifically formulated the following research questions: (1) How does the potential implementation of DF practices affects the perception on yields, variable costs and gross margin? (2) Which farm characteristics and risk attitude can explain these perceived changes in yield, variable costs, and gross margin? (3) How can farmers' expectations be incorporated into policy decision-making to increase the implementation of DF practices?

Materials and Methods

Sample

In 2017, we selected farmers in Lower Saxony from a pool of farms that are training companies and had agreed to disclose their detailed farm characteristics to the Chamber of Agriculture of Lower Saxony (n = 2097 farms). Since our major aim was to evaluate DF practices on crop production, farms specialized in animal husbandry and high stocking rates were excluded because no information about their cereal production were available. From the remaining farms, a random set of 20% of the farms in 22 counties were contacted and asked to participate in the survey, and 145 farmers accepted.

Data on yield, variable costs, and gross margin

The data for this analysis were derived from a standardized face-to-face survey (see Appendix) that focused on risk and perceived risk change through DF practices. We compiled a comprehensive questionnaire focusing on the expected yield and variable costs. To introduce the farmers to the topic of DF practices, we provided information on DF practices and their ecological-economic background at the beginning of the survey.

The survey consisted of three parts: 1. General farm characteristics, 2. Perceived change in yield and variable costs and, 3. Risk attitude and socio-demographic characteristics. We designed our questionnaire to explore perceived change of winter wheat yield and the associated variable costs based on reference yield (dt/ha) and variable costs (€/ha). To have a reference value (baseline) for the winter wheat yield and the associated variable costs, we used the records for the year 2016. When farmers had no winter wheat in their rotation in 2016, we considered yield and variable costs of other winter cereals. Overall, 93% (n = 135) of the interviewed farmers had winter wheat in their crop rotation in 2016. Among those who did not have winter wheat, 3.5% (n = 5) produced triticale, 2% (n = 3) winter barley and 1.5% (n = 2) winter rye.

Because winter wheat was by far the most cultivated crop, we refer to winter wheat but included in the analysis other winter cereals.

After identification of the baseline yield and variable costs, we asked the farmer about the percent change of the baseline yield and variable costs through the implementation of the five DF practices, the use of cover crops, diversified crop rotation, reduced tillage, direct seeding, and perennial flower strips (Figure 1). Data on yield and variable costs were collected to calculate the gross margin (€/ha). The yield represents the physical biomass amount (dt/ha) for the wheat production. Most common variable costs in agricultural include prices for labor, fuel, seed, fertilizers, and agro-chemicals. Variable costs raise as production increases and fluctuate depending on market prices. If farmers were unable to make a cost statement, we referred to 850 €/ha, the reference value from a common German recommendation for standard cost estimations (KTBL, 2020).

To determine the economic profitability of specific production programs, the gross margin is a standard indicator in farm economics (Penot et al., 2021), and it is used to evaluate the economic profitability of sustainable management practices (Bonke et al., 2021; Lüttringhaus et al., 2021). We established the gross margin by calculating the expected revenue which would result from the implementation of the DF practices and subtracting the variable costs expected by the farmers. The gross margin was calculated as follows:

$$\text{Gross margin}_{p,f} = (\text{Yield}_{p,f} \times \text{Price}) - \text{Total Variable Costs}_{p,f} \quad (1)$$

whereby the Gross $\text{margin}_{p,f}$ represents the economic profitability for the baseline and specific DF practice *p* of the individual farmer *f*. For the price calculations, we used the average price of the reference year 2016/2017 (15.94 €/dt winter wheat grains) (Statista, 2022). In the end, to calculate the gross margin (€/ha) per DF practice, we multiplied the total yield (€/dt) by the prices of winter wheat yield and subtracted the variable costs.

Scenarios for DF practices

As proposed within the pesticide-free model of sustainable agriculture and the rising social and political pressure for reducing agrochemical use, we assumed that all DF practices should be valuated based on cropping without the use of synthetic chemical pesticides and synthetic fertilizers. Within this study, we considered the following DF practices: cover crops (CC); diversified crop rotation (CR); reduced tillage (RT); direct seeding (DS); and perennial flower strips (FS). These practices have a high potential to deliver ecosystem services and therewith may save or substitute external production factors (Rosa-Schleich et al., 2019). For cover crops,

we assumed green manure (summer cover crop). For the diversified crop rotation, an extended crop rotation was presented to the farmers (oilseed rape – winter wheat – corn – barley – legume), but farmers had the opportunity to imagine a similar crop rotation that would fit better their farm conditions and current crop rotation. A crop was not allowed to be planted in two subsequent years (e.g., oilseed rape – winter wheat – winter wheat). In case of soil conservation practices, we reduced the intensity of tillage operations. Reduced tillage meant a tillage intensity of maximum 15 cm depth, loosening the soil, without turning it, with a chisel plough (UC Sustainable Agriculture Research and Education, 2017). The least intensive soil intervention was direct seeding, where no seedbed preparation is allowed, but mechanical weed control is possible. Both soil conservation practices were assumed without any use of herbicides. Flower strips were assumed to be established on the winter wheat field, making up 5% of one hectare to evaluate the yield increase or decrease (due to higher biological pest control or crop area lost) and associated operational costs.

What was your **wheat yield** _____ (dt/ha) in 2016? How high were the **variable costs** _____ (€/ha) of winter wheat production in 2016?

What percentage change in yield and variable costs do you expect from the implementation of a cover crop as green manure (e.g. mustard, field bean, clover or phacelia)?

Yield _____% variable costs _____%

What percentage change in yield and variable costs do you expect from the implementation of a diversified crop rotation (e.g. oilseed rape – winter wheat – cover crop – corn – barley – legumes)?

Yield _____% variable costs _____%

What percentage change in yield and variable costs do you expect from the implementation of reduced tillage with chisel plough without any use of herbicides?

Yield _____% variable costs _____%

What percentage change in yield and variable costs do you expect from the implementation of direct seeding without any use of herbicides?

Yield _____% variable costs _____%

What percentage change in yield and variable costs do you expect from planting 0.05 hectar area of perennial flower strips?

Yield _____% variable costs _____%

Figure 1 Illustration of the survey approach for the evaluation of % change in yield and variable costs by Diversified Farming practice. The farmers had the opportunity to ask for clarification during the face-to-face survey. In case the farmers were not willing to give an answer or could not estimate the percent change, we coded it with no answer (NA). The survey took place in 2018 and we referred to the yield and variable costs of the year 2016.

Farm characteristics & farmers´ risk attitude

For each farmer, we assessed three farm characteristics (soil quality, DF-index, farm type) and the risk attitude that we considered likely to have an influence on farmers´ expectations. In Germany, soil quality is systematically classified in the form of soil points according to its earning capacity (BMEL, 2022), ranging from 7 (lowest fertility) to 100 (highest fertility) (Ratzke & Mohr, 2005). For each farm, we calculated a DF-index by dividing the number of DF practices applied by the maximum possible number of five DF practices. We also distinguished between mixed and arable farms and evaluate the profit perception to test whether arable farms saw a higher profit due to their higher expertise with crop production technic and equipment. The risk attitude of the individual farmers was estimated using the incentive-based Holt and Laury-Lottery (chapter 4 Table S1), where farmers were asked to choose among alternative gambles with differing degrees of risk and monetary returns (Holt & Laury, 2002). Here, ten paired lottery choices were used to estimate the crossover point to the riskier lottery to indicate the degree of risk aversion (Holt & Laury, 2002).

Qualitative statements

In addition, for deeper insights into the expectations of the farmers on their expected yield and variable costs change, we asked the farmers about their explanations (qualitative statements). The interviews were recorded with the help of a dictaphone. We transcribed and analyzed these qualitative statements using MAXQDA 2022 software. Transcription followed the transcription system of (Dresing & Pehl, 2015). For the coding, the questions about the five DF practices were separated from each other. Farmers' justifications were classified into categories. The yield change responses were provided by the farmers according to different arguments that we categorized into six groups: soil quality, interaction, plant health, resource availability, site conditions, and weed pressure (Table S4). Variable costs consist of fertilizer expenses, wage costs, machinery costs, crop protection costs, and seed costs (Table S5).

Statistical analyses

Statistical analyses were performed, and graphs were created using R version 4.0.3 (R Development Core Team, 2019). Yield, variable costs, and gross margin by implementation of DF practices were estimated using separate linear mixed-effects models (function “lmer”, package lme4; Bates et al., 2022). The full models included the three farm characteristic variables (soil quality, DF-index, farm type) and risk attitude and their two-way interactions with DF practice. Farmer ID was included as random effect due to the repeated-measure design of the survey. We identified the best supported model for yield, variable costs and gross margin

using the likelihood ratio test ("step" function, package stats, (R Development Core Team, 2019)), thereby reducing the set of covariates for each model. Model performance was assessed using the "check_model" function (package performance, Lüdecke, 2022). For each best model we estimated the expected change of all three response variables by each DF practice and performed post-hoc Tukey tests between each DF practices and the baseline.

Results

The average soil quality was 48.75 soil points (ranging from 7 to 100), which represents an intermediate soil quality. The average DF index was 1.9, with farmer including between one and three DF practices into their business. Most farms were mixed farms (n = 89; 61.38%) and the rest (n = 56; 38.62%) were arable farms. Risk-averse farmers were more common (51%) than risk-loving (25.5%) and risk-neutral farmers (21%). The remaining farmers (2.5%) did not want to participate in the lottery.

Regression results

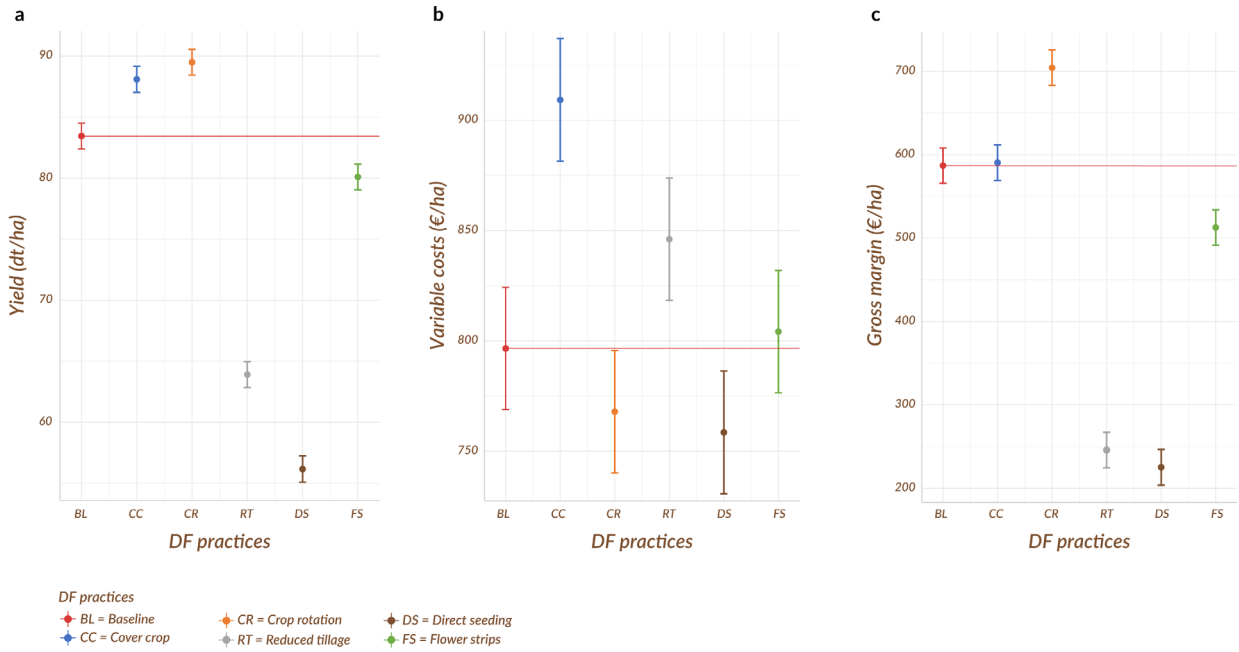

Figure 2 Farmers' perception of change in yield (a), variable costs (b) and gross margin (c) by Diversified Farming practice and average soil points of 48.75. The figure shows the mean (± SE) of the change in yield, costs, and gross margin. The perceived baseline (control – red line) describes the status quo without the implementation of any DF practices.

The best model explaining perceived change in yield included the DF practice and soil quality as main effects, while the other farm characteristics (DF-index, farm type) and farmers' risk attitude were excluded during model selection. The baseline yield, calculated by assuming average soil points of 48.75, was 84 dt/ha, which is consistent with the value provided by the German Federal Statistical Office (BMEL, 2017) (Table S1). Through the introduction of cover crops and diversified crop rotation, farmers expected an increase of winter wheat yield by 4.61 dt/ha (5.49%) and 6.02 dt/ha (7.17%), respectively (Figure 2a). In contrast, reduced tillage and direct seeding were expected to reduce the yield by 19.59 (23.32%) and 26.83 dt/ha (31.94%). Flower strips were expected to lower the winter wheat yield by 3.38 dt/ha (4.02%) (Figure 2a).

The reported variable costs for growing 1 ha winter wheat (i.e., the baseline) was on average 796.57 €/ha (Figure 1b). The best model explaining perceived change in variable costs expected by the farmers included the interaction between DF practice and soil fertility, DF practice and farm type, and DF practice and farmers' risk attitude. Particularly, direct seeding in poorer soil resulted in significantly higher costs (Table S2), while higher soil quality reversed this effect, and the variable costs fall sharply (Figure 3b). We also found that the variable costs for cover crops were estimated to be high, but with better soil quality, higher cost saving were expected (Figure 3b). Farmers working in arable farms consistently expected higher variable costs than farmers working in mixed farms (Table S2). Moreover, farmers working in mixed farms expected significantly lower variable costs for implementing reduced tillage than flower strips compared to arable farms (Figure 4). Risk-neutral farmers expected higher cost by DF practice, with one exception for direct seeding (Figure S1). We found no difference in the expectation of costs change for risk-loving farmers. Farmers estimated cover crops to increase the variable costs on average by 112.66 €/ha (14%). For diversified crop rotation, farmers expected a reduction of the variable costs (28.63 €/ha; 3.6%). In contrast, farmers expected reduced tillage to increase the average costs by about 50 €/ha (6%). This increase was due to the need to mechanically control weeds more often (Table S5). Direct seeding was expected to reduce variable costs by on average 38 €/ha (5%). Famers expected the implementation of flower strips to increased variable costs by 8 €/ha (1%).

The best model explaining perceived change in gross margin included DF practices and soil quality as the main effects, while the other farm characteristics (DF-index, farm type) and farmers' risk attitude were excluded during model selection (Table S3). Farmers expected a mean gross margin of 587.21 €/ha, which was the baseline (Figure 2c). Farmers expected cover crops to slightly increase gross margin (1%) up to 593.56 €/ha. This increase was due to a concomitant increase of expected yields and variable costs. From the farmers' point of view,

diversified crop rotation provided highest gross margin of 706.77 €/ha, an average increase of 117.36 €/ha (20%). Farmers justified their expectation by perceiving ecological benefits such as reduced weed and disease pressure and better crop development, resulting in higher yield and reduced variable costs (such as fertilizer savings, lower tillage costs and saved plant protection inputs; Tables S4 & S5). However, reduced tillage and direct seeding were considered to reduce the gross margin by 341.19 €/ha (58%) and 361.83 €/ha (61%), respectively. The perceived reduction of variable costs for direct seeding could not mitigate the yield loss. Farmers expected flower strips to decrease gross margin slightly (74.26 €/ha; 13%) due to reduced crop yield, as 5% of the crop area is taken out of production, and increased costs linked to the workload to establish the flower strips and the seeds. Overall, we found that an increase of soil quality about one point increased the gross margin by 5.64 €/ha (Figure 3c).

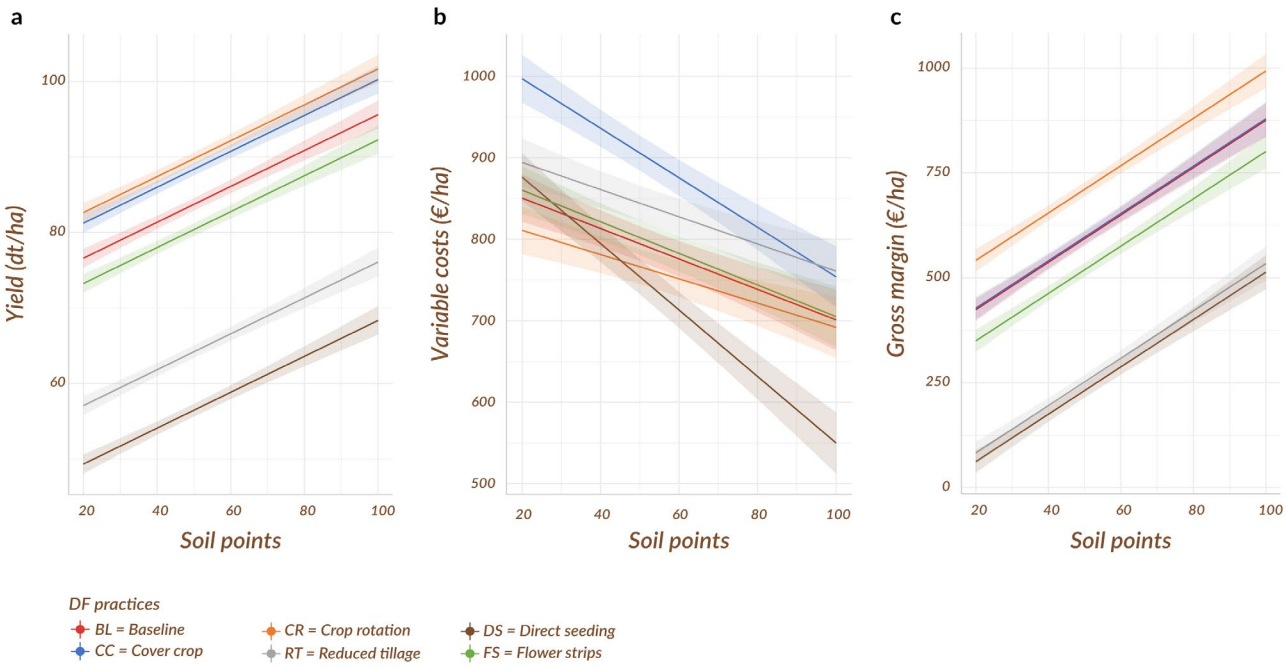

Figure 3 Model results for yield (a), variable costs (b) and gross margin (c) in dependence of soil quality (soil points). Estimates with the model specification are provided in Tables S1, S2 and S3.

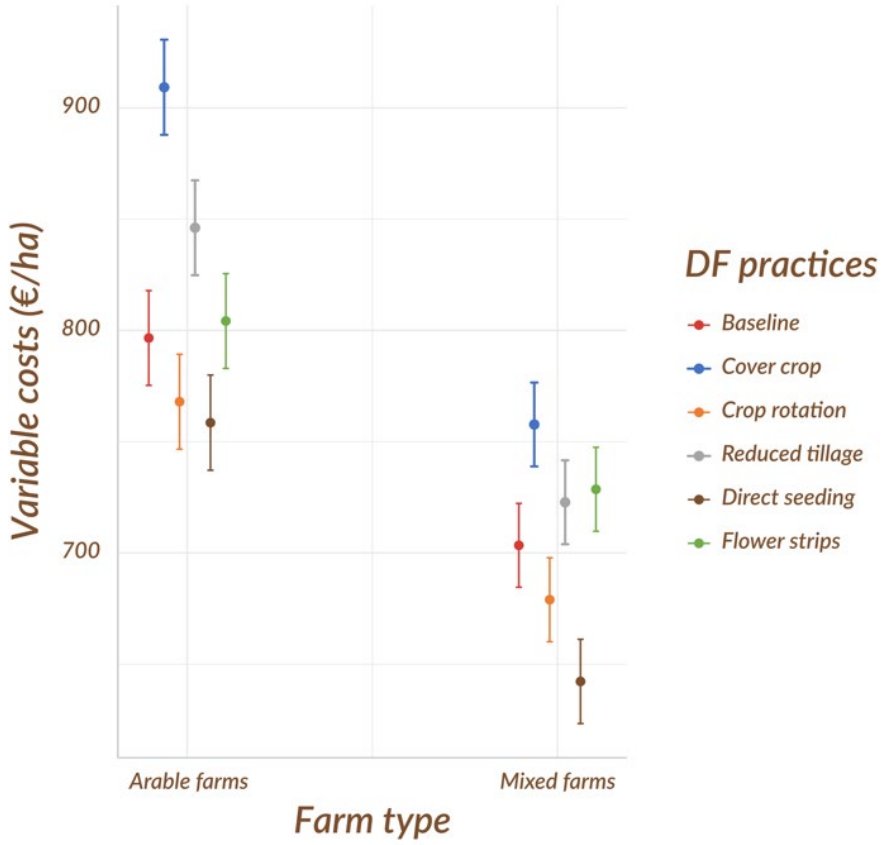

Figure 4 Estimated perceived change in variable costs by Diversified Farming practice and farm type. Estimates with the model specification are provided in Table S2.

Discussion

This is the first study analyzing farmers' perceptions of the change of ecological-economic performance through the implementation of DF practices. Overall, we found that cover crops did not affect the profitability, whereas diversified crop rotation resulted in higher profitability expected by the farmers. We found high reduction of profitability for reduced tillage and direct seeding, while flower strips slightly reduced profitability. Soil quality was found to be the major driver for higher expected ecological-economic performance, whereas DF-index and risk attitude of the farmers remain less important for farmers' expectations. The type of the farm was only relevant when considering the variable costs, here arable farmer expected higher costs in contrast to mixed farmers.

We found that farmers' expectations varied according to the specific DF practice, and that not all were negative. Cover crops and a diversified crop rotation were expected to increase the crop yield because of enhanced soil quality and crop plant development, as well as decreased disease pressure (Table S4). These results are in line with Ball et al. (2005), who also found that crop rotation improves soil structure, plant growth and disease suppression, caused by high

return of crop residues and increased activity of microbial communities. In contrast, farmers did not value the weed suppression, especially of black grass, by cover crops and a diversified crop rotation. Yet, ryegrass as a cover crop can help to reduce the emergence of blackgrass by 17% (Cordeau et al., 2018). A five-year crop rotation including winter wheat, corn, summer barley, winter oilseed rape, and winter wheat reduced blackgrass densities by 50% as compared to winter wheat-winter oilseed rape rotations (Zeller et al., 2018). Despite these benefits, farmers expected higher costs for the seeds, the seeding and for mechanical weed control, which did not enhance the gross margin compared to their conventional practices (Zeller et al., 2018). Bowman et al. (2022) found that farmers expected increased costs by 103.78 $/ha due to higher seed costs and dependency on the available machinery, which is in accordance with our findings. No change in the gross margin (e.g., cover crops), however, can be considered a success because the adoption of such DF practices leads to environmental benefits without compromising farmers' profit. Costs for diversified crop rotation were expected to be lower than the baseline variable costs, due to lower costs for mechanical weed control, savings of plant protection inputs and fungicide applications (Table S5). Diversified crop rotation was expected to significantly increase gross margin, which is consistent with other studies that evaluated the economic performance of crop rotations (Garbelini et al., 2022; Stratton et al., 2022).

Instead, reduced tillage and direct seeding were expected to strongly decrease crop yield because of weed pressure, decreased soil quality and the belief that these practices are unsuitable for farmers' site conditions. Moreover, the variable costs associated with reduced tillage were expected to be higher due to higher weeding control despite the savings in herbicides. Direct seeding was expected to lower variable costs, as farmers regarded the saving from low-intensive soil preparation and waiving herbicides higher than the costs for mechanical weeding. Weersink et al. (1992) compared the costs of different conservation tillage practices and found higher costs of reduced tillage practices compared to direct seeding because of the high machinery complement. This was due to the herbicide treatment costs, which were higher for the two reduced tillage practices. Compared to our study, although these costs for pre-emergent herbicides are avoided, farmers expected the chisel plough to increase costs for mechanical weed control. Mechanical weed control is not perceived by the farmer as efficient as pre-emergent herbicides application. Savings in labor costs associated with reduced tillage or direct seeding were not evident for the farmers in our study, whereas Weersink et al. (1992) found a ~61% annual reduction in labor costs associated with the reduced tillage systems. Here, the perception of the farmers does not match the scientific evidence.

Flower strips were expected to slightly reduce the yield of the adjacent crop because of the cultivated area loss (Table S4). In our interviews, the potentially higher biological pest control was rarely mentioned, and some farmers even expected higher pest and weed pressure due to the flower strips, which suggests that farmers do not trust the often-claimed biocontrol effect of this practice. However, in a review, flower strips were found to enhance pest control services in adjacent fields by 16% (Albrecht et al., 2020). We found that the variable costs increased because of expensive seed mixture and additional operation times (seeding costs). Overall, adopting flower strips was expected to reduce gross margin, indicating the need for targeted monetary incentives by environmental policy.

According to our perceptions, farmers expected soil fertility to increase the yield and reduce the variable costs, generating overall higher gross margin. We found that across all DF practices, higher soil fertility resulted in overall higher gross margin, which indicates that for the farmer, the physical characteristics of the farm were generally more important than the DF management. However, we found that the variable costs for cover crops and direct seeding in poor soils were expected to be higher than the baseline costs, whereas higher soil quality reverses this effect and the variable costs fall sharply. This shows that high quality soils result in lower costs, which leads us to the conclusion that the implementation of cover crops and direct seeding on high quality soils can be generally considered less expensive. From a political point of view, it can be assumed that cover crops and direct seeding on good sites is more favorable and, therefore, more likely to be accepted by farmers (Bergtold et al., 2017; Iwańska et al., 2018). On poor sites, cover crops and direct seeding leads to high costs for the farmers, which are already in an economically less favorable position, and are viewed rather skeptically.

We did not find support that farmers who already used DF practices on their farms expect higher ecological-economic performance. DF index was not related with higher yields, lower costs and overall higher gross margin, indicating, that the experience gained from using several DF practices did not enhance farmers' expectations. Here, other aspects of perceptions seem to be more relevant for the ecological-economic performance of DF practices (e.g., site conditions, farm environment or risks farmers face) (Bergtold et al., 2017; Ramsey et al., 2016; Weigel et al., 2018). Furthermore, we expected that farmers working on arable farms would perceive higher profitability from DF practices than those on mixed farms, what was partially supported by the data. Farm type did not affect yield and overall gross margin, however, farmers working in arable farms expected higher variable costs. In contrast, farmers working in mixed farms, do not rely only on crop production and may diversify their source of income and reduce income risks more easily, which is indicated by the overall lower baseline costs. Arable farms

depend on high-quality yield and may have higher costs for specialized equipment. A further possible explanation is that farmers working in arable farms need to spend more money for synthetic fertilizers, which are not needed in mixed farms.

Additionally, our expectation that risk-averse farmers would perceive lower profitability by DF practices was not supported. We found no difference between the expectations of risk-averse and risk-loving farmers. Risk-neutral farmers consistently expected the highest variable costs, except for direct seeding, where they expected the greatest reduction in variable costs (Figure S1). However, these patterns are unclear and more detailed research on the perception of production costs as a function of the risk attitude to clarify this aspect is needed.

Conclusion

In conclusions, this study shows that the perception of DF varies widely between practices and their implementation remains generally rare. Although, this study focused on German cereal growers, our results are likely representative for other cereal growing countries in the Global North, while DF practices are still widely unpopular globally (Klein et al., 2019).

Farmers were particularly skeptical about the adoption of reduced tillage and direct seeding if they cannot use herbicides, and they were concerned about the potential disadvantages associated with flower strips. These results suggest that efforts to convince the farmers of the ecological and economic benefits of these specific practices are needed. Some of the farmers' concern could be minimized by developing new technologies to improve mechanical weed control as a substitute for herbicide applications. Additionally, involving farmers in the development and testing of such technology using living labs and demonstration plots can help showing the ecological-economic benefits of DF practices (Rosa-Schleich et al., 2019). Finally, policy makers may consider higher incentives for DF practices that farmers expect to cause high economic losses. This would then provide a serious incentive for farms that expect a low gross margin due to their poor soil conditions by implementation of DF practices. Our results illustrate that environmental policy should be more closely aligned to the perceptions of the farmers, shaped by their farm conditions, particularly the soil quality.

Agriculture is one of the main drivers of environmental degradation and biodiversity loss, and its impact is expected to grow further with the increasing population (Ramankutty et al., 2018; Tilman et al., 2011). Converting our current agricultural system to a more sustainable one is essential if we want to achieve the IPBES strategic goals of conserving biodiversity and ecosystem services (Díaz et al., 2015) and the sustainable development goals.

Acknowledgments

We thank all the farmers for their cooperation and participation in this survey.

Supplementary Material

Table S1 Results of linear mixed-effects model for the dependent variable yield. Significant values are indicated in bold.

Predictors	*Estimates*	*95% CI*	*Significance*
(Intercept)	71.83	66.40 – 77.25	**<0.001**
Cover crops	4.65	2.07 – 7.22	**<0.001**
Diversified crop rotation	6.05	3.49 – 8.61	**<0.001**
Reduced tillage	-19.53	-22.09 – -16.98	**<0.001**
Direct seeding	-27.27	-29.87 – -24.68	**<0.001**
Flower strips	-3.35	-5.90 – -0.80	**0.010**
Soil points	0.24	0.14 – 0.34	**<0.001**
Random Effects			
σ^2	113.40		
$\tau_{00\ id\_lw}$	95.66		
ICC	0.46		
N_{id_lw}	135		
Observations	791		
Marginal R^2 / Conditional R^2	0.452 / 0.703		

Table S2 Results of the linear mixed-effects model for the dependent variable costs. Significant values are indicated in bold.

Predictors	*Estimates*	*95% CI*	*Significance*
(Intercept)	887.81	770.46 – 1005.17	**<0.001**
Cover crops	169.89	98.56 – 241.22	**<0.001**
Diversified crop rotation	-47.19	-117.71 – 23.34	0.189
Reduced tillage	39.74	-30.30 – 109.79	0.266
Direct seeding	69.88	-1.18 – 140.94	0.054
Flower strips	11.11	-59.02 – 81.24	0.756
Soil points	-1.87	-3.77 – 0.04	0.055
Risk attitude [n]	46.20	-41.91 – 134.32	0.304
Risk attitude [s]	-9.40	-90.95 – 72.16	0.821
type [MB]	-93.15	-165.27 – -21.02	**0.011**
Cover crops * soil points	-1.17	-2.32 – -0.02	**0.046**
Diversified crop rotation * soil points	0.38	-0.76 – 1.52	0.514
Reduced tillage * soil points	0.20	-0.94 – 1.34	0.729
Direct seeding * soil points	-2.21	-3.36 – -1.05	**<0.001**
Flower strips* soil points	-0.07	-1.21 – 1.07	0.902
Cover crops * risk attitude [n]	6.29	-47.45 – 60.03	0.818
Diversified crop rotation * risk attitude [n]	12.74	-40.35 – 65.82	0.638
Reduced tillage * risk attitude [n]	1.38	-51.63 – 54.39	0.959
Direct seeding * risk attitude [n]	-102.21	-156.74 – -47.68	**<0.001**
Flower strips* risk attitude [n]	6.99	-45.66 – 59.65	0.794
Cover crops * risk attitude [s]	-21.71	-70.72 – 27.29	0.385
Diversified crop rotation * risk attitude [s]	9.68	-39.28 – 58.64	0.698
Reduced tillage * risk attitude [s]	-4.78	-53.75 – 44.19	0.848
Direct seeding * risk attitude [s]	-2.32	-51.78 – 47.14	0.927

Flower strips * risk attitude [s]	3.01	-45.74 – 51.77	0.903
Cover crops * type [MB]	-58.37	-101.95 – -14.78	**0.009**
Diversified crop rotation * type [MB]	4.18	-39.29 – 47.66	0.850
Reduced tillage * type [MB]	-30.20	-73.61 – 13.21	0.172
Direct seeding * type [MB]	-23.12	-67.05 – 20.80	0.302
Flower strips* type [MB]	17.54	-25.56 – 60.63	0.425
Random Effects			
σ^2	7339.47		
$\tau_{00\ id\_lw}$	33882.12		
ICC	0.82		
N_{id_lw}	135		
Observations	791		
Marginal R^2 / Conditional R^2	0.139 / 0.847		

Table S3 Results of the linear mixed-effects model for gross margin. Significant values are indicated in bold.

Predictors	*Estimates*	*95% CI*	*Significance*
(Intercept)	311.59	194.22 – 428.97	**<0.001**
Cover crops	3.46	-41.09 – 48.01	0.879
Diversified crop rotation	117.36	73.11 – 161.61	**<0.001**
Reduced tillage	-341.19	-385.45 – -296.93	**<0.001**
Direct seeding	-361.83	-406.80 – -316.85	**<0.001**
Flower strips	74.29	-118.44 – -30.13	**0.001**
Soil quality (points)	5.64	3.46 – 7.82	**<0.001**
Random Effects			
σ^2	34001.15		
$\tau_{00\ id\_lw}$	50039.97		
ICC	0.60		
N_{id_lw}	135		
Observations	791		
Marginal R^2 / Conditional R^2	0.338 / 0.732		

Table S4 Qualitative statements (%) used by farmers to explain the expected yield change by DF practice. Values >10% are highlighted in green. The yield change responses were provided by the farmers according to different arguments categorized into six groups: soil quality, interaction, plant health, resource availability, site conditions, and weed pressure. CC = cover crops, CR = diversified crop rotation, RT = reduced tillage, DS = direct seeding, FS = flower strips.

Qualitative Statements	CC	CR	RT	DS	FS
	%	%	%	%	%
Soil quality					
Enhanced soil quality	31	7	3	6	-
Impaired soil quality	1	0	8	12	-
Interactions					
Enhanced plant development*	22	6	2	-	-
Impaired plant development	-	-	1	5	-
Long term effect positive	-	-	3	4	-
Long term effect negative	-	-	6	2	-
Plant health					
Disease pressure increased	1	-	6	2	1
Disease pressure decreased	6	55	1	1	-
Disease pressure unchanged	-	3	-	-	-
Biological pest control enhanced	-	-			14
Biological pest control reduced	-	-			11
Resource availability					
NS availability unchanged	-	1	-	-	-
NS availability increased	-	2	2	1	-
NS availability decreased	16	10	4	-	2
Water availability lower	8	-	2	-	-
Water availability higher	3	-	2	-	-
Site conditions					
Site suitable	3	3	2	-	12
Site unsuitable	4	4	10	10	1
Area taken out of production					43
Weed pressure					
Weed pressure reduced	3	9	-	4	-
Weed pressure increased	2	-	47	52	14
Weed pressure unchanged	-	-	2	1	1

* **Enhanced plant development includes positive effects of crop rotation,** positive pre-crop effect**,** better emergence of crops and overall better development of the crop**.**

Table S5 Qualitative statements for the expected change of variable costs by DF practice**.** Values >10% are highlighted in green. The cost change responses were provided by the farmers according to different arguments categorized into five groups: fertilizer expenditures, wage costs, machinery costs, plant protection costs, and seed costs. CC = cover crops, CR = diversified crop rotation, RT = reduced tillage, DS = direct seeding, FS = flower strips.

Qualitative Statements	CC	CR	RT	DS	FS
	%	%	%	%	%
Fertilizer expenditures					
Fertilizer savings	5	19	-	2	1
Fertilizer higher expense	4	-	2	-	-
Fertilizer no change	1	1	-	-	-
Wage costs					
Wage costs lower	-	-	3	2	-
Wage costs higher	5	-	6	6	12
Wage costs no change	-	-	-	-	1
Machinery costs					
Seeding costs lower	-	-	2	3	2
Seeding costs higher	29	-	2	8	39
Seeding costs no change	-	-	-	-	3
Tillage (soil preparation) costs lower	3	13	14	34	2
Tillage (mechanical weed control) costs higher	9	-	40	20	9
Tillage costs no change	-	-	-	4	4
Harvesting costs higher	1	-	-	4	-
General costs of machinery lower	1	9	4	1	-
General costs of machinery higher	1	-	4	1	2
General costs of machinery no change	-	-	1	-	-
Plant protection costs					
savings of plant protection input	2	26	-	-	5
increased plant protection costs	1	6	1	1	2
fungicide input lower	1	13	-	-	-
herbicides lower	1	1	20	14	
herbicides higher	1	-	-	-	
herbicides no change	1	3	-	-	2
Seed costs					
seed costs decreasing	-	1	1	-	1
seed costs increasing	29	1	-	2	25

Figures

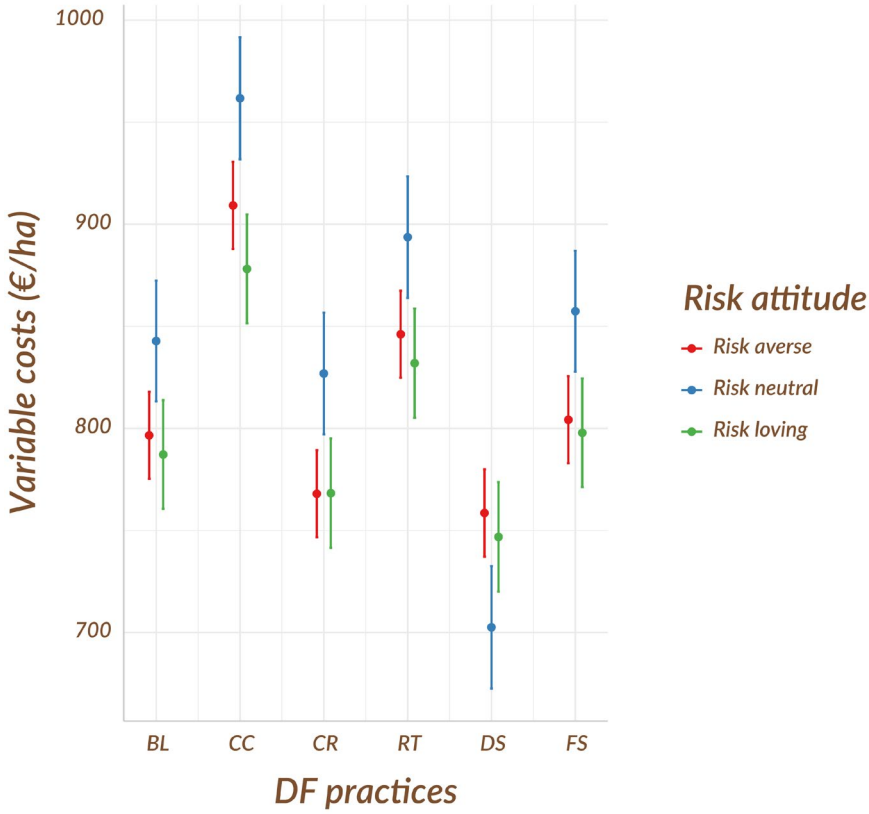

Figure S1 Estimated perceived change in variable costs by Diversified Farming practice and risk attitude.

CHAPTER 4

DIVERSIFIED FARMING PERCEIVED AS YIELD RISK REDUCTION

Winter wheat nearby Cassel (July 2022, © Julia Rosa-Schleich)

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Submitted to *Land Use Policy*, July 2022

Abstract

In times of climate change and high environmental and economic uncertainty, diversified farming practices have been considered a major risk-mitigating strategy. However, the implementation rate of diversified farming practices is still low, presumably because of a perceived lack of effectiveness to reduce yield risks. In this study, we focus on the perceived yield risk of farmers for implementing diversified farming practices, while comparing two climatic scenarios: severe droughts and above-average precipitations. In addition, we disentangle socio-economic and ecological factors that may support or hinder the implementation. Through face-to-face interviews, we analyzed the risk perception of 147 German farmers towards the potential implementation of six diversified farming practices: Intercropping, cover crops, diversified crop rotation, reduced tillage, direct seeding, and perennial flower strips. Using Generalized Linear Mixed Models, we found that, under both climate scenarios, farmers expected a risk reduction by cover crops and diversified crop rotation, due to the portfolio effect, but a risk increase by reduced tillage and no-tillage, due to greater weed pressure. Cumulative Linked Mixed Models, Multimodel Inference, and Variation Partitioning show that large farm sizes and less fertile soils are related to the perception of reduced yield risk, presumably because of additional opportunities to increase profits through the implementation of diversification. Surprisingly, the risk attitude of the farmers was only relevant under the scenario of above-average precipitation, because of the expectation of potentially high damage by strong rainfall during the harvesting time. Consideration of farm features and farmers' experience may help to adjust incentives for the implementation of diversified farming practices by agri-environmental policies.

Keywords: agricultural diversification, diversified farming systems, climate adaptation, climate change, risk perception, face-to-face survey

Introduction

Sustainable agriculture faces the challenge to balance ecological and socio-economic goods, cope with increasing demands for agricultural products, changing consumption patterns of a growing world population and climate change while maintaining biodiversity and associated ecosystem services (Rockström et al., 2017). Agricultural production is particularly sensitive to climate change (Nelson et al., 2014) such as very dry conditions in the early growing season or above-average precipitation at harvesting time, events that increased in the last years (Sundström et al., 2014). In the future, there will be a need to develop adaptive agricultural management that can buffer extreme climate conditions and minimize yield risk. Ecological evidence supports that Diversified Farming (DF) practices result in higher ecosystem services provision, temporal stability of the system, and reduction of risks that farmers are facing (Beillouin et al., 2021; Jones et al., 2021; Ramsey et al., 2019; Tamburini et al., 2020). Reducing yield risk with the help of enhanced biodiversity and associated ecosystem services through the application of DF practices promises win-win situations for the farmers. However, despite increasing evidence of the manifold potential ecological and economic benefits of DF practices, implementation rates remain low (Tamburini et al., 2020). Reasons for this inertia may be the discrepancy between scientific knowledge on the effectiveness of DF practices and farmers' perceptions on yield risks. Notwithstanding its relevance for biodiversity and climate change management, farmers' perceptions have been insufficiently considered in science as well as in political decisions (van Zonneveld et al., 2020).

Implementing DF practices is recommended to mitigate risks for the farmers brought about by climate change risks (Altieri & Nicholls, 2017; Kremen & Miles, 2012; Rosa-Schleich et al., 2019; van Zonneveld et al., 2020). DF practices include intercropping, cover crops, diversified crop rotation, reduced or no-tillage, and perennial flower strips. Using these practices, ecological services are expected to largely replace agrochemicals (fertilizer, pesticides), promoting the resilience of agricultural systems (Bowman & Zilberman, 2013; Kremen et al., 2012). For example, under rainfed conditions in dry climates, reduced tillage in combination with a diversified crop rotation can yield 7.3% higher than control systems, due to better water infiltration and greater soil moisture conservation (Ponisio et al., 2015). Several studies show that reduced tillage and no-till can decrease production costs and thus reduce risks for farmers. Thus, reduced tilling is of particular importance to organic farming where no herbicides are allowed (Mäder & Berner, 2012; Ribera et al., 2004; Zikeli & Gruber, 2017).

Considering risk is important in agricultural decision-making (Menapace et al., 2016). One main source of risk, from farmers' perspective, is the concern that productivity suffers.

Production uncertainty means that the amount and quality of output resulting from a given input are typically not known with certainty (Ullah et al., 2015). Risk can therefore be defined as a measure of the level of uncertainty and can be calculated by the probability of a hazard, multiplied by its impact (Krahmann, 2011). In qualitative risk assessment, the probability of damage and extent of damage is subjectively ranked by an expert on a scale from low to high (Mußhoff & Hirschauer, 2020). For example, considering the damage caused by hail, the probability of hail occurrence may be low, but the resulting extent of yield loss may be high, leading to a high risk for the farmers (Figure 1a). In contrast, the probability of damage caused by cereal leaf beetles is very likely but leads to small yield losses. Hence, cereal leaf beetle infestation is typically seen as a low-risk problem (Figure 1a). Farmers face potential risks due to weather or ecosystem disservices such as crop diseases, pest outbreaks, or weed invasions (Menapace et al., 2016). These disservices are influenced by changing climate and weather (Figure 1b) and can be more important under heavy rainfall at the harvesting time (Peters et al., 2014; Ramesh et al., 2017; Skendžić et al., 2021). Under drought or above-average precipitation, DF practices such as reduced tillage or direct seeding may be not preferable, because the risk of crop failure will increase (Skendžić et al., 2021). In contrast, DF practices can positively influence ecological risk factors (Kremen et al., 2012). For example, a study by Weigel et al. (2018) reports that farm diversification maintains soil fertility to buffer yield variance against adverse climatic scenarios and to substitute fertilizer use while maintaining economic competitiveness. DF practices may be a good strategy to reduce crop diseases (Villegas-Fernández et al., 2021), weed and pest infestation (Li et al., 2019; Tamburini et al., 2020), and to stabilize yields (Rosa-Schleich et al., 2019). Reasons for not adapting DF practices could be the increased risk perception due to poor soil conditions, small farm sizes, or the particular risk attitude of the individual farmers (Antonides & Van Der Sar, 1990; Ramsey et al., 2019). Farmers differ in their risk attitudes, that is, some farmers are willing to accept more risk than others (Ewald et al., 2012; Menapace et al., 2016). Because the risk attitude impacts the potential adoption of DF practices (Sarwosri & Mußhoff, 2020; van Zonneveld et al., 2020), it is important to quantify farmers' risk attitudes. Oftentimes, farmers are risk-averse and are willing to accept some economic losses in exchange for a risk reduction (Rizwan et al., 2020). Risk attitudes have been shown to influence farmers' choice of adopting new technologies and suitable management practices (e.g., crop selection or crop-rotation schemes), but the relation between risk perception and the implementation rates of DF practices have not yet been studied in depth (Duong et al., 2019; Ramsey et al., 2019).

We aim to provide an analysis of the farmers' perceived yield risk of implementing DF practices under two climate change scenarios: extreme droughts in the early growing season and above-average precipitation at harvest time. To allow for a more targeted view on the perceived risk of decreasing winter wheat yield, we include socio-economic aspects (implementation rate of DF practices, farm size, soil conditions, and risk attitude) into the analysis (Figure 1b). Furthermore, we examine the change in perceived risk under varying ecologically relevant risk factors. We address the following research questions: How does the implementation of six DF practices under the two climatic scenarios affect the perceived yield risk? Which socio-economic factors are accountable for these perceived yield risk changes? Which ecological factors are important components of the perceived yield risk under both climatic scenarios? Our study allows the identification of DF practices that can be an option for risk-reducing strategies from the farmers' perspective for better consideration of farm features and farmers' experience to adjust incentives of agri-environmental policy.

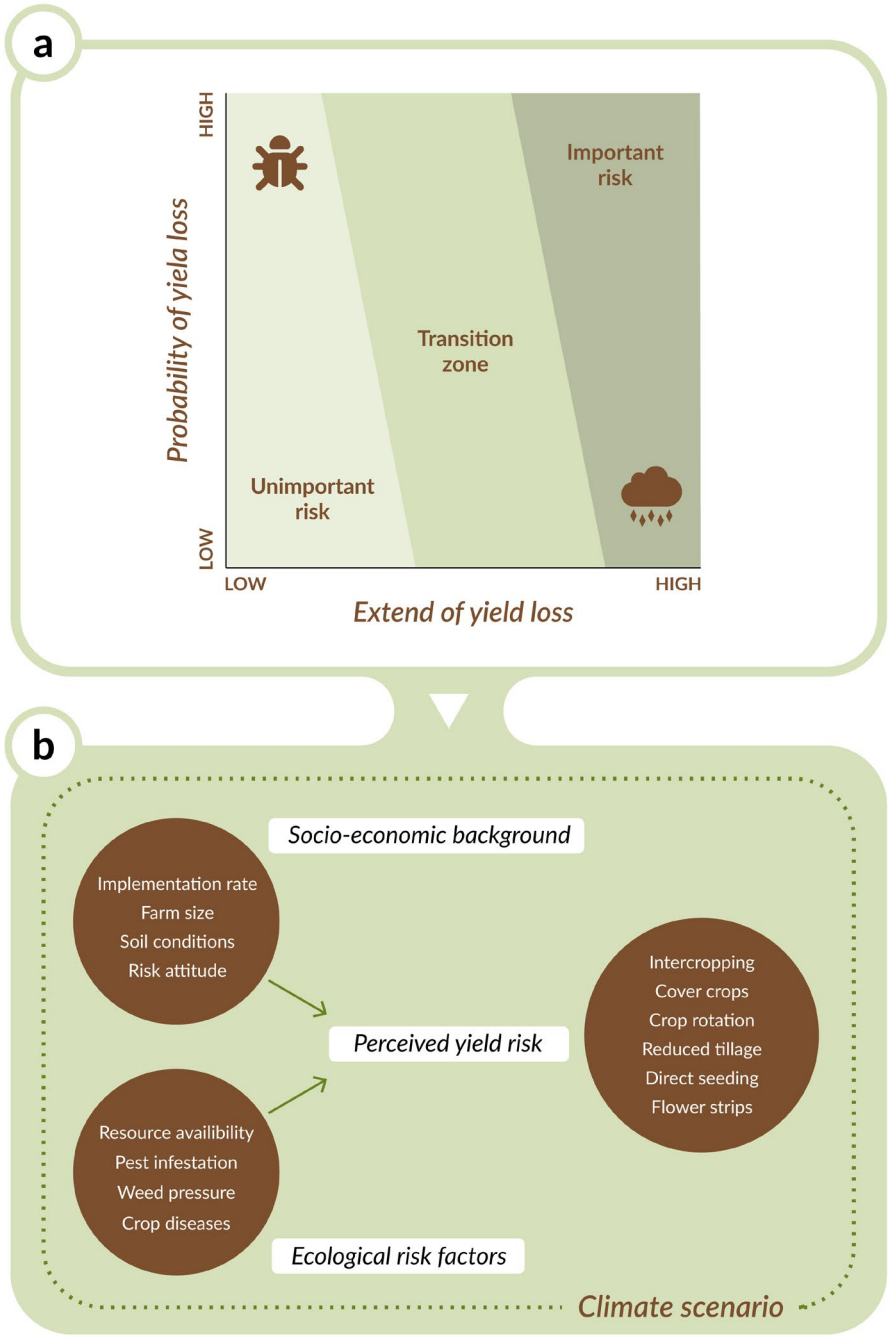

Figure 1 Schematic illustration of the risk matrix approach (a) used within qualitative risk assessment, inspired by Mußhoff & Hirschauer (2020). The probability of damage (probability of yield loss) and extent of damage (extend of yield loss) range from low to high indicating the degree of perceived risk. Within the risk matrix, three different areas can be distinguished: unimportant risk, transition zone, and important risk. The example of hail shows a high risk for the farmers because the probability of yield loss is low, while the extent of yield loss is quite high, resulting in a risk that needs to be secured by insurance. In contrast, the risk of a cereal leaf beetle outbreak is ranked as an unimportant risk because the probability of yield loss is very high, and the extent of yield loss is very low, resulting in common yield losses, that do not necessarily need to be secured by insurance. (b) Conceptual model linking socio-economic background and ecological risk factors to the perceived risk by the implementation of the six DF practices. Perceived yield risk, socio-economic background, and ecological risk factors depend on climatic scenarios. Detailed explanation of influencing factors (socio-economic background and ecological risk factors) are provided in Table 1.

Materials and Methods

To start with, we reviewed the literature on the ecological and economic performance of six DF practices. Based on this information, we conducted a pre-test with a standardized survey of 36 farmers. Using the revised version of the survey, we collected data in face-to-face surveys in Germany (Lower Saxony) in 2018. We recorded the perceived initial yield risk and its change by the implementation of the six DF practices by using a risk matrix (Figure 1a & Figure S1).

Survey data

The farmers were selected in 2017 from the pool of all farms in the federal state of Lower Saxony, and all had agreed to the publication of their farm characteristics and address details by the Chamber of Agriculture of Lower Saxony (2097 farms). Since the main aim of this study was to evaluate DF practices on crop production, districts with intensive animal husbandry and high stocking rates were excluded. We randomly selected 20% of the remaining farms, covering 22 districts, and asked for participation in the survey (147 farms). The survey consisted of three parts to evaluate the perceived yield risk change and the background of the perceived yield risk: 1. General farm characteristics, 2. Perceived yield risk change using a risk matrix (Figure S1) and perception of risk factors according to perceived yield risk change and 3. Risk attitude and socio-demographic characteristics such as implementation of the DF practices, farm size, and soil fertility.

Data on DF practices

All DF practices were assumed to take place in winter wheat production without using any chemical plant protection, following the pesticide-free model of Diversified Farming Systems (Kremen et al., 2012; Kremen & Miles, 2012). We considered DF practices that are known to deliver ecological benefits, such as increased biodiversity, soil health, nutrient availability, or water retention (Beillouin et al., 2021; Tamburini et al., 2020; Rosa-Schleich et al., 2019). Resulting in a closer examination of the following six DF practices: (1) Intercropping (IC); (2) Cover crops (CC); (3) Diversified crop rotation (CR); (4) Reduced tillage (RT); (5) Direct seeding (DS); and (6) perennial flower strips (FS). According to Vandermeer (1989), intercropping is based on the simultaneous cultivation of two or more crops on the same field at the same time. We asked the farmers about their opinion on cultivating winter wheat and winter pea together. This combination is popular in Germany and included in Agri-Environmental Schemes (AES) (Landwirtschaftskammer Nordrhein-Westfalen, 2021). For cover crops (CC), we asked the farmers about implementing summer cover crops (green manure) without using pesticides and mineral fertilizers. For the diversified crop rotation (CR)

we gave the farmers the example of a rotation with five different crops (e.g., oilseed rape – winter wheat – corn – barley – legumes). The farmers also had the opportunity to imagine a crop rotation that would be more adjusted to their farm conditions and current crop rotation. As soil management practice, we presented reduced tillage (RT) and direct seeding (DS), both without herbicide use. For structural elements, we focused on perennial flower strips (FS) in the survey.

Table 1 Description of risk perception (response variable) and personal and farm characteristics (predictor variables) used for statistical analysis.

Variable	Description	Scale
	Response	
Risk change	The change of the initial risk by the DF practice (Initial risk score minus risk score after implementation of DF practices) All responses were grouped in categorial values: IR = increased risk, NRC = no risk change, RR = reduced risk.	IR NRC RR
	Socio-economic background	
Implementation rate	Farmers applied or did not apply the individual DF practice	Yes/no
Farm size	Size of the arable farms land Categories: 0 - 99 ha = very small, 100 – 249 ha = small, 250 – 499 ha = large, > 500 ha = very large	very small small large very large
Soil points	Average soil points, which are positively related to soil fertility and are a common estimation used for the value of agricultural land in Germany (Ratzke & Mohr, 2005) Categories: 7 – 19 = very poor, 20 – 39 = poor, 40 – 59 = good, 60 – 79 = very good, 80 – 100 = excellent	very poor poor good very good excellent
Risk attitude	Holt & Laury-Lottery choices were transformed into categories: a = risk-averse, n = risk-neutral, l = risk-loving	a, n, l
	Ecological risk factors	
Resource availability	Risk changes by application of nutrients, water, and light. Explanation: -5 = low utilization of nutrients, water and light expected (declined resilience), 0 = no difference, +5 = high utilization of nutrients, water & light expected (improved resilience)	-5 to 5
Pest infestation	Risk changes by expected pressure of pests. Explanation: -5 = higher vulnerability against pests expected, 0 = no difference, +5 = lower vulnerability against pests expected	-5 to 5
Weed pressure	Risk changes by an expected pressure of weeds. Explanation: -5 = more weeds expected, 0 = no difference, +5 = less weed pressure expected (improved weed-control)	-5 to 5
Crop diseases	Risk changes by an expected outbreak of plant diseases Explanation: -5 = more plant diseases expected, 0 = no difference and +5 = less plant diseases expected	-5 to 5

Risk perception

The perception of initial risk and the risk change by the implementation of DF practices were estimated by using a risk matrix assessment. Risk matrix assessment enables the participating farmer to estimate the two dimensions of the risk that are illustrated by the levels of probability of yield loss and extent of yield loss under changing climate scenarios (Figure 1a). The farmers were asked to rank their perceptions of winter wheat yield risk and the expected change of this yield risk through the implementation of DF practices, separating the extent of yield damage and the probability of yield loss. The risk score was estimated as the product of the probability of yield loss and the extent of yield damage utilizing a Likert scale, where 10 is ranked as very high and 1 as very low. In other words, the perceived initial risk is the farmers' generally perceived risk, and the risk change is the change of the initial risk induced by the DF practice. Our risk matrix approach provides an opportunity to assess the perceived risk of agricultural production programs in different climatic scenarios (Cobon et al., 2016). For example, farmers were asked about the initial risk without any DF practices used. We then asked for the perceived risk change through the implementation of cover crops. This, for example, resulted in reduced perceived yield risk (Figure S2). In contrast, it is possible that perceived yield risk decreases under drought but increases under wet conditions. The benefit of the risk matrix approach is that the term risk is disaggregated into two components, which makes it easier for the survey participants to come to a consensus about an outcome (Cobon et al., 2016). Several studies show that the risk matrix approach (RMA) is suitable to evaluate the perception of risk through face-to-face surveys or data contained by workshops (Mußhoff & Hirschauer, 2020; Ramsey et al., 2019). We decided on the subjective-qualitative approach based on several considerations. No information about the absolute extent of the six DF practices applied was available through the Farm Accountancy Data Network (FADN). The most appropriate way was to conduct face-to-face surveys in which we explicitly asked farmers about their decision-making towards the application of DF practices. Furthermore, the risk matrix and face to face questionnaires allowed us to directly evaluate the opinion of the farmers.

Socio-economic background & ecological risk factors

In the third part of the survey, we collected socio-economic data of the farms (Table 1), including the application of DF practices, farm size, soil points, and individual risk preferences. To conclude about farmers' risk perception, we recorded whether or not a farmer implemented each of the six DF practices. Farm size was measured as the size of all arable fields per farm in hectare (ha) excluding permanent grassland. We also used soil points as an indicator of the quality of site conditions. In Germany, soils are systematically classified and valued since the

20th century to account for their properties and earning capacity (BMEL, 2022). Soil points (Bodenzahl) are defined as the relative earning capacity ranging from 7-100 (the most fertile arable land gets the highest soil points and the worst arable land gets the lowest soil points) (Ratzke and Mohr, 2005). For example, arable land with 50 soil points can be expected to have half of the earning capacity compared to the reference of Magdeburger Börde with 100 soil points. We used this classification as an indicator for the ecosystem services delivered by the soils to make assumptions about the influence of farmers' risk perception. For the evaluation of individual risk preferences, we used the incentive-based Holt and Laury-Lottery, where the farmers were asked to choose among alternative gambles with differing degrees of risk and monetary returns (Holt & Laury, 2002). Here, ten paired lottery choices were used to estimate the crossover point to the riskier lottery to indicate the degree of risk aversion (Holt & Laury, 2002) (Table S1). To explain the composition of the risk, we asked the farmer about the expected effects on resource availability, pest infestation, weed pressure, and crop diseases. Risk factors were estimated on a Likert scale ranging from -5 to 5 (Table 1). We decided to include these ecological risk factors to measure whether the perception of farmers differs from the scientific knowledge and whether or not this could explain the implementation of the DF practices.

Statistical analyses

Statistical analyses were conducted with R software version 4.0.3 (R Development Core Team, 2019). We analyzed the initial risk perception and change of this risk perception by implementation of six DF practices with generalized linear mixed effect models (function "glmmTMB", package glmmTMB; Brooks et al., 2017). The risk change was included as response variable (Table 1). DF practices, the implementation rate of DF practices, farm size, soil points, and risk attitude were included as explanatory variables (Table 1). We included farm ID as a random effect. Analyses of risk perception under both climatic scenarios were performed separately, to simplify models, which become otherwise too complex.

Data on the perception of risk score were continuous and strictly positive, so we fitted generalized linear mixed models and compared all families eligible for this type of data via the Akaike´s information criterion for small samples (AICc). Models with the smallest AICc values are best supported by the data (Burnham & Anderson, 2002). When models with a tweedy family (Bonat & Kokonendji, 2017), did not converge or residuals did not meet the model assumptions, we considered the second-best model with family gaussian using the square root transformation for interpretation.

To evaluate the effects of socio-economic predictors on categories of risk change (increased risk, no risk change, reduced risk), we conducted cumulative linked mixed models for the climatic scenario drought and wetness (function “clmm”, package ORDINAL; Christensen, 2019). We decide for categorical response variable, because of the subjective valuations by the farmers. For example, 20 risk score points can be assessed as high for one farmer but low for the others. Following a multimodel inference approach (function “dredge”, package MUMIN; Barton, 2019), all models within delta AICc < 2 in comparison with the best fitting model were considered for interpretation. According to Burnham & Anderson (2002), Akaike weights (Σwi) as a measure of the relative likelihood of the importance of explanatory variables were used for interpretation. We show the results on the predictor variables within delta AICc < 2, according to the risk change under both climate scenarios (Table 3).

To evaluate the perceived yield risk composition, we used the technique of variation partitioning (function “varpart”, package VEGAN; Oksanen et al., 2019), which can be used when two or more ecological variables may explain the variation of risk as a response variable (Legendre, 2008). Thus, the risk perception of the farmers could vary as a function of ecological risk factors (resource availability, pest infestation, weed pressure, and crop diseases). For more detailed information see Supporting Material Section Statistical analysis.

Results

Descriptive statistics of the change in perceived yield risk

In total, we analyzed 147 surveys to compare the perceived initial yield risk with the change of the perceived yield risk through the implementation of six DF practices. Most of the farmers expected a risk reduction through cover crops (69.5% of farmers) and crop rotation (62.5%) under both climatic scenarios (Table 2). For reduced tillage, 44.70% of farmers expected a decrease in yield risk under drought, but an increased yield risk under wet conditions (56.15%). However, the farmers expected an increased yield risk by the implementation of direct seeding (56%) for both climatic scenarios. For intercropping and flower strips responses varied (Table 2).

Table 2 Amount of perceived change in yield risk by the implementation of DF practices. Frequency (frq) presents the number of farmers perceiving decreased, increased, or no change of yield risk. DF practices are ordered as they were asked within the survey.

		Decreased perceived yield risk		Increased perceived yield risk		No change in perceived yield risk		n*
DF-practice	**Scenario**	**frq**	**%**	**frq**	**%**	**Frq**	**%**	
Intercropping	Drought	50	38.76	35	27.13	44	34.11	129
	Wetness	43	33.08	33	25.38	54	41.54	130
Cover crops	Drought	89	65.93	20	14.81	26	19.26	135
	Wetness	96	72.73	9	6.82	27	20.45	132
Crop rotation	Drought	81	60.90	2	1.50	50	37.59	133
	Wetness	85	63.91	5	3.76	43	32.33	133
Reduced tillage	Drought	59	44.70	54	40.91	19	14.39	132
	Wetness	33	25.38	73	56.15	24	18.46	130
Direct seeding	Drought	47	36.43	69	53.49	13	10.08	129
	Wetness	42	32.56	76	58.91	11	8.53	129
Flower strips	Drought	15	11.11	3	2.22	117	86.67	135
	Wetness	44	32.84	2	1.49	88	65.67	134

*Number of answers differed between scenarios when farmers were unable or unwilling to answer the question about risk change.

Risk perception and change by DF Practices

On average, the risk score (multiplication of the extent of damage with the probability of loss, range 1-100) for an extreme drought was 33 points and 22 points for the risk of extreme wetness, indicating an overall low perceived yield risk of the farmers. Under drought conditions in the early spring season (Figure 2a), farmers expected that cover crops and a diversified crop rotation would reduce risks by overall -8.94 and -10.82 risk score points, respectively. Similarly, under extreme wet conditions in autumn cover crops, a more diverse crop rotation

significantly reduced the perceived risk by 6.88 and 6.21 risk score points. Reduced tillage without using any herbicides were not perceived to change under the climatic scenario of drought. In contrast, under extreme wet conditions around harvesting time, reduced tillage was excepted to statistically significant increase the yield risk (6.46 more risk score points) (Figure 2b). Direct seeding increased the perceived yield risk in both climate scenarios (5.01 risk score points and respectively 8.67 risk score points). For structural elements, no significant effect was found under drought, but yield risk reduction by -2.26 risk score points under above-average precipitation. Intercropping resulted in no significant change under both climatic scenarios.

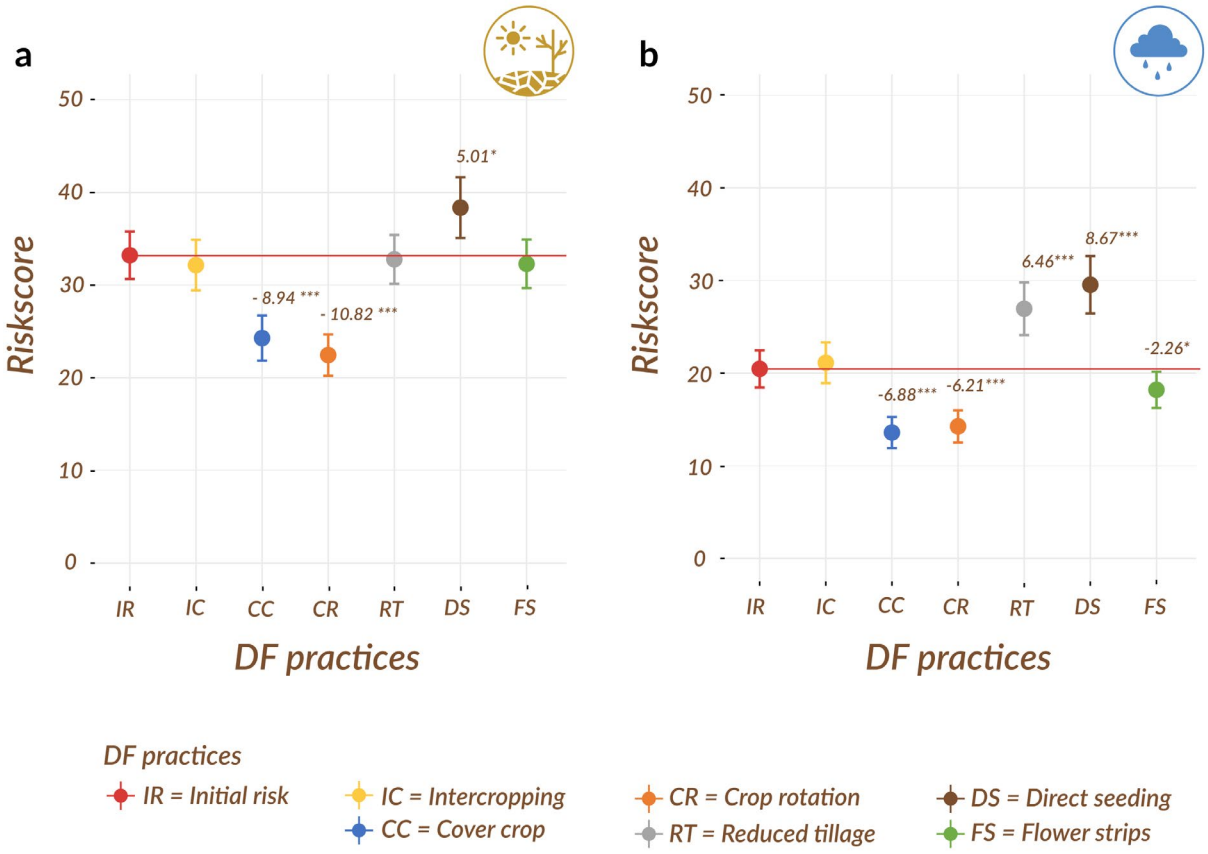

Figure 2 Farmer's perception of risk changes by the implementation of DF practices. Farmer's risk perception was calculated by the risk score (multiplication of the extent of damage with the probability of loss) for a) risk of drought and b) of above-average precipitation. The figure shows the mean of the risk score and the standard error of the mean. The perceived initial risk (control – red line) describes the status quo without the implementation of any DF practices. Estimates with the model specification are provided in Table S2.

Socio-economic influence on the risk change

The multi-model inference approach resulted in three best-fitting models for the perceived risk change under the climatic scenario of drought and four best models for the climatic scenario of above-average precipitation (Table S3). Greatest Akaike weights were found for the main effects of DF practices (Figure S3a) and soil points (Σwi = 1 respectively), followed by the interaction between DF practices and soil points (Σwi = 0.96) and the main effect of farm size (Σwi = 0.71) and implementation rate (Σwi = 0.44) under the climatic scenario of drought (Table 3). For the climatic scenario of above-average precipitation, we found the highest Akaike weights for DF practices (Σwi = 1) (Figure S3b), risk attitude (Σwi = 0.93) and application of the DF practices (Σwi = 0.92), followed by farm size (Σwi = 0.75) and soil points (Σwi = 0.59). We found moderate sums of Akaike weight for the interactions between DF practices and soil points (Σwi = 0.44) under above-average precipitation. But note that direct comparability of the sum of Akaike weight is limited due to the different number of models in which the variable occurs (Table 3). The probability of perceived reduced risk is higher when the DF practices are currently applied on the farm (Figures 3a and b). The farmers perceived a higher risk without DF practices. The effect of soil conditions differed by DF practices. Farmers expected a risk reduction through cover crops and diversified crop rotation, while the degree of risk reduction varied across soil quality. Farmers with high-quality soil expected less risk reduction, whereas farmers with low-quality soil expected higher risk reduction (Figure S4). Reduced tillage and direct seeding were generally expected to increase the risk, independent from soil quality. Farmers with larger farms expected less risk through the implementation of diversification, whereas farmers working on better soil conditions perceived a higher risk brought about through diversification (Figure 3).

For the scenario of wetness (Figure 3g), the risk attitude was important under above-average precipitation. Risk-averse farmers perceived a higher probability of risk reduction and a lower probability of increased risk. Risk-loving farmers were more likely to perceive a high probability of risk reduction and a lower probability of risk increase by diversification.

Table 3 The relative importance of explanatory variables expressed by the sum of Akaike weights (Σwi) for models to explain the effects of DF practices (dfprac), implementation of DF practices (application), farm size (farm_size.s), Holt and Laury-lottery (hll) and the interaction with DF practices on (a) risk change under the scenario drought and (b) risk change under the scenario above-average precipitation. The number of models in which the explanatory variables occur is shown in brackets.

Explanatory variables	**(a) Risk change drought**	**(b) Risk change above-average precipitation**
Dfprac	*1.00 (54)*	*1.00 (54)*
Application	*0.44 (35)*	*0.92 (35)*
farm_size.s	*0.71 (44)*	*0.75 (44)*
soil_points.s	*1 (44)*	*0.59 (44)*
Hll	*0.13 (44)*	*0.93 (44)*
Farm_size.s:dfprac	*0.07 (18)*	*0.02 (18)*
Soil_points.s:dfprac	*0.96 (18)*	*0.44 (18)*
hll:dfprac	*<0.01 (18)*	*<0.01 (18)*

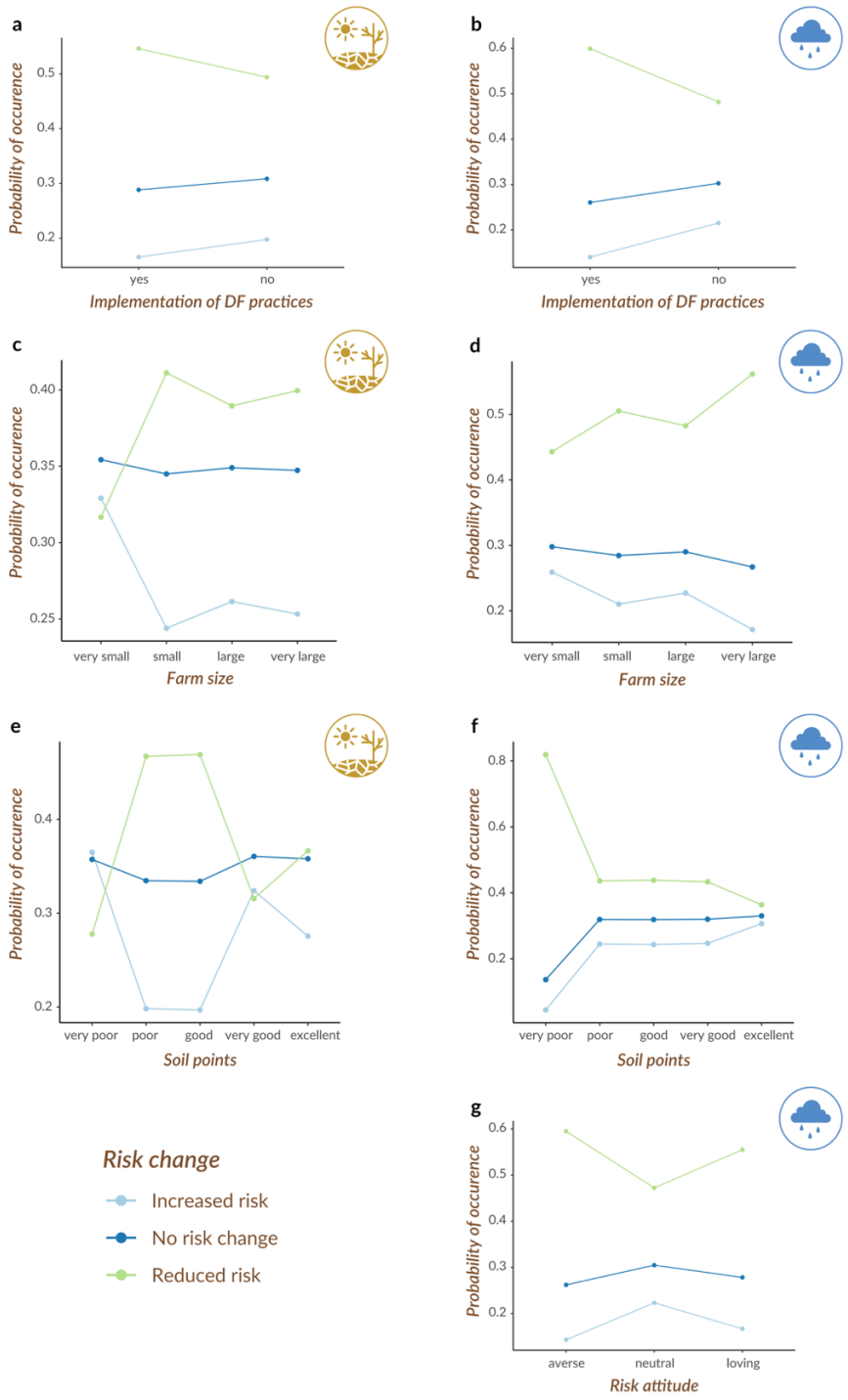

Figure 3 Main effect of application for both climatic scenarios (a & b) on the probability of occurrence of the three risk change categories (IR = increased risk, NRC = no risk change, and RR = reduced risk). The probability of risk reduction is higher if the DF practices are applied on the farm under both scenarios. Effect of farm size (ha) on the probability of occurrence (c & d) of the three risk change categories. Increasing farm size results in a higher probability of occurrence for reduced risk and the probability of higher yield risk decreases with higher farm size under both drought and wet conditions. Effect of soil points on the probability of occurrence (e & f) of the three risk change categories. With higher soil points (better soil conditions) the probability of reduced risk decreases and the probability of increased risk increases. g) Effect of risk attitude (a = risk-averse, n = risk-neutral, l = risk-loving) on the probability of occurrence of the three risk change categories. Overall risk-averse farmers perceived a higher probability of reduced risk through diversification.

Evaluation of ecological risk factors

Partitioning the variation in risk perception among four ecological predictor variables showed that resource availability explained 20% of the variation in risk composition whereas weed pressure explained only 2% of the variation under the climate scenario drought. Crop diseases and pest infestation variables had no explanatory values (Figure S5a). The four variable groups (resource availability, weed pressure, crop diseases, and pest infestation) jointly explained 4% of the variation in risk change under drought. Resource availability and weed pressure jointly explained 8% of the variation in risk change. All other fractions of variation of the ecological risk factors explained less than 4% of the variation in risk change.

Under the climatic scenario of wetness, resource availability explained 22% of the variation in risk change, whereas all other variables explained < 1% of the variation in risk change (Figure S5b). The shared fraction of all four variables explained 5% of the variation in risk change. This means that resource availability was important, whereas all other variables explained a very small shared fraction of the variation on risk change composition. However, a relationship between the ecological risk factors on the risk change was found (Figure S6). Here, other aspects seem to be more relevant for the perception of risk change.

Discussion

This study aimed at a better understanding of the farmer's decision-making towards the adoption of DF practices. Even though ecological and economic benefits (e.g. effects on biodiversity of yield) are well studied, implementation rates for DF practices remain low (Beillouin et al., 2021; Kremen & Miles, 2012; Rosa-Schleich et al., 2019; Tamburini et al., 2020). Our most important finding is that farmers' perception of yield risk can be the main driver of the adoption of DF practices. Under both climate scenarios, the majority of farmers expected a risk reduction through cover crops and a diversified crop rotation, because of higher resource stability (more nutrients and water availability, enhanced soil fertility) and less pressure by weeds, pests, and plant diseases. For reduced tillage and direct seeding, most farmers perceived higher yield risk, due to decreased resource availability, increased pest infestation and weed pressure, and higher pressure by plant diseases (Figure S6). We found a trade-off between enhanced weed pressure and yield loss under reduced and/or no-till. Ramsey et al. (2019) state that farmers with wheat in their crop rotation may expect direct seeding to be a major yield risk. Overall, the trade-offs between the amount of yield and weed pressure impact the perception of risk change of the farmers. However, studies evaluating no-till without the use of herbicides (e.g., in organic agriculture) also state positive effects, for example saving of fuel, costs, or labor (Mäder & Berner, 2012; Zikeli & Gruber, 2017).

The risk perceptions may be also based on the individual personal background and experiences; environmental variables (such as climate), farm characteristics (such as farm size), and risk preference (such as risk attitudes) (Ramsey et al., 2016). The implementation of DF practices, the farm size, the quality of soil conditions, and the general risk attitude of the farmers belonged to the most important influencing variables on the risk perception in our study. We found that experience with implementing DF practices resulted in a perceived risk reduction because farmers know how, when and what crop to use. Our results are in line with other studies, showing that experience with the implementation of DF practices fosters their adoption and that knowledge gaps hinder their adoption (Greiner et al., 2009; Hurley et al., 2022; Ramsey et al., 2019; Wang et al., 2007).

Perceived yield risk by the implementation of DF practices is lower with increasing farm size. Bigger farms with much land to cultivate crops in different ways experienced less risk in adopting DF practices, in comparison to small farms that cannot compensate for potential failures (Hurley et al., 2022). The Common Agricultural Policy, which demands a minimum of three crops for farms larger than 30 hectares, led to a more diverse crop portfolio and higher on-farm diversification (Weigel et al., 2018). We found a correlation between farm size and the amount of DF practices applied, which is in line with the results that larger farms were more diversified in their production portfolio. However, small field sizes and small farms are very important for biodiversity conservation (Tscharntke et al., 2021, Tscharntke et al., 2022) and may need more financial support or higher compensation payment than currently offered by the Common Agricultural Policy.

Farmers with better soil quality expected higher yield risk by the implementation of DF practices. This may have resulted from the fact that farms with higher soil quality already profited from high yields and may fear only the potential yield losses through diversification, and trust that higher soil quality can be a buffer against adverse climatic events such as droughts (Sileshi et al., 2008; Weigel et al., 2018). Thus, farms with low soil quality are in need to reduce their risk through on-farm diversification, which is politically better supported. We found that the perceived interaction between DF practices and soil conditions seemed to be important for the expected yield risk. This is in support of similar studies showing that climate conditions and soil quality have a strong impact on crop choice (Duong et al., 2019; Ullah et al., 2015; Weigel et al., 2018). Positive individual farmers' perceptions of the implementation, particularly concerning soil fertility, and opportunities for on-farm trialing may encourage the implementation of DF practices (Ramsey et al., 2019).

The risk attitude of the farmers was more important under the climatic scenario of above-average precipitation than under droughts, possibly because there is no risk strategy available to mitigate extreme wet conditions at harvesting time. In contrast, droughts may be mitigated with irrigation. Surprisingly, we found no support for a difference in a prior risk attitude between risk-averse and risk-loving farmers. Both groups perceived a low probability for increased yield risk by diversification, and therewith, expected a risk reduction due to higher water use capacity, less water erosion, and higher potential for better water infiltration. There may be different leverage points of risk-averse and risk-loving farmers with the same outcome of potential risk reduction expected. Most literature on the adoption of conservation practices indicates that risk-averse farmers foster a risk reduction only in exchange for expected higher economic return (Sarwosri & Mußhoff, 2020). Findings by Di Falco & Perrings (2005) show that risk aversion may be an important driving force for crop biodiversity conservation. For risk-loving farmers, other factors may possibly explain the perception of yield risk reduction by diversification, that we did not measure within this study.

Conclusion

Our results show that the perceived yield risk depended on the type of DF practice and differs with farm size, soil quality, and risk attitude of the farmers. Although Common Agricultural Policy offers some compensation for small farms, the incentives seem to be insufficient to increase implementation rates of DF practices and to balance the risk small-scale farmers perceived. Our study allows the identification of strategies for incentives to increase the implementation rate of DF practices in Germany by better considering farmers' perceived yield risk and site-specific factors (farm size, soil quality, and risk attitude of the farmers). This finding is relevant because crop diversification practices are a particularly promising option to decrease farmers' yield risk. Furthermore, we show that farmers expected higher potential for increased risk of DF practices on lower soil quality. One strategy to account for less-quality soils is to develop more appropriate diversification schemes according to regional soil conditions including the farmers involved. Higher incentives should be set for conservation soil practices to compensate for the possibly higher yield loss or increased weed pressure. The strong impact of socio-economic background on the risk perception of the farmers shown in this study suggests that respective policies should be adapted to farm characteristics (such as farm size and soil fertility) at the local farm scale. By investigating the risk perception and extent of perceived yield risk change through the implementation of DF practices, we provide a basis for policymakers and scientists to include farmers' perception of risks in future decision-making and research upon the existing knowledge base.

Acknowledgments

We thank all the farmers for their cooperation and participation in this survey.

Supplementary material

Statistical analyses

We analyzed the change of farmers' risk perception by the hypothetical implementation of six DF practices with generalized linear mixed effect models using the glmmTMB package (Brooks et al. 2017) and for the residual diagnostic of hierarchical regression, we use the packages DHARMa (Hartig, 2022). Answers from the same individual share common backgrounds and therefore are not statistically independent. As we worked with a hierarchical data structure, common statistical methods such as linear regression was inappropriate and would have led to a type I error (Musca et al., 2011). Data on the perception of the risk score are strictly positive so we fitted generalized linear mixed models as descript in the article.

Ordered categorial data are common in social sciences because humans are used as measurement instrument. Cumulative linked mixed models are a powerful and flexible model class for categorial ordered data that allows in-depth analyses. To evaluate the effects of socio-economic background on categories of risk change (increased risk, no risk change and reduced risk), we used cumulative linked mixed models for both climate scenarios and farm ID as a random effect (Christensen, 2019).

For the model selection, we followed the multimodel inference approach by Burnham and Anderson (2002). Based on the null model, all candidate models, containing all possible combinations of predictor variables were fitted with the dredge function of the MuMin package (Barton, 2019). The combinations of predictor variables were ordered by second-order Akaike Information Criterion (AICc) and Akaike weights (wi) were used to estimate relative support of a model to have the best fit across all models (Burnham & Anderson, 2002). Variables in the candidate models for the risk change models were restricted to a maximum of ten. The sum of Akaike weights (Σwi) of all predictor variables across all models that include the respective variable were used as measure of the relative importance. We interpreted all models with a delta AICc < 2 compared to the best fitting model and we interpret the effects of all predictor variables with $\Sigma wi > 0.4$.

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Figures

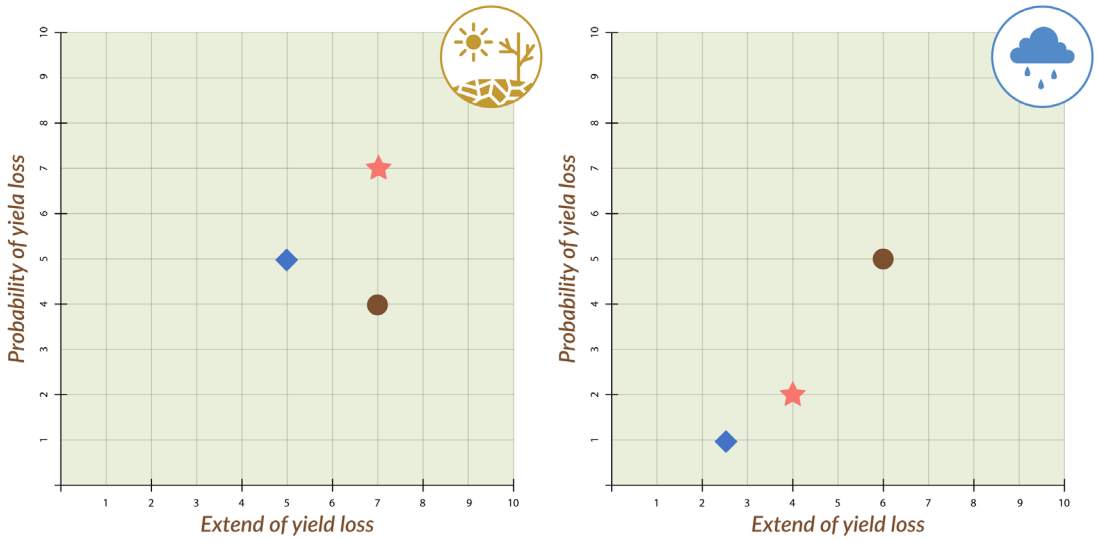

Figure S1 Risk matrix approach. Schematic illustration of the risk matrix approach as used within the survey. Example of the survey procedure, according to both climate scenarios (on the left-side drought and on the right-side above-average precipitation). Indicated with the star is the initial yield risk, hash mark (blue) indicates the change of the initial risk after implementation of a cover crop and brown circle indicates farmer's perception after implementation of direct seeding. This approach was applied for each DF practices trough out the survey.

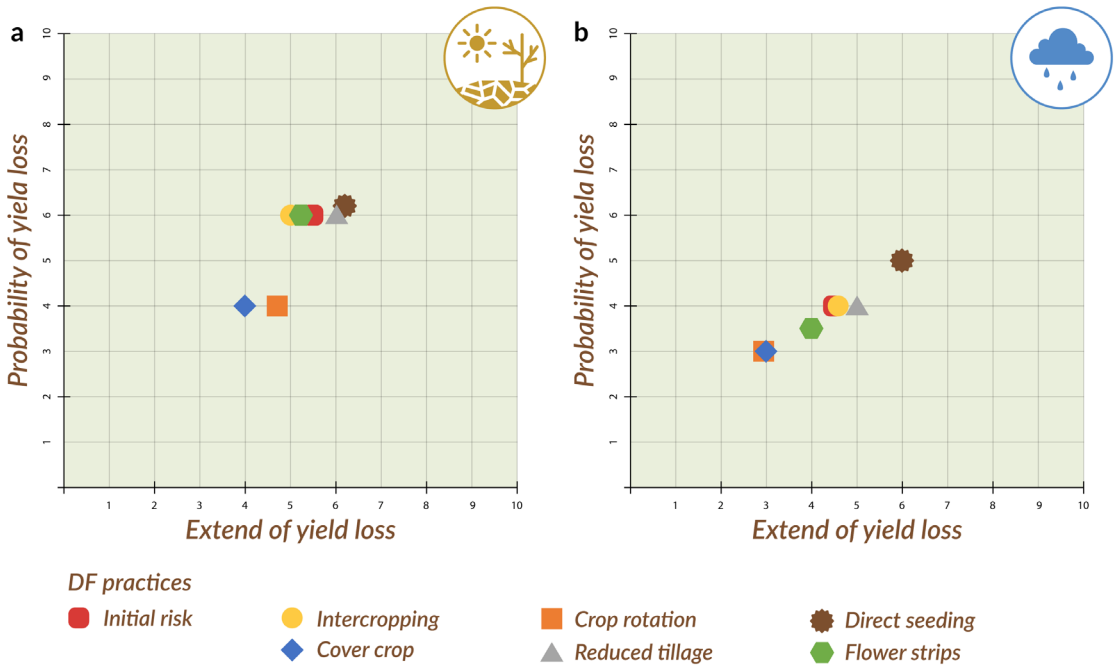

Figure S2 Perceived risk change by DF practices applied. Illustration of the perceived change of the two risk components on the x-axes extend of yield loss and y-axes probability of yield loss is shown for the climate scenario of a) extreme drought conditions in the early summer period & b) above-average precipitation at harvesting time. For all DF practices, median risk change for all farmers is shown with the different icons. For crop rotation and cover crops highest risk reduction was observed, while direct seeding and reduced tillage resulted in higher perceived yield risk. Intercropping and flower strips show

no change of the median risk change under drought conditions, but flower strips result in a slight risk reduction under above-average precipitation.

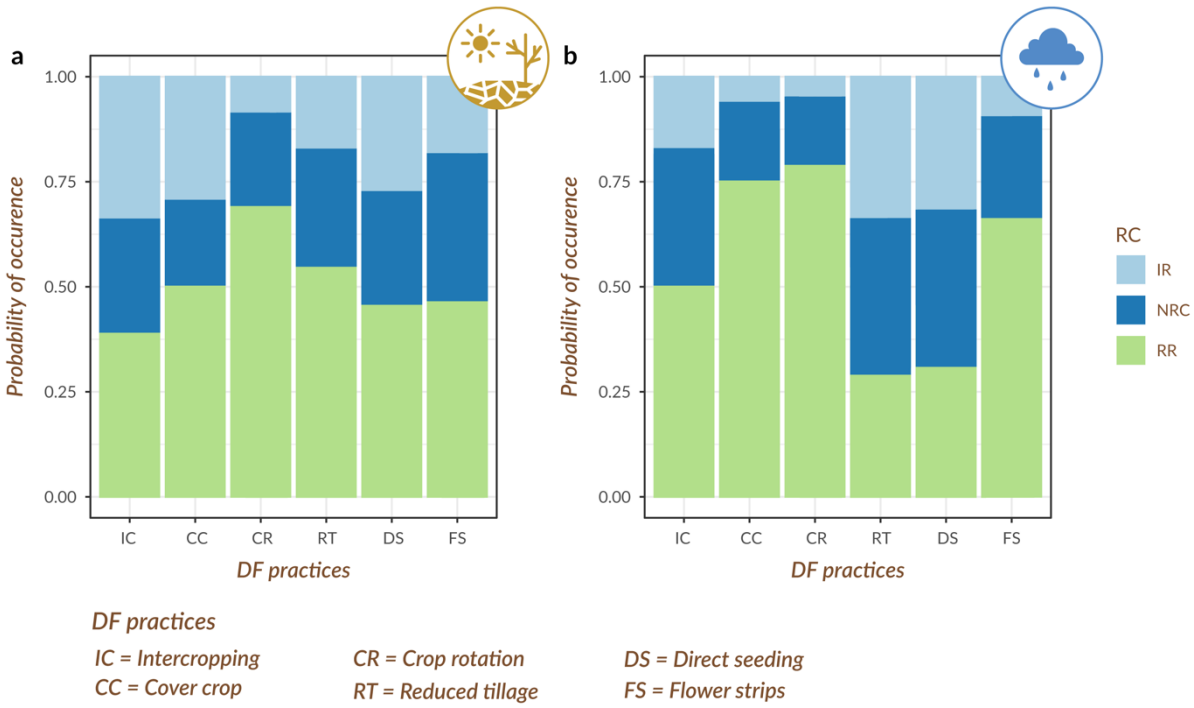

Figure S3 Main effect of DF practices on the probability of occurrence. The three risk change categories (IR = increased risk, NRC = no rick change and RR = reduced risk) for both climate scenarios are shown.

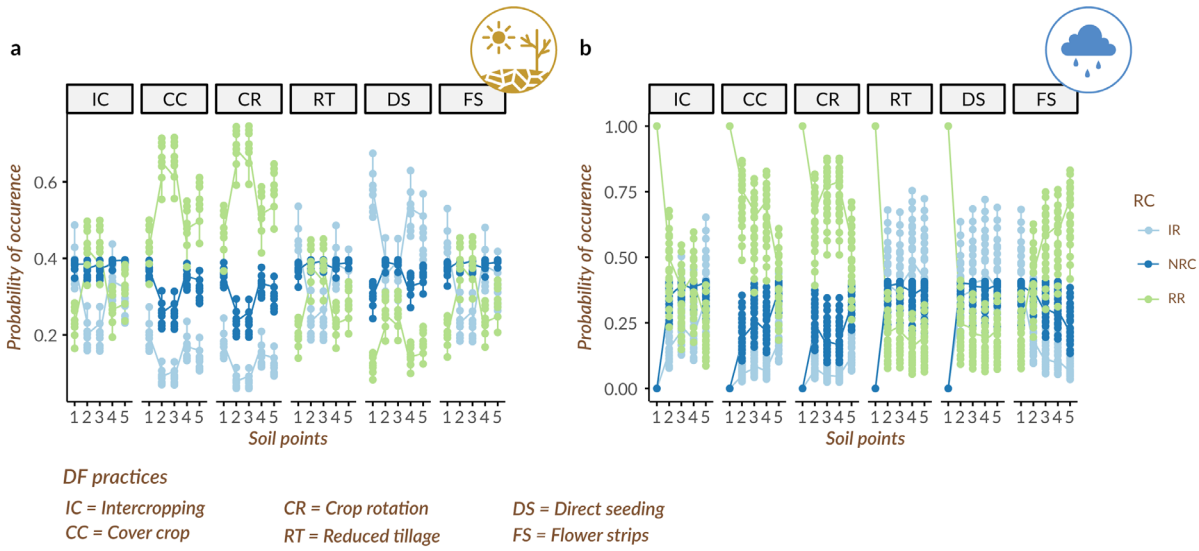

Figure S4 Interaction of soil points and DF practices under both climate scenarios on the three risk change categories (IR = increased risk, NRC = no risk change and RR = reduced risk). The effect of soil fertility differed by DF practices, higher probability of risk reduction was found for cover crops and diversified crop rotation under both climate scenarios, independent from soil fertility, indicating that farmers with high quality soil conditions also expected a high probability of reduced risk. For the DF practices reduced tillage and direct seeding higher probability of increased risk under above-average precipitation is expected by the farmers also independent from soil fertility, whereas under the climate scenario of drought higher degree of variability is detected.

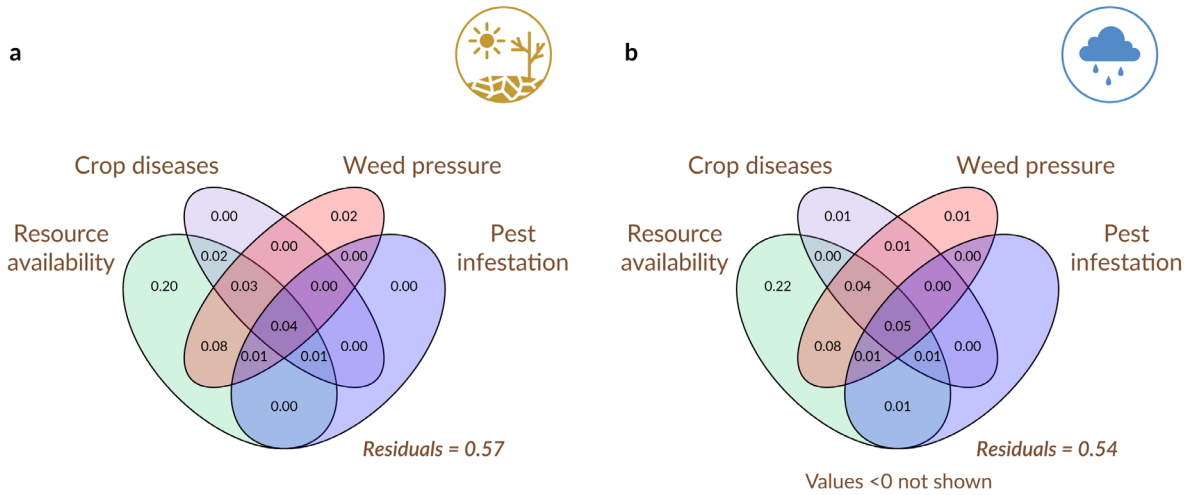

Figure S5 Ven diagram of the variation partitioning in risk perception for both climate scenarios. Most variation is explained by resource availability, whereas the explanatory value of the remaining variance for the ecological risk factors is quite low.

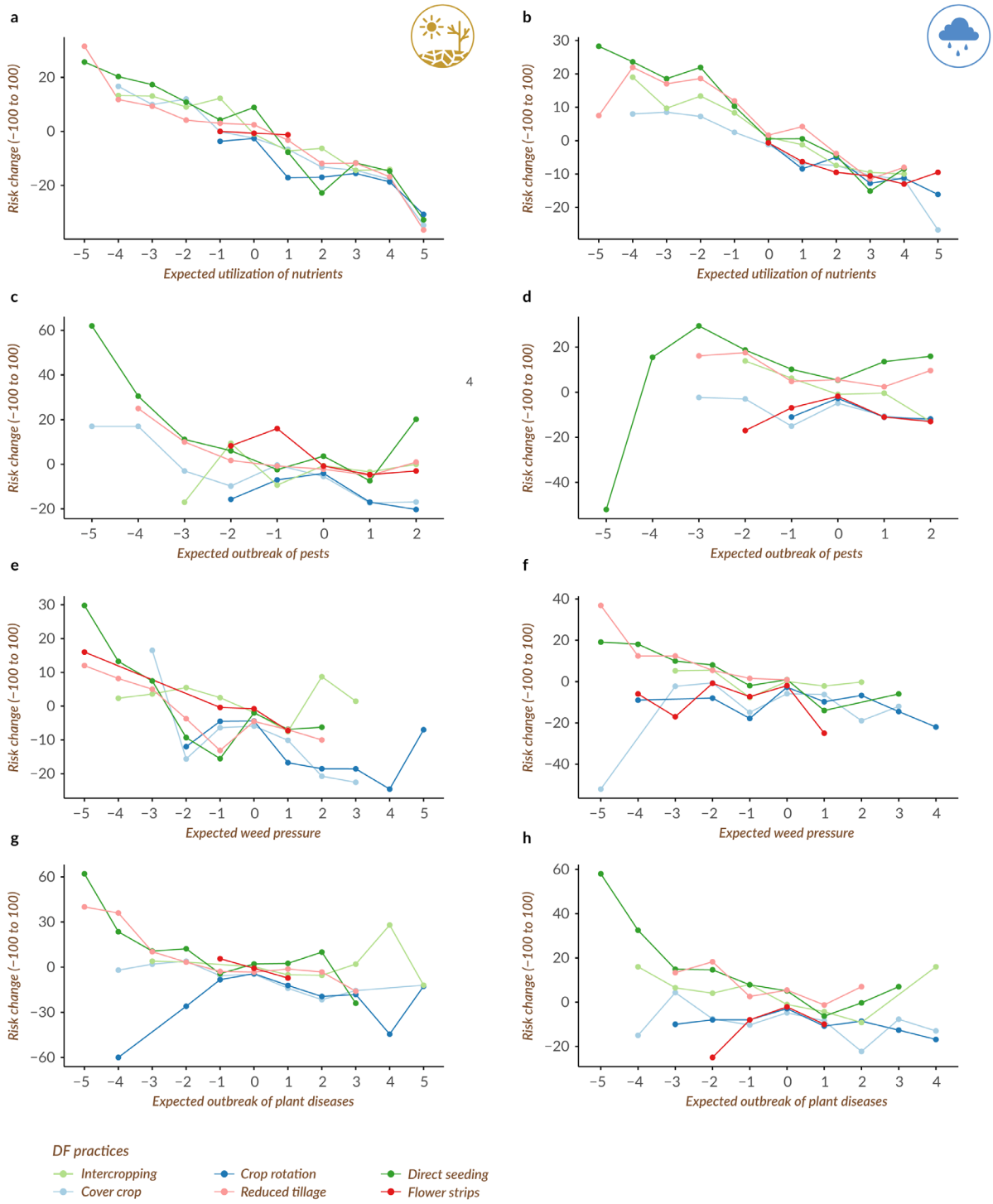

Figure S6 Responses of the participants towards the relationship of ecological risk factors and perceived risk change under both climate scenarios. On the x-axes expected extend of the ecological risk factors measured on Likert scale from -5 to 5, and y-axes expected risk change. Risk change by expected resource availability ranging from - 5 (low utilization of nutrients, water and light expected), 0 (no difference), + 5 (high utilization of nutrients, water & light expected) under a) drought and b) above-average precipitation. We found that with higher resource availability expected by the farmers the risk decreases under both climate scenarios and for all DF practices. Risk change by expected outbreak of pests ranging from - 5 (higher vulnerability against pests), 0 (no difference), + 5 (lower vulnerability against pests) under c) drought and d) above-average precipitation. Under drought climate we found a positive relationship for lower pest pressure and risk reduction, whereas under above-average precipitation no clear effect was found. Risk change by expected weed pressure ranging from - 5 (more

weeds expected), 0 (no difference), + 5 (less weeds expected) under e) drought and f) above-average precipitation. We found that with better weed control expected the risk decreases under both climate scenarios and for all DF practices. Risk change by expected outbreak of crop diseases ranging from - 5 (more plant diseases expected), 0 (no difference), + 5 (less plant diseases expected) under g) drought and h) above-average precipitation. We found that for a diversified crop rotation more plant diseases by lower risk were expected under drought climate, while the other practices can be characterized by less plant diseases along with lower risk for both climate scenarios.

Tables

Table S1 Payment choices for the Holt & Laury-Lottery after (Holt &Laury, 2005; Ewald et al. 2012). Here ten paired lottery choices were used to estimate the crossover point to the high-risk lottery (Course of action B) to infer the degree of risk aversion (Holt & Laury, 2005). Overall, the payoff for the Course of action A (less risky) is less variable than the potential payoffs of Course of action B (riskier). "When the probability of the high-payoff outcome increases enough, a person should cross over to option B. For example, a risk-neutral person would choose A four times before switching to B. Even the most risk-averse person should switch over by decision 10 in the bottom row, since Option B yields a sure payoff of 385 Euro (Holt & Laury, 2002)". Expected payoff differences were not shown to the participating farmers.

Decision situation	Course of action 1 (Option A)	Course of action 2 (Option B)	Expected payoff difference
1	1/10 of 200 €, 9/10 of 160 €	1/10 of 385 €, 9/10 of 10 €	116.5 €
2	2/10 of 200 €, 8/10 of 160 €	2/10 of 385 €, 8/10 of 10 €	83.0 €
3	3/10 of 200 €, 7/10 of 160 €	3/10 of 385 €, 7/10 of 10 €	49.5 €
4	4/10 of 200 €, 6/10 of 160 €	4/10 of 385 €, 6/10 of 10 €	16.0 €
5	5/10 of 200 €, 5/10 of 160 €	5/10 of 385 €, 5/10 of 10 €	-17.5 €
6	6/10 of 200 €, 4/10 of 160 €	6/10 of 385 €, 4/10 of 10 €	-51.0 €
7	7/10 of 200 €, 3/10 of 160 €	7/10 of 385 €, 3/10 of 10 €	-84.5 €
8	8/10 of 200 €, 2/10 of 160 €	8/10 of 385 €, 2/10 of 10 €	-118.0 €
9	9/10 of 200 €, 1/10 of 160 €	9/10 of 385 €, 1/10 of 10 €	-151.5 €
10	10/10 of 200 €, 0/10 of 160 €	10/10 of 385 €, 0/10 of 10 €	-185.0 €

Table S2 Estimates with model specification. Model terms, z values and significance levels (Pr(>z)) for generalized linear mixed-effects models for perceived risk change by implementation of DF practices (Interventions) for both climate scenarios A and B. All models based on glmmTMB with varying family: model for scenario A = family gaussian (sqrt transformation of response variable) and scenario B = family tweedie.

Response variable	Explanatory variable	Z value	Pr(>z)	
Climate scenario A				
Initial risk		47.29		
(Intercept)	Intercropping	-0.68	0.493	
	Cover crop	-6.90	<0.001	***
	Crop rotation	-8.46	<0.001	***
	Reduced tillage	-0.64	0.523	
	Direct seeding	2.33	0.019	*
	Structural elements	-0.78	0.434	
Climate scenario B				
Initial risk		36.87	<0.001	***
(Intercept)	Intercropping	0.46	0.643	
	Cover Crop	-6.89	<0.001	***
	Crop rotation	-6.27	<0.001	***
	Reduced tillage	4.73	<0.001	***
	Direct seeding	6.63	<0.001	***
	Structural elements	-2.23	0.025	*

Table S3 Summary of the best fitting candidate (dAICc<2) and null-models for a) perceived risk change under drought and b) perceived risk change under above-average precipitation. The multi-model inference approach resulted in three best fitting models for the perceived risk change under the climate scenario drought and in four best fitting models for the climate scenario above-average precipitation. Explanatory variables are Dfprac = risk change per DF practices, farm_size.s = standardized size of arable land in hectare (ha), soil_points.s = standardized measurement of soil points (ranging from 7 to 100) as indicator for soil fertility, application = Implementation rate of DF practices on the farm, hhl = Holt & Laury-Value (measurement of risk attitude). Detailed information on explanatory variables can be found in Table 1 main text.

Response variable	Model	DF	AICc	dAICc	Akaike weight (wi)	Explanatory variables
Risk change	mod_A	15	1592.1	0.00	0.30	Dfprac+farm_size.s+soil_points.s+dfprac:soil_points.s+(1|id_lw)
Climate scenario A	mod_A2	16	1592.6	0.49	0.24	Application+Dfprac+farm_size.s+soil_points.s+dfprac:soil_points.s+(1|id_lw)
	mod_A3	14	1593.7	1.62	0.13	Dfprac+ soil_points.s+dfprac:soil_points.s+(1|id_lw)
	rcA0	3	1698.1	106.00	<0.00	1
Risk change	Mod_B	18	1495.7	0		application + dfprac + farm_size.s + hhl + soil_points.s + dfprac:soil_points.s + (1|id_lw)
Climate scenario B	Mod_B2	12	1495.7	0.02		application + dfprac + farm_size.s + hhl + (1|id_lw)
	Mod_B3	17	1497.6	1.93		application + dfprac + soil_points.s + hhl + dfprac:soil_points.s + (1|id_lw)
	Mod_B4	13	1497.6	1.95		application + dfprac + hhl + soil_points.s + farm_size.s + (1|id_lw)
	rB0	3	1693.5	197.86		1

SYNTHESIS

The major challenge for DF systems is to combine economically efficient strategies of agricultural land use with the maintenance or restoration of biodiversity and associated ecosystem services. This thesis contributed to overcome this challenge by investigating the ecological-economic benefits and trade-offs of DF systems. Further, we linked farmers' perceptions on the ecological-economic dimensions of DF systems to highlight what can make DF systems more attractive for farmers.

According to our overarching aim that DF practices results in high ecological benefits and low economic costs, we found that DF practices provide substantially higher biodiversity and ecosystem service than non-diversified farming (**chapter 2**). However, the ecological benefits for the farmer were partly insufficient to outbalance economic costs in the short term. The findings indicate that some DF practices, such as cover crops or diversified crop rotation, are economically efficient and ecologically valuable. We found research gaps considering the economic evaluation of DF practices. Thus, future research needs to consider the economic performance of DF practices to understand and assess the individual cost aspects better (for example, machinery, labor, and input costs). Furthermore, we showed that combining DF practices deliver the highest ecological and economic benefits at the farm level. Thus, political effort and financial instruments should be linked to develop environmental schemes that combine DF practices.

We presented the results from face-to-face surveys designed to assess whether there is a discrepancy between farmers' perception and the actual conditions linked to DF practices. We could confirm that farmers currently expected some obstacles by DF practices implementation. Thus, farmers are often reluctant to implement soil conservation practices because of expected reduced yield, high variable costs or decreased overall gross margin (**chapter 3**) and higher risk (**chapter 4**). The major limitation from farmers' perspective was the restriction of herbicide application. These restrictions do not appear to be practical from the farmers' point of view. Here, more research must investigate environmental-friendly weeding strategies that are less expensive and time-consuming. These finding also show that soil conservation practices, which perform very well from an ecological point of view (**chapter 2**), need financial support for their adoption.

Moreover, we found that diversified crop rotation is expected to perform well from both ecological and economic perspectives (**chapter 4**). Similar practices such as three-fold crop rotation and the use of cover crops are supported by the current agricultural policy, thus farmers may have experienced environmental benefits already (like pest control and disease suppression

etc.). Therefore, farmers can incorporate the knowledge acquired into the evaluation of crop diversification schemes.

Additionally, in both cases studies, soil quality was the major influencing factor on the change profitability (**chapter 3**) and change of risk (**chapter 4**). Across all DF practices, increased soil fertility resulted in higher gross margin, which indicates that for the farmer, the physical characteristics of their farm seem to be more important than the management practices applied. In contrast, high quality soils results in higher risks because it indicates already high earning capacity at stake. Specifically, we found that the variable costs for cover crops and direct seeding were expected to increase in poor soils, whereas rich soils reduce variable costs for direct seeding more than for cover crops. It can be assumed that cover crops and direct seeding on good sites are more favorable and, therefore, more likely to be accepted by farmers. These findings indicate the need for additional financial support for farmers with poor soil conditions.

Furthermore, we evaluated the perception on risk change by implementation of DF practices. We found that the perceived yield risk depended on the type of DF practice and differed with farm size, soil quality and farmers risk attitude. Larger farms and less fertile soils were expected to reduce risks of yield loss. Large farms have more land available for differentiate production methods and thus, the risks are lower than for small farms with few land available. Farmers with poor soils expected DF practices to improve the soil conditions and result in higher yield security and resilience against external disturbances. In conclusion, although Common Agricultural Policy offers some compensation for small farms, the incentives seem to be insufficient to increase implementation rates of DF practices and to balance the risk small-scale farmers perceived.

This thesis highlights the high potential of DF systems to achieve a sustainable agriculture model providing a suitable alternative to intensified land use. A recurring finding is that although DF practices often provide ecological benefits, these may not be sufficient without a simultaneous assessment of the economic costs and the farmers' perception of DF practices. The results from this thesis indicate that subsidies are still a crucial mean to move toward a more sustainable agriculture. This is so, because the ecological and economic benefits of DF practices are not always available in the short term and because farmers perceive specific conventional management tools irreplaceable (e.g., herbicides). Therefore, efficient agricultural policies should not only finance the farmers for their possible loss but should involve them at the development and testing stages of DF practices to win their trust. Trust can be won through stronger agroecologists-farmers cooperation and developing living labs and long-term regional

projects. Such cooperation could facilitate the transfer of the already existing knowledge into practices and minimize the discrepancy between farmers' expectations and scientific evidence, especially in the case of soil conservation practices such as reduced tillage and direct seeding. Farmers are not always aware of the environmental benefits produced through DF practices, or expect that ecological disservices exceed the benefits. Therefore, cooperation with farmers is crucial as much as well-tailored subsidies.

Overall, DF systems can be the foundation of a sustainable agricultural model that support biodiversity and associated ecosystem services, reduce external costs for the society and secure livelihood of farmers. Such a novel agricultural system is urgently required if we want to reach the Sustainable Development Goals for 2030 and guarantee a livable planet for future generations.

SYNTHESE

Diversifizierte landwirtschaftliche Systeme stehen der Herausforderung gegenüber, wirtschaftlich effiziente Strategien landwirtschaftlicher Produktionsverfahren mit der Erhaltung der biologischen Vielfalt und der ihr assoziierten Ökosystemleistungen zu vereinen. Diese Arbeit hat zum Ziel, die ökologisch-ökonomischen Vorteile und Nachteile von diversifizierten landwirtschaftlichen Systemen zu untersuchen. Zusätzlich haben wir die Wahrnehmung der Landwirt*innen bezogen auf die ökologischen und ökonomischen Dimensionen von diversifizierten landwirtschaftlichen Systemen miteinander verknüpft, um aufzuzeigen, wie diversifizierte landwirtschaftliche Systeme attraktiver für die Landwirt*innen gestaltet werden können.

Entsprechend unseres übergeordneten Ziels, dass diversifizierte Anbaumethoden zu einem hohen ökologischen Nutzen und geringen wirtschaftlichen Kosten führen, haben wir festgestellt, dass diversifizierte Anbaumethoden eine wesentlich höhere biologische Vielfalt und Ökosystemleistungen erbringen, verglichen mit nicht-diversifizierten Anbaumethoden (**Kapitel 2**). Der ökologische Nutzen für die Landwirt*innen reichte jedoch teilweise nicht aus, um die wirtschaftlichen Kosten kurzfristig auszugleichen. Die Ergebnisse deuten darauf hin, dass einige der Diversifizierungsmaßnahmen, wie z. B. Zwischenfrüchte oder eine diversifizierte Fruchtfolge, wirtschaftlich effizient und ökologisch wertvoll sind. Weiterhin haben wir Forschungslücken bei der wirtschaftlichen Bewertung von konservierenden Bodenbearbeitungsmethoden festgestellt. Künftige Studien sollten daher vor allem die Wirtschaftlichkeit von konservierenden Bodenbearbeitungsverfahren in den Fokus stellen, um die einzelnen Kostenaspekte (z. B. Maschinen-, Arbeits- und Betriebsmittelkosten) besser verstehen und bewerten zu können. Darüber hinaus haben wir gezeigt, dass die Kombination von diversifizierten Anbaumethoden den höchsten ökologischen und wirtschaftlichen Nutzen für die Betriebe bereitstellt. Daher sollten politische und finanzielle Instrumente die Entwicklung von Umweltprogrammen mit kombinierten diversifizierten Anbaumethoden fokussieren.

Weiterhin haben wir innerhalb der Arbeit die Ergebnisse von persönlichen Umfragen vorgestellt, um festzustellen, ob es eine Diskrepanz zwischen der Wahrnehmung der Landwirt*innen und den tatsächlichen Bedingungen im Zusammenhang mit der Umsetzung von diversifizierten Anbaumethoden gibt. Wir konnten bestätigen, dass die Landwirt*innen derzeit einige Hindernisse bei der Umsetzung der diversifizierten Anbaumethoden erwarten. So zögern die Landwirt*innen häufig, konservierende Bodenbearbeitungsverfahren anzuwenden, weil sie geringere Erträge, hohe variable Kosten oder einen geringeren Deckungsbeitrag

(**Kapitel 3**) und ein höheres Risiko (**Kapitel 4**) erwarten. Die größte Einschränkung für die Landwirt*innen war die Beschränkung des Herbizidmitteleinsatzes. Diese Einschränkungen scheinen aus Sicht der Landwirt*innen nicht praktikabel zu sein. Hier müssen weitere Forschungsarbeiten umweltfreundliche Beikrautbekämpfungsstrategien erforschen, die weniger kostspielig und zeitaufwändig sind. Diese Ergebnisse zeigen auch, dass konservierende Bodenbearbeitungsverfahren, die aus ökologischer Sicht sehr wertvoll sind (**Kapitel 2**), finanzielle Unterstützung für die tatsächliche Umsetzung benötigen.

Darüber hinaus haben wir festgestellt, dass eine diversifizierte Fruchtfolge sowohl aus ökologischer als auch aus ökonomischer Sicht geeignet erscheint (**Kapitel 4**). Ähnliche Maßnahmen, wie eine drei-gliedrige Fruchtfolge und der Zwischenfruchtanbau werden derzeitig agrarpolitisch gefördert, so dass die Landwirt*innen möglicherweise bereits Erfahrungen mit ökologischen Vorteilen gesammelt haben (z. B. biologische Schädlings- und Krankheitsbekämpfung). Daher konnten die Landwirt*innen das bereits erworbene Wissen in die Bewertung der Maßnahmen zur Anbaudiversifizierung einfließen lassen.

Außerdem war in beiden Fallstudien die Bodenqualität der wichtigste Einflussfaktor für die Änderung der Rentabilität (**Kapitel 3**) und die Änderung des Risikos (**Kapitel 4**). Bei allen diversifizierten Anbaumethoden führte eine höhere Bodenfruchtbarkeit zu einem höheren Deckungsbeitrag, was darauf hindeutet, dass für die Landwirt*innen die physischen Betriebsmerkmale wichtiger zu sein scheinen als die angewandten Bewirtschaftungspraktiken. Im Gegensatz dazu, führt eine hohe Bodenqualität zu einem höher angenommenen Risiko, da sie mit einer hohen Ertragsfähigkeit der Böden einhergeht und die Landwirt*innen negative Auswirkungen auf die Bodenqualität durch Einführung diversifizierter Anbaumethoden erwarten. Insbesondere wurde festgestellt, dass die variablen Kosten für Zwischenfrüchte und Direktsaat auf schlechten Böden steigen, während reiche Böden die variablen Kosten für Direktsaat stärker senken als für Zwischenfrüchte. Es kann davon ausgegangen werden, dass Zwischenfrüchte und Direktsaat auf guten Standorten günstiger sind und daher von den Landwirt*innen eher akzeptiert werden. Diese Ergebnisse deuten auf die Notwendigkeit zusätzlicher finanzieller Unterstützung für Landwirt*innen mit schlechten Bodenverhältnissen hin.

Darüber hinaus untersuchten wir, wie sich die Risikowahrnehmung der Landwirte in Abhängigkeit der Anwendung von diversifizierten Anbaumethoden verändert. Es zeigte sich, dass das wahrgenommene Ertragsrisiko von der diversifizierten Anbaumethode abhing und mit der Betriebsgröße, der Bodenqualität und der Risikoeinstellung der Landwirte variierte. Größere Betriebe und weniger fruchtbare Böden führten zu einer Verringerung des erwarteten

Ertragsrisikos. Große Betriebe haben mehr Land für unterschiedliche Produktionsmethoden zur Verfügung, so dass die Risiken geringer eingeschätzt werden als bei kleinen Betrieben mit weniger Fläche. Landwirt*innen, die auf Standorten mit geringerer Bodenqualität wirtschaften, erwarteten, dass diversifizierte Anbaumethoden die Bodenbedingungen verbessern und zu einer höheren Ertragssicherheit und Widerstandsfähigkeit gegenüber externen Störungen führen können. Zusammenfassend lässt sich sagen, dass die Gemeinsame Agrarpolitik zwar einen gewissen Ausgleich für Kleinbetriebe bietet, die Anreize aber offenbar nicht ausreichen, um die Umsetzungsrate von diversifizierten Anbaumethoden zu erhöhen und das von den kleinbäuerlichen Betrieben wahrgenommene Risiko auszugleichen.

In dieser Arbeit wurde das Potenzial der Diversifizierung landwirtschaftlicher Systeme als nachhaltiges Landbewirtschaftungsmodell hervorgehoben, welches eine geeignete Alternative zur intensivierten Landnutzung darstellt. Eine immer wiederkehrende Erkenntnis ist, dass diversifizierte Anbaumethoden zwar offensichtliche ökologische Vorteile bieten, diese aber ohne eine gleichzeitige Bewertung der wirtschaftlichen Kosten und der Wahrnehmung von diversifizierten Anbaumethoden durch die Landwirt*innen möglicherweise nicht ausreichen. Die Ergebnisse dieser Arbeit zeigen, dass Subventionen immer noch ein entscheidendes Mittel sind, um zu einer nachhaltigeren Landwirtschaft beizutragen. Die ökologischen und wirtschaftlichen Vorteile diversifizierter Anbaumethoden sind nicht immer kurzfristig verfügbar und Landwirt*innen sehen bestimmte konventionelle Bewirtschaftungsmethoden (z. B. Herbizideinsatz) als unersetzlich an. Daher sollte eine effiziente Agrarpolitik die Landwirt*innen nicht nur für ihre möglichen Verluste entschädigen, sondern sie auch in die Entwicklung und Erprobung von diversifizierten Anbaumethoden einbeziehen, um ihr Vertrauen zu gewinnen. Dieses Vertrauen kann durch eine stärkere Zusammenarbeit zwischen Agrarökolog*innen und Landwirt*innen, sowie durch die Entwicklung von Living Labs und langfristigen regionalen Projekten gewonnen und gestärkt werden. Eine solche Zusammenarbeit könnte den Transfer des bereits vorhandenen Wissens in die Praxis erleichtern und die Diskrepanz zwischen den Erwartungen der Landwirt*innen und den wissenschaftlichen Erkenntnissen minimieren, insbesondere bei konservierenden Bodenbearbeitungsverfahren, wie reduzierter Bodenbearbeitung und Direktsaat. Die Landwirt*innen sind sich nicht immer des ökologischen Nutzens bewusst, der durch diversifizierte Anbaumethoden entsteht, oder erwarten, dass die ökologischen Nachteile den Nutzen übersteigen. Daher ist die Zusammenarbeit mit den Landwirten ebenso wichtig wie gut abgestimmte Subventionen.

Insgesamt können diversifizierten Anbaumethoden die Grundlage für ein nachhaltiges Agrarmodell bilden, welches die biologische Vielfalt und die damit verbundenen

Ökosystemleistungen fördert, die externen Kosten für die Gesellschaft verringert und den Lebensunterhalt der Landwirt*innen sichert. Die Schaffung eines solchen Agrarökosystems ist dringend erforderlich, wenn wir die Ziele für nachhaltige Entwicklung bis 2030 erreichen wollen und einen lebenswerten Planeten für künftige Generationen garantieren wollen.

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SURVEY

Liebe Teilnehmer(innen),

vielen Dank für die Unterstützung bei dieser Befragung. Im Rahmen meiner Doktorarbeit untersuche ich, inwiefern sich unterschiedliche Bewirtschaftungsmaßnahmen auf das betriebliche Ertragsrisiko auswirken. Eine Option zur Reduzierung von betrieblichen Ertragsrisiken wird darin gesehen, Diversifizierungsmaßnahmen anzuwenden. Unter Diversifizierungsmaßnahmen werden landwirtschaftliche Bewirtschaftungsmaßnahmen verstanden, die die natürlichen Funktionen innerhalb eines Ökosystems fördern und erhalten (z.B. biologische Schädlingskontrolle und Bodenfruchtbarkeit).

In dieser Befragung geht es um Ihre Meinung zu den Auswirkungen unterschiedlicher Bewirtschaftungsmaßnahmen auf klimatisch bedingte Ertragsrisiken (anhaltende Trockenperiode und überdurchschnittliche Niederschlagsmengen). Dabei gibt es keine richtigen oder falschen Antworten. Wir interessieren uns für Ihr individuelle Meinung.

Die Teilnahme an der Befragung umfasst insgesamt fünf Teile: (1) Allgemeine Angaben zum Betrieb (2) Angaben zu unterschiedlichen Bewirtschaftungsmaßnahmen (3) Risiko und Auswirkungen von Diversifizierungsmaßnahmen auf das Risiko (4) Ihre Entscheidungen bei einer Lotterieauswahl (hier besteht die Möglichkeit ein Preisgeld zu gewinnen) sowie (5) Angaben zu Ihrer Person.

Insgesamt wird die Befragung circa 40 Minuten Ihrer Zeit in Anspruch nehmen. Selbstverständlich werden Ihre Angaben vertraulich behandelt und die Daten anonymisiert ausgewertet (siehe Datenschutzvereinbarung & Einwilligung im Anhang).

GEORG-AUGUST-UNIVERSITÄT
GÖTTINGEN

1. ALLGEMEINE ANGABEN ZUM BETRIEB

Codierung:			**Zeit:**
1.1 Bewirtschaftete Fläche insgesamt			ha
Davon:	Ackerland	Grünland	Dauerkulturen
Eigenland	ha	ha	ha
Pachtland	ha	ha	ha
1.2 Welche der folgenden pflanzlichen Produktionsverfahren umfasste Ihr Betrieb in 2017?			
□ Getreide	Davon:		ha
	□ Sommerweizen		ha
	□ Winterweizen		ha
	□ Sommergerste		ha
	□ Wintergerste		ha
	□ Hafer		ha
	□ Roggen		ha
	□ Sonstige:		ha
□ Raps			ha
□ Kartoffeln			ha
□ Zuckerrübe			ha
□ Silomais (Futterbau)			ha
□ Silomais (Biogas)			ha
□ Sonstige:			ha
1.3 Welche der folgenden tierischen Produktionsverfahren umfasste Ihr Betrieb in 2017?			
□ Milchkühe			Stück
□ Weibl. Nachzucht			Stück
□ Bullenmast			Plätze
□ Kälbermast			Plätze
□ Mutterkühe			Stück
□ Sauen			Stück
□ Ferkelaufzucht			Plätze
□ Mastschweine			Plätze
□ Hähnchenmast			Plätze
□ Putenmast			Plätze
□ Legehennen			Plätze
□ Mutterschafe			Stück
□ Sonstige:			

1.4 Welche Rechtsform hat Ihr Betrieb?			
□ EU	□ eG	□ GmbH	□ KG
□ GbR	□ AG	□ GmbH & Co. KG	□ andere:
1.5 Wie hoch war Ihr Weizenertrag (dt/ha) im Jahr 2017?			
Art:	dt/ha	Art:	dt/ha
Art:	dt/ha	Art:	dt/ha
1.6 Wie hoch war der niedrigste Weizenertrag in den letzten 10 Jahren?			
Art:	dt/ha	Art:	dt/ha
Art:	dt/ha	Art:	dt/ha
1.7 Wie hoch war der höchste Weizenertrag in den letzten 10 Jahren?			
Art:	dt/ha	Art:	dt/ha
Art:	dt/ha	Art:	dt/ha

1.8 Was denken Sie, wie sich die Weizenerträge in den nächsten zehn Jahren entwickeln?										
□	□	□	□	□	□	□	□	□	□	□
0	1	2	3	4	5	6	7	8	9	10
Sinken massiv										Steigen massiv

1.9 Was sind die Gründe für Ihre Auswahl? (offene Frage)

2. Welche der folgenden Bewirtschaftungsmaßnahmen wenden Sie an? Bitte geben Sie zusätzlich an, auf wie viel Hektar Sie die Maßnahme durchführen.	
□ Reduzierte Bodenbearbeitung mit Einsatz von Herbiziden	ha
□ Reduzierte Bodenbearbeitung ohne Einsatz von Herbiziden	ha
□ Mischwirtschaft (Ackerbau und Viehzucht)	ha
□ Mehrgliedrige Fruchtfolge (mind. 3 Glieder)	ha
□ Zwischenfruchtanbau mit Einsatz von chemisch-synthetischen Pflanzenschutzmitteln & mineralischem Stickstoffdüngemittel	ha
□ Nutzung als Gründüngung	ha
□ Nutzung als Futter	ha
□ Strukturelemente	ha
□ Einjährige Blühstreifen	ha
□ Hecken	ha
□ Brache	ha
2.1 Welche der folgenden spezifischeren Bewirtschaftungsmaßnahmen wenden Sie an? Bitte geben Sie zusätzlich an, auf wie viel Hektar Sie die Maßnahme durchführen.	
□ Mischkulturen (Weizen/Erbse)	ha
□ Zwischenfruchtanbau als Gründüngung ohne chemischen Pflanzenschutz & mineralischem Dünger (Gemenge: Senf, Ackerbohne & Klee)	ha
□ 5-gliedrige Fruchtfolge (Raps-WW-ZF-Mais-Gerste-ZF (Leguminosen-Mischung) -Raps)	ha
□ minimal wendende konservierende BB (Grubber) ohne Einsatz von Herbiziden	ha
□ Direktsaat ohne Einsatz von Herbiziden	ha
□ Mehrjährige Blühstreifen (Anteil 5% = 0,05 ha)	ha
	ha
2.2 Auf wie viel Hektar führen Sie keine der genannten Maßnahme durch?	
	ha

2.3 Welche Aspekte spiegeln Ihre Meinung zur Umsetzung von DFS-Maßnahmen am ehesten wieder?											
	Stimme gar nicht zu										Stimme absolut zu
(AD, red. BB, SE)	-5	-4	-3	-2	-1	0	1	2	3	4	5
2.3.1 Verlust der Anbaufläche	□	□	□	□	□	□	□	□	□	□	□
2.3.2 Zusätzliche Absatzmärkte	□	□	□	□	□	□	□	□	□	□	□
2.3.3 Erhöhter Arbeitsaufwand	□	□	□	□	□	□	□	□	□	□	□
2.3.4 Erschwerte Bedingungen beim Einsatz von PSM	□	□	□	□	□	□	□	□	□	□	□
2.3.5 Beitrag zu einer höheren Artenvielfalt	□	□	□	□	□	□	□	□	□	□	□
2.3.6 Verringerter Einsatz von PSM notwendig	□	□	□	□	□	□	□	□	□	□	□
2.3.7 Verlust von nützlichen Arten: Schlupfwespe, Marienkäfer, …	□	□	□	□	□	□	□	□	□	□	□
2.3.8 Effiziente Nutzung von Nährstoffen, Wasser und Licht	□	□	□	□	□	□	□	□	□	□	□
2.3.9 Beitrag zur Landschaftsqualität	□	□	□	□	□	□	□	□	□	□	□
2.3.10 Erhöhte Rentabilität	□	□	□	□	□	□	□	□	□	□	□
2.3.11 Gewinnmaximierung	□	□	□	□	□	□	□	□	□	□	□
2.3.12 Geringes Anbaurisiko	□	□	□	□	□	□	□	□	□	□	□
2.3.13 Hohe Verunkrautung	□	□	□	□	□	□	□	□	□	□	□
2.3.14 Bessere Abwehr von potenziellen Schaderregern	□	□	□	□	□	□	□	□	□	□	□
2.3.15 Hohe soziale Akzeptanz Nachbarn/ Gesellschaft	□	□	□	□	□	□	□	□	□	□	□
2.3.16 Finanzielle Anreize über Förderung	□	□	□	□	□	□	□	□	□	□	□
2.4 Beantragen Sie oder haben Sie Fördermittel beantragt? (Fördermittel sind AUM oder Erfüllung der Greening-Voraussetzungen)											
□ Ja											
	Welche:										
□ Nein											
2.5 durchschnittliche Bodenpunkte:											
2.6 Bodeneigenschaften:											

[R] 3.1 Wie hoch war Ihr Weizenertrag _____ dt/ha in 2016? Wie hoch waren die variablen Kosten _____ €/ha der Weizenproduktion?			
Welche Veränderung (%) des Weizenertrags und der variablen Kosten erwarten Sie …			
[R1] 3.1.1 … durch die Einführung einer Mischkultur (Weizen/Erbse)?			
Ertrag	%	Variable Kosten	%
[R1.1] 3.1.1.1 Was sind Ihrer Meinung nach die Gründe für diese Veränderung?			
[R2] 3.1.2 … durch die Einführung einer Zwischenfrucht als Gründüngung (Gemenge: Senf, Ackerbohne & Klee)?			
Ertrag	%	Variable Kosten	%
[R2.1] 3.1.2.1 Was sind Ihrer Meinung nach die Gründe für diese Veränderung?			
[R3] 3.1.3 … durch die Einführung einer 5-gliedrigen Fruchtfolge (Raps-WW-ZF-Mais-Gerste-ZF (Leguminosen-Mischung) -Raps)?			
Ertrag	%	Variable Kosten	%
[R3.1] 3.1.3.1 Was sind Ihrer Meinung nach die Gründe für diese Veränderung?			
[R4] 3.1.4 … durch die Einführung minimal wendender konservierender Bodenbearbeitung (Grubber) ohne Einsatz von Herbiziden?			
Ertrag	%	Variable Kosten	%
[R4.1] 3.1.4.1 Was sind Ihrer Meinung nach die Gründe für diese Veränderung?			
[R5] 3.1.5 … durch die Einführung von Direktsaat ohne Einsatz von Herbiziden?			
Ertrag	%	Variable Kosten	%
[R5.1] 3.1.5.1 Was sind Ihrer Meinung nach die Gründe für diese Veränderung?			
[R6] 3.1.6 … durch die Neuanlage eines mehrjährigen Blühstreifens (Anteil 5% = 0,05 ha)?			
Ertrag	%	Variable Kosten	%
[R6.1] 3.1.6.1 Was sind Ihrer Meinung nach die Gründe für diese Veränderung?			

3.2 War Ihr Unternehmen in der Vergangenheit von den folgenden Risiken betroffen? Wenn ja, war die jeweilige Situation existenzgefährdend?				
Mögliche Risiken, die zu Ertragseinbußen bzw. Rentabilitätsverlusten im Weizenanbau führen können:				
	Betroffen		Existenzgefahr	
	Nein	Ja	Nein	Ja
A Extremereignisse Trockenheit	☐	☐	☐	☐
B Extremereignisse überdurchschnittliche Niederschläge	☐	☐	☐	☐

Bitte bewerten Sie die Schadenswahrscheinlichkeit und die Schadenshöhe der nachfolgenden landwirtschaftlichen Risiken für Ihren Betrieb. Beispiel: Sie halten eine Zunahme von klimatischen Extremereignissen für sehr wahrscheinlich, glauben jedoch, dass dieses Risiko den Ertrag und damit den wirtschaftlichen Erfolg ihres Unternehmens nur schwach beeinflussen wird. Geben Sie bitte eine Schadenswahrscheinlichkeit = 8 und Schadenshöhe = 2 an.

3.3 Risikomatrix A – klimatisches Extremereignis (Dürre oder Trockenheit)

A Was erwarten Sie, wie hoch ist die Wahrscheinlichkeit dafür, dass durch eine extreme Trockenperiode ein Ertragsrückgang auftritt und wie hoch schätzen Sie den daraus resultierenden Schaden (Reduzierung des Weizenertrags) ein? (Matrix Skala 1-10)										
A1 Welche Veränderung dieses Ausgangsrisikos erwarten Sie durch die Einführung einer Mischkultur (Weizen/Erbse)?										
Geben Sie bitte an, welcher der folgenden Aspekte diese Veränderung am ehesten begründet: (-5 stimme absolut nicht zu, 5 stimme voll und ganz zu)										
A1.1 Verringert den zusätzlichen Ausbruch von Pflanzenkrankheiten (schlechter Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A1.2 Nutzung von Nährstoffen, Wasser und Licht ist ausgewogener (verbesserte Widerstandsfähigkeit)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A1.3 Bodenstruktur und -fruchtbarkeit wird verbessert (Anfälligkeit gegenüber externen Störungen wird reduziert)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A1.4 Verringerung von Verunkrautung (verbesserte Unkrautkontrolle)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A1.5 Höhere Anfälligkeit gegenüber Schädlingen (bessere Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sonstige: (offene Nennung)										

A2 Welche Veränderung des Ausgangsrisikos erwarten Sie durch die Einführung einer Zwischenfrucht als Gründüngung (Gemenge: Senf, Ackerbohne & Klee)?										
Geben Sie bitte an, welcher der folgenden Aspekte diese Veränderung am ehesten begründet: (-5 stimme absolut nicht zu, 5 stimme voll und ganz zu)										
A2.1 Verringerung von Verunkrautung (verbesserte Unkrautkontrolle)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A2.2 Bodenstruktur und -fruchtbarkeit wird verbessert (Anfälligkeit gegenüber externen Störungen wird reduziert)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A2.3 Höhere Anfälligkeit gegenüber Schädlingen (bessere Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A2.4 Verringert den zusätzlichen Ausbruch von Pflanzenkrankheiten (schlechter Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A2.5 Nutzung von Nährstoffen, Wasser und Licht ist ausgewogener (verbesserte Widerstandsfähigkeit)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sonstige: (offene Nennung)										
A3 Welche Veränderung des Ausgangsrisikos erwarten Sie durch die Einführung einer 5-gliedrigen Fruchtfolge (Raps-WW-ZF-Mais-Gerste-ZF (Leguminosen-Mischung) -Raps)?										
Geben Sie bitte an, welcher der folgenden Aspekte diese Veränderung am ehesten begründet: (-5 stimme absolut nicht zu, 5 stimme voll und ganz zu)										
A3.1 Höhere Anfälligkeit gegenüber Schädlingen (bessere Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A3.2 Bodenstruktur und -fruchtbarkeit wird verbessert (Anfälligkeit gegenüber externen Störungen wird reduziert)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A3.3 Verringerung von Verunkrautung (verbesserte Unkrautkontrolle)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A3.4 Nutzung von Nährstoffen, Wasser und Licht ist ausgewogener (verbesserte Widerstandsfähigkeit)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

A3.5 Verringert den zusätzlichen Ausbruch von Pflanzenkrankheiten (schlechter Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sonstige: (offene Nennung)										
A4 Welche Veränderung des Ausgangsrisikos erwarten Sie durch die Einführung minimal wendender konservierender Bodenbearbeitung (Grubber) ohne Einsatz von Herbiziden?										
Geben Sie bitte an, welcher der folgenden Aspekte diese Veränderung am ehesten begründet: (-5 stimme absolut nicht zu, 5 stimme voll und ganz zu)										
A4.1 Bodenstruktur und -fruchtbarkeit wird verbessert (Anfälligkeit gegenüber externen Störungen wird reduziert)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A4.2 Nutzung von Nährstoffen, Wasser und Licht ist ausgewogener (verbesserte Widerstandsfähigkeit)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A4.3 Verringert den zusätzlichen Ausbruch von Pflanzenkrankheiten (schlechter Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A4.4 Höhere Anfälligkeit gegenüber Schädlingen (bessere Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A4.5 Verringerung von Verunkrautung (verbesserte Unkrautkontrolle)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sonstige: (offene Nennung)										
A5 Welche Veränderung des Ausgangsrisikos erwarten Sie durch die Einführung von Direktsaat ohne Herbizide?										
Geben Sie bitte an, welcher der folgenden Aspekte diese Veränderung am ehesten begründet: (-5 stimme absolut nicht zu, 5 stimme voll und ganz zu)										
A5.1 Verringert den zusätzlichen Ausbruch von Pflanzenkrankheiten (schlechter Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A5.2 Nutzung von Nährstoffen, Wasser und Licht ist ausgewogener (verbesserte Widerstandsfähigkeit)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A5.3 Bodenstruktur und -fruchtbarkeit wird verbessert (Anfälligkeit gegenüber externen Störungen wird reduziert)										

-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A5.4 Verringerung von Verunkrautung (verbesserte Unkrautkontrolle)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A5.5 Höhere Anfälligkeit gegenüber Schädlingen (bessere Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sonstige: (offene Nennung)										
A6 Welche Veränderung des Ausgangsrisikos erwarten Sie durch die Neuanlage eines mehrjährigen Blühstreifens (Anteil 5% = 0,05 ha)?										
Geben Sie bitte an, welcher der folgenden Aspekte diese Veränderung am ehesten begründet: (-5 stimme absolut nicht zu, 5 stimme voll und ganz zu)										
A6.1 Höhere Anfälligkeit gegenüber Schädlingen (bessere Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A6.2 Verringerung von Verunkrautung (verbesserte Unkrautkontrolle)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A6.3 Bodenstruktur und -fruchtbarkeit wird verbessert (Anfälligkeit gegenüber externen Störungen wird reduziert)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A6.4 Verringert den zusätzlichen Ausbruch von Pflanzenkrankheiten (schlechter Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
A6.5 Nutzung von Nährstoffen, Wasser und Licht ist ausgewogener (verbesserte Widerstandsfähigkeit)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sonstige: (offene Nennung)										

3.4 Risikomatrix B - klimatisches Extremereignis (überdurchschnittlicher Niederschlag)

B Was erwarten Sie, wie hoch ist die Wahrscheinlichkeit dafür, dass durch extreme Feuchtigkeit (überdurchschnittliche Niederschläge) ein Ertragsrückgang auftritt und wie hoch schätzen Sie den daraus resultierenden Schaden (Reduzierung des Weizenertrags) ein?										
B1 Welche Veränderung dieses Ausgangsrisikos erwarten Sie durch die Einführung einer Mischkultur (Weizen/Erbse)?										
Geben Sie bitte an, welcher der folgenden Aspekte diese Veränderung am ehesten begründet: (-5 stimme absolut nicht zu, 5 stimme voll und ganz zu)										
B1.1 Nutzung von Nährstoffen, Wasser und Licht ist ausgewogener (verbesserte Widerstandsfähigkeit)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B1.2 Bodenstruktur und -fruchtbarkeit wird verbessert (Anfälligkeit gegenüber externen Störungen wird reduziert)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B1.3 Höhere Anfälligkeit gegenüber Schädlingen (bessere Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B1.4 Verringert den zusätzlichen Ausbruch von Pflanzenkrankheiten (schlechter Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B1.5 Verringerung von Verunkrautung (verbesserte Unkrautkontrolle)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sonstige: (offene Nennung)										
B2 Welche Veränderung des Ausgangsrisikos erwarten Sie durch die Einführung einer Zwischenfrucht als Gründüngung (Gemenge: Senf, Ackerbohne & Klee)?										
Geben Sie bitte an, welcher der folgenden Aspekte diese Veränderung am ehesten begründet: (-5 stimme absolut nicht zu, 5 stimme voll und ganz zu)										
B2.1 Höhere Anfälligkeit gegenüber Schädlingen (bessere Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B2.2 Verringerung von Verunkrautung (verbesserte Unkrautkontrolle)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B2.3 Verringert den zusätzlichen Ausbruch von Pflanzenkrankheiten (schlechter Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

B2.4 Bodenstruktur und -fruchtbarkeit wird verbessert (Anfälligkeit gegenüber externen Störungen wird reduziert)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B2.5 Nutzung von Nährstoffen, Wasser und Licht ist ausgewogener (verbesserte Widerstandsfähigkeit)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sonstige: (offene Nennung)										
B3 Welche Veränderung des Ausgangsrisikos erwarten Sie durch die Einführung einer 5-gliedrigen Fruchtfolge (Raps-WW-ZF-Mais-Gerste-ZF (Leguminosen-Mischung) -Raps)?										
Geben Sie bitte an, welcher der folgenden Aspekte diese Veränderung am ehesten begründet: (-5 stimme absolut nicht zu, 5 stimme voll und ganz zu)										
B3.1 Verringert den zusätzlichen Ausbruch von Pflanzenkrankheiten (schlechter Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B3.2 Nutzung von Nährstoffen, Wasser und Licht ist ausgewogener (verbesserte Widerstandsfähigkeit)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B3.3 Höhere Anfälligkeit gegenüber Schädlingen (bessere Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B3.4 Verringerung von Verunkrautung (verbesserte Unkrautkontrolle)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B3.5 Bodenstruktur und -fruchtbarkeit wird verbessert (Anfälligkeit gegenüber externen Störungen wird reduziert)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sonstige: (offene Nennung)										
B4 Welche Veränderung des Ausgangsrisikos erwarten Sie durch die Einführung minimal wendender konservierender Bodenbearbeitung (Grubber) ohne Einsatz von Herbiziden?										
Geben Sie bitte an, welcher der folgenden Aspekte diese Veränderung am ehesten begründet: (-5 stimme absolut nicht zu, 5 stimme voll und ganz zu)										
B4.1 Verringerung von Verunkrautung (verbesserte Unkrautkontrolle)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B4.2 Bodenstruktur und -fruchtbarkeit wird verbessert (Anfälligkeit gegenüber externen Störungen wird reduziert)										

-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B4.3 Nutzung von Nährstoffen, Wasser und Licht ist ausgewogener (verbesserte Widerstandsfähigkeit)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B4.4 Verringert den zusätzlichen Ausbruch von Pflanzenkrankheiten (schlechter Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B4.5 Höhere Anfälligkeit gegenüber Schädlingen (bessere Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sonstige: (offene Nennung)										
B5 Welche Veränderung des Ausgangsrisikos erwarten Sie durch die Einführung von Direktsaat ohne Herbizide?										
Geben Sie bitte an, welcher der folgenden Aspekte diese Veränderung am ehesten begründet: (-5 stimme absolut nicht zu, 5 stimme voll und ganz zu)										
B5.1 Verringerung von Verunkrautung (verbesserte Unkrautkontrolle)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B5.2 Verringert den zusätzlichen Ausbruch von Pflanzenkrankheiten (schlechter Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B5.3 Bodenstruktur und -fruchtbarkeit wird verbessert (Anfälligkeit gegenüber externen Störungen wird reduziert)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B5.4 Höhere Anfälligkeit gegenüber Schädlingen (bessere Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B5.5 Nutzung von Nährstoffen, Wasser und Licht ist ausgewogener (verbesserte Widerstandsfähigkeit)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sonstige: (offene Nennung)										
B6 Welche Veränderung des Ausgangsrisikos erwarten Sie durch die Neuanlage eines mehrjährigen Blühstreifens (Anteil 5% = 0,05 ha)?										
Geben Sie bitte an, welcher der folgenden Aspekte diese Veränderung am ehesten begründet: (-5 stimme absolut nicht zu, 5 stimme voll und ganz zu)										
B6.1 Höhere Anfälligkeit gegenüber Schädlingen (bessere Entwicklungsbedingungen)										

-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B6.2 Bodenstruktur und -fruchtbarkeit wird verbessert (Anfälligkeit gegenüber externen Störungen wird reduziert)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B6.3 Verringerung von Verunkrautung (verbesserte Unkrautkontrolle)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B6.4 Nutzung von Nährstoffen, Wasser und Licht ist ausgewogener (verbesserte Widerstandsfähigkeit)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
B6.5 Verringert den zusätzlichen Ausbruch von Pflanzenkrankheiten (schlechter Entwicklungsbedingungen)										
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sonstige: (offene Nennung)										

3.5 Welche Risikomanagementstrategien nutzen Sie in Ihrem Unternehmen**?**
☐
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☐

4.1 Wie schätzen Sie ihre persönliche Einstellung gegenüber Risiken ein?

Vermeide Risiken konsequent								Gehe sehr gern Risiken ein		
0	1	2	3	4	5	6	7	8	9	10
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

4.2 Risikobereitschaft - Instruktionen entsprechend Holt und Laury, 2002

In der folgenden Lotterie werden drei Teilnehmer zufällig ausgewählt, die eine Geldprämie erhalten. Hier hängt die Höhe von Ihren eigenen Entscheidungen und dem Zufall ab. Ich biete Ihnen zehn Wahlmöglichkeiten zwischen zwei Lotterien an: Lotterie A und Lotterie B. Sie können mit bestimmten Wahrscheinlichkeiten in Lotterie A 200 € oder 160 € und in Lotterie B 385 € oder 10 € gewinnen. Die Wahrscheinlichkeiten werden systematisch variiert, so dass sich zehn verschiedene Ausgangssituationen ergeben. Bitte entscheiden Sie sich in jeder vorgestellten Wahlmöglichkeit für jeweils eine der Lotterien.

Beispiel Wahlmöglichkeit vier. Sie müssen sich zwischen der Lotterie A, in der Sie 200 € mit 40%iger bzw. 160 € mit 60%iger Wahrscheinlichkeit gewinnen können, und Lotterie B, in der Sie 385 € mit 40%iger bzw. 10 € mit 60%iger Wahrscheinlichkeit gewinnen können, entscheiden.

Ihre Geldprämie kommt wie folgt zustande: Ein zehnseitiger Würfel bestimmt: 1. Wurf: ...welches der zehn Lotteriepaare für Ihre Geldprämie letztlich ausschlaggebend sein wird. Wird z. B. die Augenzahl 4 gewürfelt, so ist das vierte Lotteriepaar entscheidend. 2. Wurf: ...welcher Geldbetrag aus der entscheidenden Lotterie für Ihre Geldprämie zählt. Wenn Sie sich beispielsweise beim vierten Lotteriepaar für Option A (40 %: 200 €; 60 %: 160 €) entschieden haben und die Augenzahl des Würfels zwischen 1 und 4 liegt, gewinnen Sie 200 €. Ist die Augenzahl größer als vier, erhalten Sie 160 €. Bitte denken Sie gut über Ihre Entscheidungen nach, da jedes Lotteriepaar und jeder Betrag für Ihre Geldprämie ausgelost werden könnten. Nun möchten wir Sie bitten, sich in jeder der folgenden zehn Zeilen für jeweils eine der zwei Lotterien A oder B zu entscheiden. Am Ende des Spieles wird zufällig eine der zehn Entscheidungen als auszahlungsrelevant ausgewählt.

Lotterie siehe Riskiomatrix (s.u.)

5. SOZIODEMOGRAFISCHE ANGABEN

5.1 Geburtsjahr:			□ keine Angabe
5.2 Geschlecht:	□ Männlich	□ Weiblich	□ Sonstige
5.3 Kinder:	□ Ja Anzahl:	□ Nein	
5.4 Stellung im Betrieb:	□ Betriebsleiter(in)/Geschäftsführer(in)		
	□ Hofnachfolger(in)		
	□ Verwalter(in)		
	□ Leiter(in) eines Betriebszweiges		
	□ andere		
5.5 Höchster Bildungsabschluss:	□ abgeschlossene Ausbildung/ Lehre (Landwirtschaft)		
	□ Staatlich geprüfter Landwirt(in) (einjährige Fachschule)		
	□ Landwirtschaftsmeister(in)		
	□ Agrarbetriebswirt (zweijährige Fachschule)		
	□ Landwirtschaftliches Studium		
	□ andere		
Endzeit:			

ZUSICHERUNG DES DATENSCHUTZES

Am _____ findet in _____ im Rahmen der Doktorarbeit:

„Auswirkungen von Diversifizierungsmaßnahmen auf landwirtschaftliche Risiken“ von Julia Rosa eine Datenaufnahme mit Fragebogen und Audiogerät durch die genannte Person statt.

Die Datenerhebung erfolgt unter Wahrung der Vertraulichkeit und Zusicherung der Geheimhaltung der Daten, der Anonymität für alle Beteiligten sowie unter Zusicherung ihrer anonymen Auswertung; diese erfolgt allein für wissenschaftliche Zwecke. Die Erhebung und die Verwendung der Daten entsprechen den Regelungen des Niedersächsischen Datenschutzgesetzes (NDSG)1.

Die Erhebung erfolgt anonym, das heißt, alle Personendaten werden von Julia Rosa anonym festgehalten, so dass sie keine Rückschlüsse auf die Identität der Personen zulassen. Es wird keine Liste mit den authentischen Personendaten und deren Codierung angefertigt, sodass keine Rückverfolgung möglich ist. Die Analyse erfolgt ausschließlich an den vollständig anonymisierten Daten; die Originaldaten werden nur den unmittelbar mit dem Projekt betrauten Personen zugänglich sein. Alle mit dem Projekt betrauten Personen sichern die Geheimhaltung und vertrauliche Behandlung der Daten mit ihren Unterschriften zu (Unterschriften s. umseitig).

Das Projekt wird interdisziplinär am Department für Nutzpflanzenwissenschaften und am Department für Agrarökonomie und Rurale Entwicklung der Georg-August-Universität Göttingen durchgeführt. Über die Ergebnisse informiert Sie Julia Rosa anschließend gerne.

PROJEKTBESCHREIBUNG

Im Rahmen dieser Doktorarbeit untersucht Julia Rosa, inwiefern sich unterschiedliche Bewirtschaftungsmaßnahmen auf das betriebliche Ertragsrisiko auswirken. Landwirtschaftliche Erträge können nicht exakt vorhergesagt werden, da sie von unterschiedlichen Risikoquellen abhängen. Ursachen für Ertragsrisiken (Ertragseinbußen, Qualitätseinschränkungen oder Ernteerschwernisse) sind z.B. erhöhter Schädlings- und Unkrautdruck, Pilzerkrankungen, Wetterextreme, unzureichende Bestäubung und Degradierung von Böden. Eine Option zur Reduzierung von betrieblichen Ertragsrisiken wird darin gesehen, Diversifizierungsmaßnahmen anzuwenden. Unter Diversifizierungsmaßnahmen werden landwirtschaftliche Bewirtschaftungsmaßnahmen verstanden, die die natürlichen Funktionen innerhalb eines Ökosystems fördern und erhalten (z.B. Bestäubung, biologische Schädlingskontrolle und Bodenfruchtbarkeit). Die Auswirkungen von Diversifizierungsmaßnahmen auf das Ertragsrisiko sind nur unzureichend untersucht. Im Rahmen dieser Befragung wird der Einfluss unterschiedlicher Diversifizierungsmaßnahmen auf das betriebliche Ertragsrisiko analysiert.

ZUSICHERUNG DES DATENSCHUTZES UND DER ANONYMISIERUNG DER DATEN DURCH DIE MIT DEM PROJEKT BETRAUTEN PERSONEN:

Die unten genannte durchführende Person sichert Ihnen zu,

o dass Ihre persönlichen Daten nicht an Dritte weitergegeben werden;

o dass Ihre persönlichen Daten vertraulich behandelt werden;

o dass Ihre persönlichen Daten nur in anonymisierter Form für die Untersuchung verwendet werden; es ist nicht möglich, von Ihren anonymisierten Aussagen auf Ihre Person zu schließen;

o dass Ihre persönlichen Daten so aufbewahrt werden, dass Unbefugte sie nicht einsehen können;

o dass ohne Ihr Einverständnis für die weitere Verwendung der gesammelten Daten (Fragebogen/Audioaufnahmen), diese nach Abschluss des Projekts nicht weiter verwendet werden.

Ort und Datum:

(Julia Rosa)

Unterschrift: ----------

EINVERSTÄNDNISERKLÄRUNG

Mit meiner Unterschrift bestätige ich, dass ich mit der Erhebung und Verwendung der von mir erhobenen Gesprächsdaten/Interviewdaten im Projekt „Auswirkungen von Diversifizierungsmaßnahmen auf landwirtschaftliche Risiken“ einverstanden bin.

Ich wurde darauf hingewiesen, dass die Erhebung und die Verwendung meiner Daten dem Niedersächsischen Datenschutzgesetzes (NDSG) entsprechen. Alle Personendaten werden von Julia Rosa codiert, so dass sie nicht nach einzelnen Personen erschlossen werden können.

o Ich erkläre hiermit, dass ich über den Inhalt und Zweck des Projekts informiert worden bin und bin einverstanden, am Projekt teilzunehmen.

o Ich bin damit einverstanden, dass Gespräche mit mir bzw. von denen ich Teil bin, mit Aufnahmegerät (Audio) aufgezeichnet werden.

o Ich bin damit einverstanden, dass meine Aussagen im Rahmen des Projekts, seiner Dokumentation und in den Veröffentlichungen (ggf. Ausstellung und nachfolgende Publikationen) in anonymisierter Form verwendet werden.

Ort und Datum:

Unterschrift:

Vor- und Nachname:

Adresse

bzw. E-Mail-Adresse

(für Rückmeldungen, falls gewünscht)

Risikomatrix A – klimatisches Extremereignis (Trockenheit)

Legende:

A Status Quo (Ausgangsrisiko)

A1 Mischkultur (Weizen/Erbse)

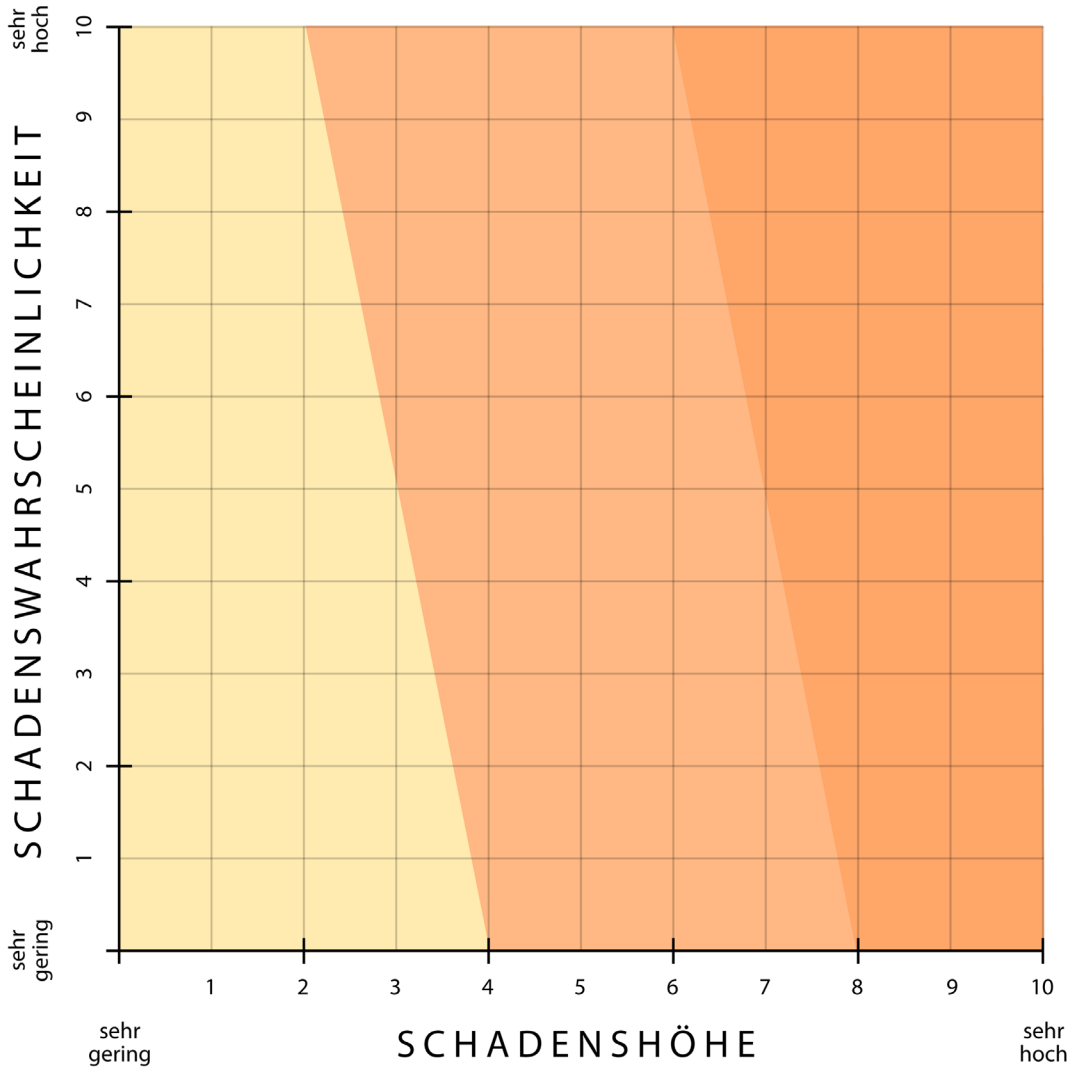
A2 Zwischenfrucht als Gründüngung (Gemenge: Senf, Ackerbohne & Klee)

A3 5-gliedrige Fruchtfolge (Raps-WW-ZF-Mais-Gerste-ZF (Leguminosen Mischung) –Raps)

A4 minimal-wendende konservierende BB ohne Herbizide

A5 Direktsaat ohne Herbizide

A6 Mehrjährige Blühstreifen (Anteil 5% = 0,05 ha)?



Risikomatrix B - klimatisches Extremereignis (überdurchschnittlicher Niederschlag)

Legende:

B Status Quo (Ausgangsrisiko)

B1 Mischkultur (Weizen/Erbse)

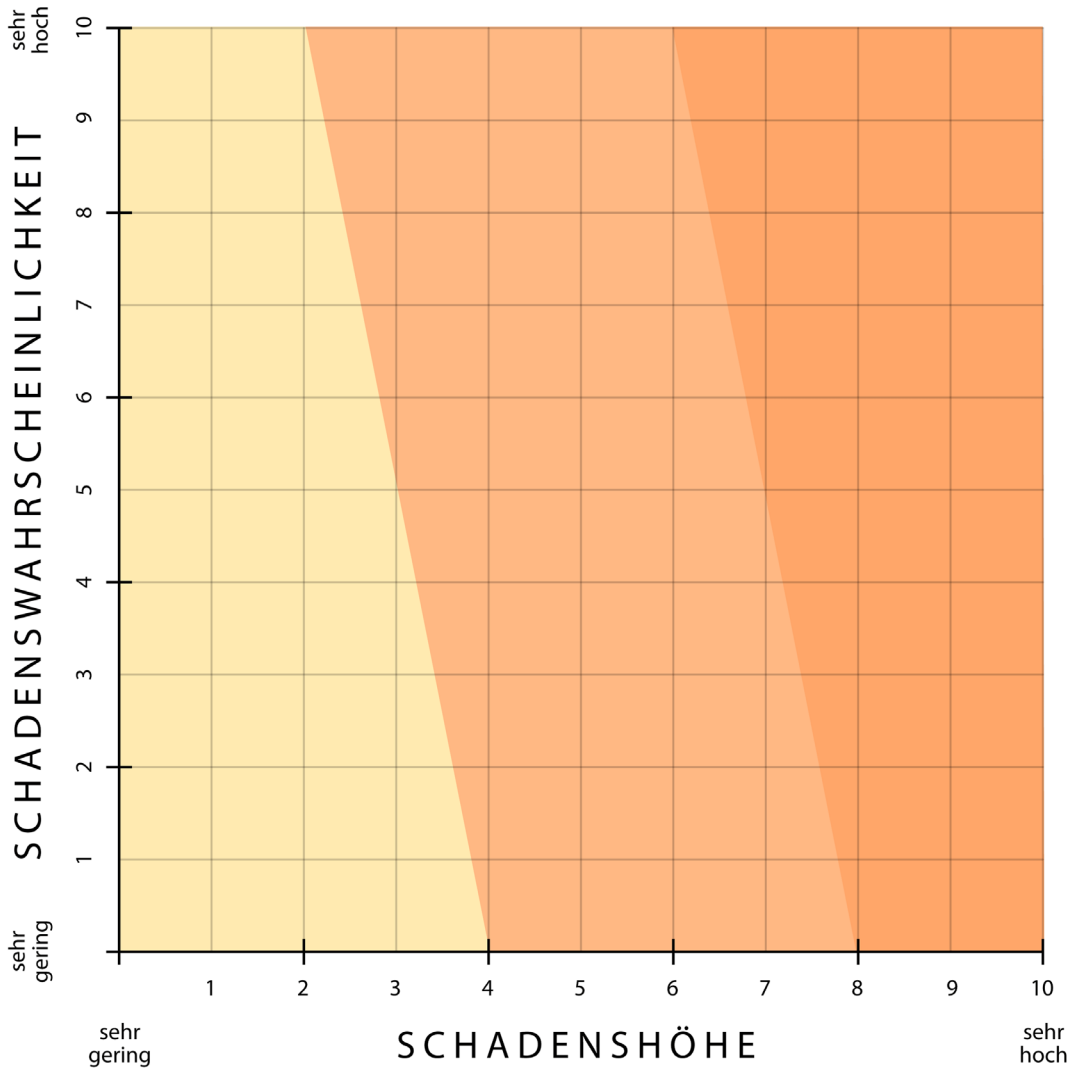
B2 Zwischenfrucht als Gründüngung (Gemenge: Senf, Ackerbohne & Klee)

B3 5-gliedrige Fruchtfolge (Raps-WW-ZF-Mais-Gerste-ZF (Leguminosen Mischung) –Raps)

B4 minimal-wendend konservierende BB ohne Herbizide

B5 Direktsaat ohne Herbizide

B6 Mehrjähriger Blühstreifen (Anteil 5% = 0,05 ha)



Holt and Laury-Lotterie:

Betrag:

	Lotterie A				Lotterie B	
	200 €	**160 €**			**385 €**	**10 €**
1	10%	90%	□	□	10%	90%
2	20%	80%	□	□	20%	80%
3	30%	70%	□	□	30%	70%
4	40%	60%	□	□	40%	60%
5	50%	50%	□	□	50%	50%
6	60%	40%	□	□	60%	40%
7	70%	30%	□	□	70%	30%
8	80%	20%	□	□	80%	20%
9	90%	10%	□	□	90%	10%
10	100%	0%	□	□	100%	0%

ACKNOWLEDGEMENTS

Writing a PhD thesis means starting an exciting journey that not only brings countless overwhelming experiences and moments, but also means setbacks and defeats. On my personal journey through this thesis, many amazing and brilliant people have accompanied me, to whom I would like to say

THANK YOU ♡

To my family:

Emma & Paul thank you for the boundless love you give me every day. This has given me the strength to always go on!

My Mugel, ***Stefan***, thank you for your support, respect, understanding, patience and for always giving me the opportunity not only to go through with this amazing journey, but also encouraging me to continue and always believing in me. Which I don't think is a given, considering we have two wonderful children, and many other responsibilities. Bringing everything under one roof was not always easy 😉. You always helped me to find my center, even if I took a detour from time to time. You often put your own needs behind to give me the opportunity to pursue my goals. For that, I love you ♡ from the bottom of my heart and thank you so much. Also thank you for your creativity, your support and help with the figures that you have created with me often until late night ▯.

To my supervisors:

Teja, I would like to thank you for giving me the great opportunity for this exciting PhD journey. You motivated me so many times to keep going and gave me confidence that I can handle it. In times when I was lost with the huge amount of work or complications have arisen, you were responsive and supported me with your great expertise and extraordinary empathy. I am very grateful for your encouragement, enthusiasm, and ideas. Without you, none of this would have been possible. You brought this thesis very much forward. Thank you so much for everything 💗.

I am grateful to have been co-supervised by ***Prof. Dr. Oliver Mußhoff*** from the department of agricultural economics and rural development. I would like to thank you for your guidance and ideas that also have brought this thesis much forward. I thank you for always being available and for giving me super-fast feedback 😊. Our meetings were always very productive and successful. Thank you so much!

Jacqueline, how lucky I have been to have you by my side from the beginning on. Thank you for your fantastic advice, the many productive meetings that always took place in a great friendly atmosphere. Thank you for the emotional support you gave me with your so wonderfully lovely and empathic nature ▯. You were always confident in this work, and I learned so much from you. You will always be a great role model for me. Chaka!

To the farmers:

A very big thank you to all the **farmers** who made this work so valuable and overall possible with their time, opinions, and perspectives on diversification in agriculture 🧑🌾👩🌾. I would also like to thank all farmers for welcoming me so warmly, a special thank you for the sleeping facilities, the farm tours and for coffee and cake breaks 😋.

To the Agroecology & Functional Agrobiodiversity group:

Susanne, thank you for always being there and explaining things again and again 😉. I also would like to thank you for helping me with preparation of lectures, material for the students and your support with FlexNow and StudIP. Thank you for the many small talks often between door and doorbell and your loving guidance over the past years 🦋.

Heike, thank you for your support in all organizational things. You are such an amazing person. Thank you for always cheering for me when I had to submit an article or give a presentation or just finishing this thesis. I enjoyed the time with you and Charlotte very much ♡ and thank you from the bottom of my heart for taking such good care of my Mega 🐴.

Catrin, thank you for the time in both working groups, and for always make sure that I was not overwhelmed by the many duties. I also thank you 🙏 for giving me the opportunity to teach independently, which gave me a lot of self-confidence and was super fun because I had the chance to exchange my knowledge about diversification in agriculture ▯.

Marco, my dear, you are a very openminded, lovely, and extremely motivated person 🤩. I would like to thank you for your support with statistics in R and especially for your help with the third manuscript, the editing and writing and your good ideas and thoughts. You are an amazing teacher 🧑🏫, I have learned a lot from you. Thank you for the very delicious Italian food 😘. Big hug!

Felix, my friend, thank you from the bottom of my heart for the many great conversations, your R scripts and your helpfulness. You are such a kind and intelligent person! I think science need more people like you ♡.

Kathrin, my dear, I must thank you for many things, that you have provided your sofa for me (it is the best sofa ever 🛋), that you have stood by me with advice and assistance in the formatting of this thesis and listening to me all the time 🐟. We have spent so many beautiful evenings together watching trash on TV ▯. I´m glad to have you in the office. You are grown very close to my heart!

Annemarie, I appreciate you for your extreme open, uncomplicated, colorful, and very kind nature. You are always ready for a conversation, infinitely helpful and interested in everything. I will never forget our karaoke night 🎤 at the writing retreat. Thank you for everything, my dear 🦋.

Annika, you are a real powerful woman 💪 and I am very happy to have met you and your family. Thank you for the many nice conversations and the cooperation in matters of teaching. We always had a great time at conferences, during the writing retreat or in the office. Thank you!

Stefan, you are a true sunshine, always in a good mood and always open for a short conversation. We had many great moments at the writing retreat 😊. You have to keep your optimistic and friendly manner. Thank you for your tips on questionnaire editing 🙏.

Arne, thank you for the beautiful picture of me and the very nice lunch breaks at the Mensa 😊. You are always chilled and that is very contagious. Stay the way you are 💪.

Nicole, my dear, thank you for the nice and efficient work together. We also had many nice moments and conversations, on all activities of the working group 🦋. You are always helpful and do all things immediately. Keep up the good work and good luck for your future 😊.

Svenja, my dear, you are such a wonderful and friendly person. The time in the office with you was so nice and funny, you are super motivated and always worked very hard, be proud of yourself 🦋. Thank you for the great time together and I hope we will have many more conferences together! Special thanks also for the R scripts and your scientific input 🙏.

And in addition, I would like to say a big thank you to: ***Manu, Kevin Li***, ***Andr***y, ***Kevin Darras, Emmeline & Felix Klaus, Sandra, Mina, Gabi, Felipe, Carolina, Isabelle, Ingo Grass, Péter Batáry*** who have also been part of this exciting journey. All of you are amazing people in your own way 🙏. I think this is what makes the working group so successful and no matter where your path takes you, make sure to embrace the spirit of helping and leading each other instead of being against each other ♡. Thank you all 🦋🌼🦋.

A big thank you goes to my Master students and research assistants. It was a great pleasure to work with you: ***Julia P.*** and ***Clara*** 🥇.

Selma, you transcribed a big part of the questionnaires for me, during your Master's thesis. It was a lot of work, and you did a very great job 💪. I wish you all the best for your future and thank you very much 🤗.

Last but not last to my friends:

Denise, my farm-girl, you are unique and irreplaceable! Always ready and immediately at hand. You also gave me so much encouragement and always supported me. Thank you for the many practical advice 🚚 and for always being there. I can rely on you 100%. I am very happy to have you in my life 🙏. Love 🙏.

Hannah, we met at the office and now you are part of my family as godmother to our Emma. You are such a wonderful person with so many facets, for your loved ones you give everything, thank you 💐! I thank you from the bottom of my heart for the hours we worked together and the many nights in which you gave me shelter and we watch “cover my tattoo” 🤣 together that was so much fun after having a hard day at work. I thank you, for your support whenever things got difficult on this journey, you had a good advice or just brought me back down. Thanks for being there 🌞. I love you ♡.

Andrea, my soulmate, with you one can steal horses 🐎**.** From the first second we were really close to each other. You always have an open ear and tried to understand everything that concerns my work and you listen amazingly well. You are especially good at calming me down and refocusing me on what's important, so thank you for that ♡. A big thank you also for always encouraging me and taking such great care of Mega and Jakob, giving me space to finish this work. Thanks for your love, support, and care 😘.

Julia T.**,** my first contact in the working group and by now one of my best friends, thank you for all the great moments at conferences, in the office and on festivals, dancing the whole night 🕺. You always supported me and gave me self-confidence 💪. It is so nice that we still have such close contact despite the distance 💌. You are also the only person I know who makes bugs puke 🐞. LOL. Ich habe dich sehr lieb ♡.

CURRICULUM VITAE

Wissenschaftliche Interessen

Diversifizierung in der Landwirtschaft | Biodiversität & Ökosystemfunktionen | Agrarökosysteme

Arbeitserfahrung

September 2020 – heute

Universität Göttingen, Agrarökologie – *Wissenschaftliche Mitarbeiterin & Doktorandin*

Durchführung und Verantwortung für Lehre, Betreuung von Abschlussarbeiten, Wissenschaftskommunikation, Datenanalyse und Publikationen

Mai 2019 – September 2020: Mutterschutz & Elternzeit

Universität Göttingen, Agrarökologie – *Wissenschaftliche Mitarbeiterin & Doktorandin*

Januar 2017 – Mai 2019

Universität Göttingen, Agrarökologie– *Wissenschaftliche Mitarbeiterin & Doktorandin*

Beginn der Doktorarbeit bei gleichzeitigem Vertrag zur wissenschaftlichen Mitarbeiterin | Aufgaben: Projektentwicklung- und Koordination, Datenerhebung (Befragung Landwirte in Niedersachsen), Projektberichte erstellen und präsentieren, Auswertung und Veröffentlichung der Ergebnisse

Januar 2016 – Dezember 2016

Universität Göttingen, Agrarökologie – *Studentische Hilfskraft*

Projektentwicklung, Planung der Dissertation und Beantragung von Drittmitteln (DBU, DFG, Heinrich-Böll-Stiftung)

April 2012 – Oktober 2012

Markus Gemeinschaft e.V., Hauteroda, Deutschland – *Landwirtschaftliches Betriebspraktikum*

Haupttätigkeiten | Mithilfe bei der Milchviehwirtschaft, Ackerbau und Gemüseanbau

September 2010 – Juli 2011

Agrarsoziale Gesellschaft e.V., Göttingen, Deutschland – *Praktikum & Ehrenamtliche Aushilfe*

Haupttätigkeiten | Literaturrecherche, Schreiben und Korrekturlesen von Artikeln für die Zeitschrift Ländlicher Raum, Organisation von Veranstaltungen

Ausbildung

Januar 2017 – heute

Universität Göttingen, Agrarökologie – *PhD (Dr. sc. agr.)*

Diversified Farming Systems – ecological-economic benefits & risks farmers face

Oktober 2013 – Dezember 2015

Universität Göttingen, Agrarökonomie und Rurale Entwicklung– *Master of Science (Agrarwissenschaften – Schwerpunkt Ressourcenmanagement)*

Kontingente Bewertung von Ökosystemdienstleistungen – Ermittlung von Einflussfaktoren auf die Höhe der Zahlungsbereitschaft für den Erhalt des Biotoptyps Magerrasen

Oktober 2009 – März 2013

Universität Göttingen, Agrarökonomie und Rurale Entwicklung – *Bachelor of Science (Agrarwissenschaften – Schwerpunkt Ressourcenmanagement)*

Phenomenon of global large scale land acquisitions – Impacts & chances for ecological and social sustainability

August 2006 – September 2009

Hessenkolleg Kassel – *Abitur*

September 2003 – September 2006

Krankenhaus Bad Arolsen – *Ausbildung zur Gesundheits- und Krankenpflegerin*

Sprachen

Muttersprache: Deutsch

Andere Sprachen: English

Soziales Engagement

Mitgliedschaft Agrarsoziale Gesellschaft e.V.

Unterstützung bei der Durchführung von Frühjahrs- & Herbsttagung, Mitwirken internationale Grüne Woche in Berlin

Mitgliedschaft Reitverein Hofgeismar

Reitunterricht für Kinder, Organisation und Durchführung von Sportveranstaltungen (Reitabzeichenlehrgänge & Turniere)

Weitere Qualifikationen und Erfahrungen

Lehre - BSc und MSc Kurse in Agrarökologie, Grundlagen der Agrarökologie, Seminar Landwirtschaft & Naturschutz, Methodisches Arbeiten: Interdisziplinäre Projektarbeit, Projektpraktikum, Einführung in R Statistik

IT-Fähigkeiten
Office – MS Powerpoint, MS Word, MS Excel (sehr gute Kenntnisse)
Betriebssysteme – Mac OS, Microsoft Windows (sehr gute Kenntnisse)
Statistik – R (+ Studio), SPSS (sehr gute Kenntnisse)
Andere – Adobe Photoshop, Adobe Illustrator, GIS, SoSciSurvey & MAXQDA (gute Kenntnisse)

Führerschein - B, BE

Kurse im Promotionsstudiengang
Ecology Seminar
Scientific Writing and Publishing in Crop Science
Linear statistical models with R
Pflanzenproduktion und vor- und nachgelagerter Bereich in Mitteleuropa
Systematic review and meta-analysis in ecology
Schreibwerkstatt kompakt

LIST OF PUBLICATIONS

Publikationen

Rosa-Schleich J., Loos J., Ferrante M., Mußhoff O. & Tscharntke T. (submitted) Mixed farmers` perception of the ecological-economic performance of diversified farming. *Ecological Economics*

Rosa-Schleich J., Loos J., Mußhoff O. & Tscharntke T. (submitted) Diversified farming perceived as yield risk reduction. *Land Use Policy*

Rosa-Schleich J., Loos J., Mußhoff O. & Tscharntke T. (2019) Ecological-economic trade-offs of Diversified Farming Systems – A review (*Ecological Economics, **DOI:** 10.1016/j.ecolecon.2019.03.002)*

Grass, I., Loos, J., Baensch, S., Batáry, P., Librán-Embid, F., Ficiciyan, A., Klaus, F., Riechers, M., **Rosa, J.,** […] & Tscharntke, T. (2019) Land-sharing/-sparing connectivity landscape for ecosystem services and biodiversity conservation (*People and Nature, **DOI:** 10.1002/pan3.21)*

Loos, J., Batáry, P., Bosem Baillod, A., Bänsch, S., Grass, I., Hass, A.L., **Rosa, J.** & Tscharntke, T. (2019). Vulnerability of ecosystem services in farmland depends on landscape structure. In: *Atlas of Ecosystem Services – Risks and Opportunities* (eds Klotz S., Bonn A., Seppelt R., Schröter M., Baessler C.), Springer. ***DOI:*** *10.1007/978-3-319-96229-0_15*)

Rosa, J. (2010) Mit Äpfeln Wohnhaus und Betrieb heizen. Klimaschutz- und Anpassungsstrategien in Landwirtschaft und ländlichem Raum, *Ländlicher Raum 61 Jg.*, Schwerpunktheft 03/2010 (Agrarsoziale Gesellschaft e.V.)

Rosa, J. & K., Zander (2010) Nutzungsmöglichkeiten der Geothermie. Klimaschutz- und Anpassungsstrategien in Landwirtschaft und ländlichen Räumen, *Ländlicher Raum 61 Jg.*, Schwerpunktheft 03/2010 (Agrarsoziale Gesellschaft e.V.)

Rosa, J., (2010) Güssing, Österreich: Energieautarke Region – Biomassevergasung zum Zweck der Stromerzeugung. Klimaschutz- und Anpassungsstrategien in Landwirtschaft und ländlichen Räumen, *Ländlicher Raum 61 Jg.*, Schwerpunktheft 03/2010 (Agrarsoziale Gesellschaft e.V.)

Vorträge & Posterbeiträge

11/2020 Eingeladene Referentin auf der Tagung der Sächsischen Landestiftung Natur und Umwelt mit dem Titel „Integration von Artenhilfsmaßnahmen in die ackerbauliche Produktionsfläche"

11/2019 Eingeladener Fachvortrag zur Herbsttagung der Arbeitsgemeinschaft bäuerliche Landwirtschaft Niedersachsen: „Ursachen des Artenrückgangs in Agrarlandschaften / ökologische & ökonomische Aspekte diversifizierter Anbausysteme" (Rosa-Schleich, J.)

09/2018 Vortrag Jahreskonferenz der Gesellschaft für Ökologie e.V. in Wien: "Can diversified farming practices reduce farmer´s yield risk?" (Rosa, J., Loos, J., Mußhoff, O. & T. Tscharntke)

12/2017 Vortrag „Ecology Across Borders" - Konferenz in Ghent, Belgien: "Diversified Farming Systems: a review on ecological-economic trade-offs and benefits" (Rosa, J., Loos, J., Mußhoff, O. & T. Tscharntke)

09/2016 Posterpräsentation Jahreskonferenz der Gesellschaft für Ökologie e.V. in Marburg, Hessen: "Benefits, costs & risks of Diversified Farming Systems " (Rosa, J., Loos, J., Mußhoff, O. & T. Tscharntke)

DECLARATION

I hereby confirm that I have written this doctoral thesis independently, that I have not used other sources or facilities other than the ones mentioned, that I have not used unauthorized assistance and that I have not submitted this thesis previously in any form for another degree at any university or institution.

Göttingen, August 2022

Julia Rosa-Schleich