CONTRIBUTION OF ORGANIC AGRICULTURE TO GLOBAL SUSTAINABLE FOOD SECURITY

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ABSTRACT

Organic agriculture has been proposed as a more sustainable alternative to current conventional agriculture. The debate about organic agriculture is, however, often polarized and ideologically charged and not sufficiently informed by scientific evidence. In order to assess the potential contribution of organic agriculture to sustainable food security we need to systematically evaluate the costs and benefits of this farming system across multiple dimensions. In this thesis I evaluate organic agriculture through several different lenses – from an agronomic, an ecological, a social, and a policy perspective. I start by examining the yield performance of organic agriculture, concluding that organic yields are, on average, significantly lower than conventional yields, but that under certain circumstances they can nearly match those from conventional systems. From an ecological perspective I examine how landscape context influences the biodiversity benefit of organic agriculture, finding that landscape context matters, but that different organism groups differ in the type of landscape characteristics where organic agriculture provides the strongest benefit. I use a case study in Southern India to examine some of the social consequences of organic agriculture. Analysing organic farmer livelihoods in two districts in the state of Kerala reveals that the success of organic agriculture varies between different farmer groups, and depends on the type of organic agriculture practiced, their livelihood characteristics, as well as the motives of organic farmers. Finally, I examine organic agriculture from a policy perspective, analysing organic regulations across the world, and how they have codified organic principles. I conclude that regulations today mostly define organic agriculture in terms of concepts of 'natural' versus 'artificial' inputs, while environmental or social principles are largely absent. My thesis concludes by suggesting that we need to concentrate more on nuances, on the particular strengths and weakness of organic agriculture under different contexts, rather than searching for a simple 'yes' or 'no' answer to the question of whether organic farming can contribute to global sustainable food security.

RÉSUMÉ

L'agriculture biologique a été suggérée comme alternative plus durable à l'agriculture conventionnelle actuelle. Toutefois, le débat entourant l'agriculture biologique est souvent polarisé et idéologiquement chargé tout en n'étant pas suffisamment supporté par des preuves scientifiques. Afin d'évaluer la contribution potentielle de l'agriculture biologique à la sécurité alimentaire durable, nous devons évaluer systématiquement les coûts et les avantages de ce système agricole à travers de multiples dimensions. Dans cette thèse, j'évalue l'agriculture biologique à travers plusieurs lentilles différentes : à partir d'un point de vue agronomique, écologique, social, et politique. Je commence par examiner la performance du rendement de l'agriculture biologique, concluant que les rendements biologiques sont, en moyenne, significativement plus faibles que les rendements conventionnels, mais que dans certaines circonstances ils peuvent être similaires à ceux des systèmes conventionnels. D'un point de vue écologique, j'examine comment le contexte paysager influence le bénéfice en terme de biodiversité de l'agriculture biologique, estimant que le contexte paysager importe, mais l'avantage qu'offre l'agriculture biologique dépend à la fois des caractéristiques du paysage et des groupes d'organismes considérés. J'utilise une étude de cas en Inde du Sud pour examiner quelques-unes des conséquences sociales de l'agriculture biologique. L'analyse des moyens de subsistance des agriculteurs biologiques dans deux districts du Kerala révèle que le succès de l'agriculture biologique varie selon les différents groupes d'agriculteurs, et dépend du type d'agriculture biologique pratiqué, de leurs caractéristiques de subsistance, ainsi que de leurs motivations. Enfin, j'examine l'agriculture biologique à partir d'un point de vue politique et j'analyse la règlementation de l'agriculture biologique à travers le monde, et comment on a codifié les principes organiques. Je conclus que la règlementation actuelle définit l'agriculture biologique principalement en fonction du concept d'intrants 'naturels' versus 'artificiels', tandis que les principes environnementaux ou sociaux sont largement absents. Ma thèse conclut en suggérant que nous devons nous concentrer davantage sur les nuances ainsi que sur les

forces et les faiblesses de l'agriculture biologique dans différents contextes, plutôt que de tenter d'obtenir un simple ‘oui’ ou ‘non’ à la question de savoir si l'agriculture biologique peut contribuer à la sécurité alimentaire mondiale durable.

For my parents, who made me curious of this world

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Because I could not say it any better, I want to start with the words with which Patrick Heller begins his book about the labour movement in Kerala:

> *"A very wise and famous sociologist once told me that good scholarship was first and foremost about humility. He then went on to say that if you think you have an original idea, it only means you have a lousy memory. This book is the sum total of many ideas that I have absorbed, pilfered, and possibly mangled, from many different people, some of whom I remember, some of whom I don't. My thanks and apologies to all of them."* – Patrick Heller, The Labour of development: workers and the transformation of capitalism in Kerala, India.

This PhD has been a long and wonderful journey, the most important component of which were the people I met on the way and who have directly or indirectly contributed to this thesis. I will attempt to mention as many as I can, but there are countless others who have contributed to the thinking, the data and the science going into this thesis who have to go unnamed here.

First of all I want to thank my supervisor Navin Ramankutty for being the best supervisor I could possibly have imagined. He allowed me to ramble and to explore, to follow my curiosity, and to learn. He was a mentor who not only challenged me intellectually, exposed me to new ideas, who pushed and guided me through the process of writing this thesis, but also a mentor who supported me in my development as a young scientist beyond the thesis. If it was not for him I would not be where I am. Most of all, however, I thank him for teaching me that there are more questions than answers, and that this is good so.

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Andrea Reid and Morgan Boenke for being the most reliable, independent, fun and skilful assistants and data managers one could wish for; thanks to Stephanie Austin, Tabea Mayerhofer, Rebekka Gerlach, Miriam Aczel, and Lauren Mechak for your invaluable help on my projects and for allowing me to mess with yours; thanks to Aneeta Antony, Johanna Bleecker, Daniel Haberman, Susanna Klassen, Corey Lesk, Zelda Moran, Natasha Salter, Qorvette Wafford, and Melinda Yogendran for the countless hours dedicated to data entry and data manipulation without which these data monsters of projects would never have been possible, as well as for the simple fun of working with you.

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"The important thing is not to catch something. What matters in life is the pursuit, and everything we learn along the way. The important thing is moving." – Kilian Jornet

PREFACE

This is a manuscript-based thesis and Chapters 2-5 are written as stand-alone pieces, with connecting statements between them. Each of these four manuscripts has been published or is planned for submission to an academic journal. The four manuscripts have been or will be submitted to journals from a variety of different disciplines, and the style of writing and presentation of results of each chapter therefore varies depending on disciplinary norms. A general introduction precedes the four manuscripts and provides a rationale for the whole thesis. A synthesis chapter summarizes the findings across all four thesis manuscripts, and highlights the new contributions of the thesis. Reference formatting follows the journal *Ecology Letters*. Approval for all interviews and data collection conducted during the fieldwork for Chapter 4 was received from the McGill Research Ethics Board 1 (REB File # 163-0913).

I am the lead author of every manuscript included in this thesis. In each case I developed the research question and the research framework, carried out (part or most) of the data collection, conducted the majority of data analysis, and led writing of the manuscripts. Navin Ramankutty provided supervision and guidance throughout this process – from the design of each study to the writing of the manuscripts - and is a co-author on each of the manuscripts. In addition, several other co-authors contributed to each manuscript as detailed below. Further contributions from specific individuals are mentioned in the acknowledgements of each manuscript.

Chapter 2 (manuscript 1) explores the yield differences between organic versus conventional agriculture through a meta-analysis of the scientific literature. This chapter was co-authored with Jonathan A. Foley who provided feedback on the results and contributed to writing the paper. **This chapter has been published**: Seufert, V., Ramankutty, N. & Foley, J. (2012). Comparing the yields of organic and conventional agriculture. *Nature*, 485, 229-232.

Chapter 3 (manuscript 2) explores the influence of landscape context on the biodiversity in organic agriculture through a meta-analysis of the scientific literature. This chapter was co-authored with Andrea J. Reid, Sylvia A. Wood, Daniel Haberman, Jeanine Rhemtulla, Andrew Gonzalez, Tim Benton, and Doreen Gabriel. Andrea J. Reid carried out large parts of the biodiversity data collection and part of the data analysis under my supervision. Daniel Haberman carried out the GIS part of the data analysis. All co-authors were involved in designing the research question and study framework. In addition, Guillaume Larocque provided advice on the statistical analysis, while Lauren Mechak helped with initial data collection. **This chapter is in preparation for publication**: Seufert, V., Ramankutty, N., Reid, A., Wood, S. L., Haberman, D., Rhemtulla, J., Gonzalez, A., Benton, T., & Gabriel, D. Landscape context controls the biodiversity benefits of organic agriculture. *Landscape Ecology*.

Chapter 4 (manuscript 3) is based on fieldwork conducted in Kerala, India, examining the reasons for farmers to convert to organic management as well as the livelihood outcomes of organic farming. This chapter was co-authored with Stephanie A. Austin, Sarah Turner, and Madhav Badami. Stephanie A. Austin provided assistance during interviews and field research. All co-authors were involved in designing the research question and study framework. In addition, Haseena Kadiri and Vishnu Satheesan provided translation services during fieldwork. Kathy Impey, Melinda Yogendran, Lea Rakovsky and Luca Seufert provided help with transcription of interviews. **This chapter is in preparation for publication**: Seufert, V., Ramankutty, N., Austin, S.A., Turner, S. & Badami, M. Success of organic farming depends on who adopts it and why. *World Development*.

Chapter 5 (manuscript 4) is based on a review and analysis of organic regulatory texts across the world and examines how organic ideas have been codified in regulations. This chapter was co-authored with Tabea Mayerhofer and Sarah Turner. Tabea Mayerhofer helped with coding of organic regulations. All co-authors were involved in designing the research question and study framework. **This chapter is in preparation for**

publication: Seufert, V., Meyerhofer, T., Turner, S. Ramankutty, N. What is this thing called organic? – How organic farming is codified in regulations. *Food Policy*.

1. INTRODUCTION

“Non credi mai a quello che è vero, perchè è vero anche il contrario.”[1] Gianna Nannini, Radio Baccano.

Agriculture is central to human survival - it provides food and fuel, is an important source of livelihood, and plays a crucial role in economic development. Agriculture is, however, also a major source of environmental degradation, contributing to climate change, depleting freshwater resources, degrading soil fertility and polluting the environment through fertilizer and pesticide use (Foley *et al.* 2005). Ironically, food production is critically dependent on the very natural resources it is degrading. ‘Sustainable food security’ therefore requires not only that all people at all times have access to sufficient food (Pinstrup-Andersen 2009) but also that this food be produced with minimal environmental impact (Godfray *et al.* 2010).

Current conventional agriculture[2] fails in achieving such sustainable food security on numerous fronts: Agriculture today is not only a leading driver of environmental degradation and a major force driving the Earth System beyond the ‘safe-operating space’ for humanity (Rockström *et al.* 2009; Bennett *et al.* 2014) - it also does not feed people adequately. Currently still more than one in eight people in developing countries are undernourished due to lack of sufficient access to food (FAO *et al.* 2015). Given that we have not achieved sustainable food security today and that we will probably need to double food production by 2050 to feed nine billion people with increasing demand for meat and dairy products (Kearney 2010; Tilman *et al.* 2011), there is a drastic need for changes in the food system. From an agricultural perspective we need to produce more

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[1] “You never believe in what is true, because the opposite is also true.”

[2] Conventional agriculture in the context of this thesis is any farming system as dominantly practised today. See more detailed definition in each individual thesis chapter.

food in the right location at affordable prices, ensuring livelihoods to farmers and with reduced environmental impact.

Considering the huge challenge ahead of us, it is important to assess the potential contribution of different types of farming systems to sustainable food security. ‘Alternative’ farming systems that try to mimic ecological processes while minimizing external inputs are often suggested as more sustainable forms of food production. Organic agriculture[1] is the most prominent of these alternative farming systems, currently (in the year 2013) covering 0.98% of global agricultural land and contributing up to 1-8% of total food sales in many European and North American countries (Willer & Lernoud 2015). To assess the potential contribution of organic agriculture to sustainable food security we need to understand the yield potential and environmental benefits of organic agriculture as well as the potential contribution of organic agriculture to agricultural development and its suitability to poor farmers’ needs.

1.1 LITERATURE REVIEW

1.1.1 GLOBAL SUSTAINABLE FOOD SECURITY

Food security is commonly defined as a situation “when all people at all times have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life” (FAO *et al.* 2015, p. 53). This definition translates into the four dimensions of food security: availability, accessibility, utilization and stability of the previous three dimensions over time. People are thus food insecure if they do not produce enough food (physical access), if they are not able to purchase food (economic access), if they cannot utilize food correctly due to health or care issue (social access) and/or if they have inadequate access to food on a periodic basis.

Food production is an ecosystem service that is dependent on natural resources like water, soil nutrients, clean air and biodiversity. However, food production also leads to the degradation of these natural resources it depends on: Water is consumed in irrigation; fertilizer and pesticides applied to crops escape to the environment, leading to air and water pollution; land cover change results in changes in water and surface radiation balance; soil processes are disrupted and greenhouse gases emitted (Foley *et al.* 2005). Food security is thus a balance between taking advantage of the ecosystem service of food production for human use, while preventing the exploitation of natural resources to a degree that undermines the ability of the ecosystem to produce this food. Sustainable food security therefore requires that sufficient food is produced for nourishing present generations without compromising the ability of future generations to produce sufficient and nutritious food for their own needs.

The concept of sustainable food security does not, however, end with ensuring food production into the future. It also requires that the process of food production does not undermine other key ecosystem services provided by the Earth system. The exploitation of natural resources by agriculture is in many places of the world proceeding at a rate that undermines the stability and function of ecosystems and consequently the welfare of the human society, which is dependent on the services provided by the biosphere (Foley *et al.* 2005; Robertson & Swinton 2005; Bennett & Balvanera 2007). Sustainable agriculture is thus also about the balance between producing enough food without undermining the ability of the Earth system to provide ecosystem services like climate regulation, carbon sequestration or water cycling.

In addition to sustainable food production, sustainable food security also needs to ensure long-term access to nutritious food for all people. This implies that agriculture needs to provide sustainable livelihoods to farmers and that food be produced at prices that are affordable to consumers. Sustainable food security thus represents a multidimensional and multi-disciplinary task that requires the consideration of interlinked social, economic and environmental aspects. Sustainable food security can only be achieved in a resilient and equitable food system that involves all stages, from producing, storing, processing, packaging, distributing, retailing to consuming food (Ingram 2011; Misselhorn *et al.* 2012). The focus of this thesis is the examination of the contribution of organic agriculture to global sustainable food security. But organic agriculture is mainly an alternative *production* system and does not directly address other components of the food system[3]. This thesis will therefore mainly focus on the agricultural side of the food system. From an agricultural perspective to achieve sustainable food security we need to find ways to (1) produce more food in the places where it is needed, (2) do so at reduced environmental impact, and (3) achieve this through methods that improve farmer's livelihoods and that are accessible to farmers.

1.1.2 ORGANIC AGRICULTURE

Organic agriculture is a farming system aimed at producing food with minimal harm to ecosystems, animals or humans (FAO & WHO 2001). Lampkin (1994) defines the aim of organic agriculture as (Lampkin 1994, p. 5):

> To create integrated, humane, environmentally and economically sustainable production systems, which maximise reliance on farm-derived renewable resources and the management of ecological and biological processes and interactions, so as to provide acceptable levels of crop, livestock and human nutrition, protection from pests and disease, and an appropriate return to the human and other resources.

Organic agriculture - according to these original definitions - encompasses not only environmental sound management practices but also a farming system that is socially just and economically responsible. These broad goals of organic agriculture originate in the ideas of organic pioneers like Albert Howard, Eve Balfour, and J. I. Rodale, developed in the 1920s and 1940s in Europe and North America, who perceived organic farming as an alternative to the arising conventional food system, which was focused on efficiency, large-scale farming, technology and artificial inputs.

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[3] Organic agriculture often comes in association with other alternative food strategies like local food systems in developed countries or fair trade markets in developing countries. But organic agriculture by itself mainly denotes an alternative production system.

Today organic agriculture is one the fastest growing food sectors and most consumers in Europe and North America consume organic food at least occasionally (Hartman Group 2006; COTA 2013). Even though consumers buy organic food primarily for personal health reasons, beliefs that organic agriculture represents a farming systems that is environmentally and socially superior to the conventional food system are still common motives amongst organic consumers (Zanoli & Naspetti 2002; Hughner *et al.* 2007). Critics of conventional agriculture who are seeking to develop a more sustainable and more just food system also often propose organic agriculture as a viable alternative that could provide more environmental sustainability, as well as increased food security (Padel & Lampkin 1994; Tilman 1998; Scialabba & Hattam 2002; Pimentel *et al.* 2005; Halberg *et al.* 2006; Badgley *et al.* 2007; Azadi *et al.* 2011). Productionist critics of organic agriculture, instead, dismiss organic farming as a less efficient and thus less environmentally friendly practice that would not be able to provide sufficient food to feed the world (Trewavas 2001; Goklany 2002; Chen & Wan 2005; Connor 2008; Paarlberg 2009). Organic agriculture is, however, also criticised from the other end of the spectrum – some critics argue that organic agriculture is too embedded into the conventional food system and simply replicates the environmental problems as well as social inequalities of conventional agriculture (Allen & Kovach 2000; Guthman 2004; Raynolds 2004; Getz & Shreck 2006; Scott *et al.* 2009). The result of these strongly differing opinions is an often polarized and heated debate about the merits of organic farming, not only in public media (Lappe 2010; Paarlberg 2010), but also within the scientific community (see e.g. Avery *et al.* 2005; Pimentel 2005; Chappell *et al.* 2009; Fischer *et al.* 2009).

Table 1.1 provides an overview of the different arguments raised in favour of and against organic agriculture in terms of its environmental performance, and its potential for improved food security.

Table 1.1. An overview of arguments in favour of and against organic agriculture in terms of its environmental performance and its food security potential. Note that I differentiate between direct local effects of organic management (e.g. on soils or energy use) and the broader environmental and food security outcomes of these effects (e.g. for biodiversity or food production). Sometimes the distinction between local effects and broader outcomes is not straightforward, as interactions are complex rather than linear (e.g. organic management supposedly increases biodiversity, which leads to increased biological pest control, which results in reduced need for pesticide application, which in turn leads to increased biodiversity).

Advocates		**Critics**	
Local effect	**Outcome**	**Local effect**	**Outcome**
Environment			
More wildlife-friendly management Better biological pest control	Higher biodiversity Higher production	Higher pest outbreaks Use of harmful 'organic' pesticides	Lower production Same harm on biodiversity
Similar yields	Same land area needed	Lower yields	Lower biodiversity due to land expansion Higher C emissions from land expansion
More fertile soils	Less soil degradation C capture due to higher soil organic matter Higher water-use efficiency	More tillage needed	Higher C emissions from soils
Lower use of chemical fertilizers	Lower N pollution	Lower N use efficiency	Same or higher N pollution
Lower fossil fuel use	Higher energy efficiency	/	/
Food Security			
Higher yields	Increased farmer income Higher food supply Lower food prices	Lower yields	Lower farmer income Lower food supply Higher food prices
Diversification & better soils	Higher resilience Increased drought & pest resistance	Higher pest outbreaks	Lower resilience

Use of local resources	Reduced input costs Less dependence on outside resources	Higher labour requirements	Higher costs
Includes traditional knowledge		Rejects technological improvements	
Yields do matter for food security		Yields do not matter for food security	

On most of these arguments no consensus has been found yet. Some of these questions can be answered and simply need more scientific evidence (e.g. on yields, or nitrogen pollution). On other questions, instead, simply examining the performance of organic farming cannot solve the controversy, as it stems from a broader disagreement about values and belief systems. These disagreements are related, for example, to questions of whether we are faced primarily with a production or with a distribution problem, whether technology or traditional knowledge are better able to help solve our societal problems, or whether we need to prioritize resilience or efficiency. Such questions, supposedly, also can be answered, but the debate goes far beyond organic agriculture. This thesis will therefore focus only on those arguments and controversies that are directly related to the performance of organic agriculture.

1.2 THESIS FRAMEWORK

In this thesis I will take a holistic approach and will examine organic agriculture from multiple perspectives that are of relevance for increasing global sustainable food security from an agricultural perspective, namely the three central questions of (1) productivity, (2) environmental performance, and (3) farmer livelihoods (see p. 4). Within these three broader questions I will try to address particular knowledge gaps where a better understanding can help inform the debate about organic agriculture. Each of these dimensions requires a different lens of analysis and I will use various approaches and conduct analyses at various scales that are most appropriate for each particular question. I will conclude the thesis by examining the policy context of organic agriculture and suggesting concrete ways in which the contribution of organic agriculture to sustainable food security can be improved.

The research questions addressed in this thesis are:

1. What is the yield performance of organic agriculture compared to conventional agriculture? (**Chapter 2**)
2. How does landscape context influence the biodiversity benefit of organic agriculture? (**Chapter 3**)
3. Drawing on a case study in Southern India, why do farmers adopt organic agriculture and what are the impacts of organic agriculture on farmer livelihoods? (**Chapter 4**)
4. What does organic agriculture mean today and how are organic principles codified in organic regulations? (**Chapter 5**)

In **Chapter 2** I examine the key question of organic yield performance. Yields are central to any discussion of sustainability of a farming system, as productivity determines not only how much land is needed to produce food, but it also determines farmer income, food supply and food prices. Yields of organic agriculture are thus often at the centre of the debate on the environmental impact as well as the food security potential of organic agriculture (Table 1.1). Critics of organic agriculture argue that yields of organic systems are considerably lower and that organic management would therefore require a larger land area to grow our food, and that organic methods would not be able to feed the world (Trewavas 2001, 2004; Connor 2008). Proponents of organic agriculture claim, instead, that organic yields are comparable to those from conventional agriculture and that organic agriculture can avoid the trade-off between yield and environmental impact, achieving high yields in a sustainable way, particularly in developing countries (Scialabba & Hattam 2002; IFAD 2003; Pretty *et al.* 2003; IFAD 2005; Parrott *et al.* 2006; Pretty *et al.* 2006; Badgley *et al.* 2007; UNCTAD & UNEP 2008). The evidence collected by many of the studies to date is, however, difficult to generalize, as the reported data often comes from surveys of projects that lack an adequate control (Phalan *et al.* 2007). This chapter therefore aims to re-assess the question of organic yield performance through a rigorous meta-analysis of the scientific literature.

In **Chapter 2** I will examine the influence of organic management on biodiversity, and particularly how landscape context interacts with organic management. We know that organic management typically increases the biodiversity in agricultural fields (Bengtsson *et al.* 2005; Hole *et al.* 2005; Tuck *et al.* 2014), but numerous studies also suggest that landscape context is more important than local field management for biodiversity (Weibull *et al.* 2000; Boutin *et al.* 2009; Jonason *et al.* 2012). In this chapter I will therefore examine how organic agriculture influences biodiversity in agricultural fields across a variety of different landscapes through a global meta-analysis of the scientific literature. I will try to identify the specific landscape characteristics that influence the effectiveness of organic management (moving beyond the classification of landscapes based simply on the amount of semi-natural habitat), and with a particular focus on landscape configuration (which is often overlooked in landscape studies; Fahrig 2003).

Chapter 3 takes a look at organic farmers, and examines their reasons to adopt organic agriculture, as well as the impact organic management has on their livelihood outcomes. Unlike the previous two chapters that use quantitative methods and conduct analysis at the global scale, in this chapter I will use qualitative methods and focus on a regional scale, conducting a case study in the South Indian state of Kerala. According to Flyvbjerg (2006) "there does not and probably cannot exist predictive theory in social science. Social science has not succeeded in producing general, context-independent theory." A global analysis of the impact of organic agriculture on farmer livelihoods is thus futile. But a regional case study can provide a nuanced understanding of the context-dependent livelihood influences of organic agriculture. India is a particularly interesting case study for organic agriculture, as, one the one hand, Green Revolution practices have been adopted widely since the 1960s, but on the other hand, India plays a special role in organic agriculture (having been called the Shangri-La of the early organic movement, Conford 2001), as many of the early organic pioneers were inspired by traditional Indian farming methods, and it also currently is home to a prominent organic movement

(Thottathil 2014). Kerala thus provides an interesting context for a study to contribute to the very limited and often conflicting evidence we have about the impact of ‘true’ organic agriculture[4] on farmer livelihoods in developing countries (Lyngbaek *et al.* 2001; Bray *et al.* 2002; Mendoza 2004; Bacon 2005; Eyhorn *et al.* 2007; Bakewell-Stone *et al.* 2008; Valkila 2009; Méndez *et al.* 2010; Bachmann 2012; Panneerselvam *et al.* 2011; Panneerselvam *et al.* 2012; Morris *et al.* 2013; Bacon *et al.* 2014; Patil *et al.* 2014; Jacobi *et al.* 2015).

In **Chapter 4** I will finally try to understand what organic agriculture means today by examining how it is codified in today’s organic regulations. A core issue in debates about organic agriculture is the lack of clear vocabulary and confusion regarding concepts of ‘agroecological’ and ‘sustainable’ agriculture (Rigby & Cáceres 2001). Regulatory texts are thus interesting points from which to start understanding what organic agriculture means today. This analysis applies qualitative content analysis of organic regulatory texts to identify the principles used to regulate organic agriculture. By examining the policy context of organic agriculture across the world this analysis also allows me to formulate recommendations for increasing the sustainability of organic agriculture from a policy perspective.

By examining organic agriculture from an agronomic (Chapter 2), ecological (Chapter 2), social (Chapter 3) and policy (Chapter 4) perspective this thesis contributes important insights into how organic agriculture could contribute to global sustainable food security. Taken together, the highly interdisciplinary analyses in this thesis help to inform the often-polarized debate with new evidence on the problems and benefits of organic agriculture.

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[4] Note that in this thesis I exclude low-input farming systems that are organic by default, or that use small amounts of chemical inputs from the definition of organic agriculture. But see each individual chapter for a more detailed definition of organic farming.

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CONNECTING STATEMENT

In the previous chapter I have laid out the thesis rationale, including a discussion of the motivation for conducting this thesis, as well as identifying the knowledge gaps I will be addressing in this thesis. The following chapter will start by examining the first research question of my thesis by analysing the yields in organic versus conventional agriculture through a global meta-analysis of the literature. The chapter is formatted in an unusual way, as it has been published in the journal *Nature*, and therefore follows *Nature*'s formatting guidelines.

2. COMPARING THE YIELDS OF ORGANIC AND CONVENTIONAL AGRICULTURE

"If I were a rule, I would bend." - Pink Floyd, If

Nature 485 (2012), 229-232

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2.1 ABSTRACT

Numerous reports have emphasized the need for major changes in the global food system: agriculture must meet the twin challenge of feeding a growing population, with rising demand for meat and high-calorie diets, while simultaneously minimizing its global environmental impacts (Godfray *et al.* 2010; Foley *et al.* 2011). Organic farming - a system aimed at producing food with minimal harm to ecosystems, animals or humans - is often proposed as a solution (McIntyre et al. 2009; Schutter 2010). However, critics argue that organic agriculture may have lower yields and would therefore need more land to produce the same amount of food as conventional farms, resulting in more widespread deforestation and biodiversity loss, and thus undermining the environmental benefits of organic practices (Trewavas 2001). Here we use a comprehensive meta-analysis to examine the relative yield performance of organic and conventional farming systems globally. Our analysis of available data shows that, overall, organic yields are typically lower than conventional yields. But these yield differences are highly contextual, depending on system and site characteristics, and range from 5% lower organic yields (rain-fed legumes and perennials on weak-acidic to weak-alkaline soils), 13% lower yields (when best organic practices are used), to 34% lower yields (when the conventional and organic systems are most comparable). Under certain conditions - that is, with good management practices, particular crop types and growing conditions - organic systems can thus nearly match conventional yields, whereas under others it at present cannot. To establish organic agriculture as an important tool in sustainable food production, the factors limiting organic yields need to be more fully understood, alongside assessments of the many social, environmental and economic benefits of organic farming systems.

2.2 INTRODUCTION

Although yields are only part of a range of ecological, social and economic benefits delivered by farming systems, it is widely accepted that high yields are central to sustainable food security on a finite land basis (Godfray *et al.* 2010; Foley *et al.* 2011). Numerous individual studies have compared the yields of organic and conventional farms, but few have attempted to synthesize this information on a global scale. A first study of this kind (Badgley *et al.* 2007) concluded that organic agriculture matched, or even exceeded, conventional yields, and could provide sufficient food on current agricultural land. However, this study was contested by a number of authors; the criticisms included their use of data from crops not truly under organic management and inappropriate yield comparisons (Cassman 2007; Connor 2008).

We performed a comprehensive synthesis of the current scientific literature on organic-to-conventional yield comparisons using formal meta-analysis techniques. To address the criticisms of the previous study (Badgley *et al.* 2007) we used several selection criteria: (1) we restricted our analysis to studies of 'truly' organic systems, defined as those with certified organic management or non-certified organic management, following the standards of organic certification bodies (see Supplementary Material S2.4); (2) we only included studies with comparable spatial and temporal scales for both organic and conventional systems (see Methods); and (3) we only included studies reporting (or from which we could estimate) sample size and error. Conventional systems were either high- or low-input commercial systems, or subsistence agriculture. Sixty-six studies met these criteria, representing 62 study sites, and reporting 316 organic-to-conventional yield comparisons on 34 different crop species (Supplementary Table S2.4).

2.3 RESULTS AND DISCUSSION

The average organic-to-conventional yield ratio from our meta-analysis is 0.75 (with a 95% confidence interval of 0.71 to 0.79); that is, overall, organic yields are 25% lower than conventional (Fig. 2.1a). This result only changes slightly (to a yield ratio of 0.74) when the analysis is limited to studies following high scientific quality standards (Fig. 2.2). When comparing organic and conventional yields it is important to consider the food output per unit area and time, as organic rotations often use more non-food crops like leguminous forage crops in their rotations (Cassman 2007). However, the meta-analysis suggests that studies using longer periods of non-food crops in the organic rotation than conventional systems do not differ in their yield ratio from studies using similar periods of non-food crops (Fig. 2.2 and Supplementary Table S2.5). It thus appears that organic rotations do not require longer periods of non-food crops, which is also corroborated by the fact that the majority of studies (that is, 76%) use similar lengths of non-food crops in the organic and conventional systems.

The performance of organic systems varies substantially across crop types and species (Fig. 2.1a–c; see Supplementary Table S2.5 for details on categorical analysis). For example, yields of organic fruits and oilseed crops show a small (-3% and -11% respectively), but not statistically significant, difference to conventional crops, whereas organic cereals and vegetables have significantly lower yields than conventional crops (-26% and -33% respectively) (Fig. 2.1a).

These differences seem to be related to the better organic performance (referring to the relative yield of organic to conventional systems) of perennial over annual crops and legumes over non-legumes (Fig. 2.1b). However, note that although legumes and perennials (and fruits and oilseed crops) show statistically insignificant organic-to conventional yield differences, this is owing to the large uncertainty range resulting from their relatively small sample size (n=34 for legumes, n=25 for perennials, n=14 for fruits and n=28 for oilseed crops; Fig. 2.1), and combining legumes and perennials reveals a significant, but small, yield difference (Fig. 2.2).

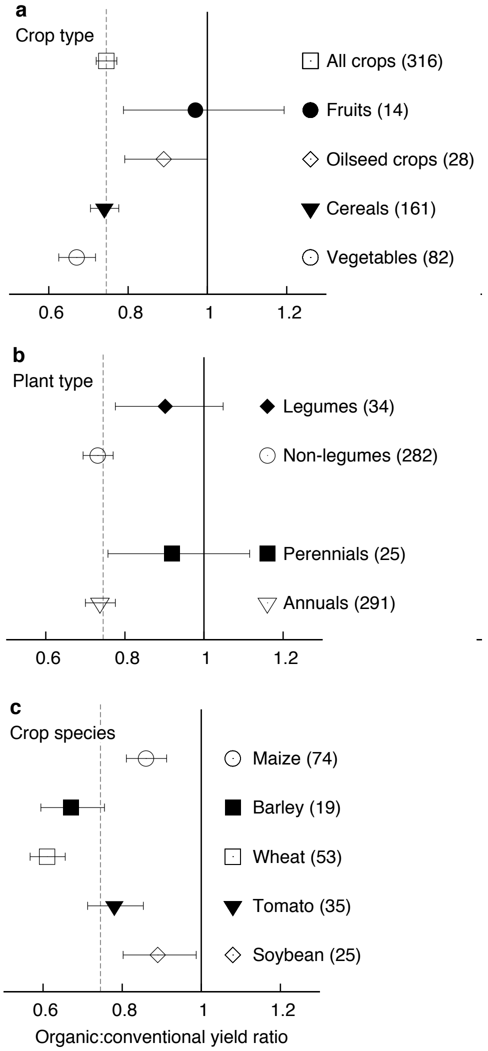

Figure 2.1. Influence of different crop types, plant types and species on organic-to-conventional yield ratios. a–c, Influence of crop type (a), plant type (b) and crop species (c) on organic-to-conventional yield ratios. Only those crop types and crop species that were represented by at least ten observations and two studies are shown. Values are mean effect sizes with 95% confidence intervals. The number of observations in each class is shown in parentheses. The dotted line indicates the cumulative effect size across all classes.

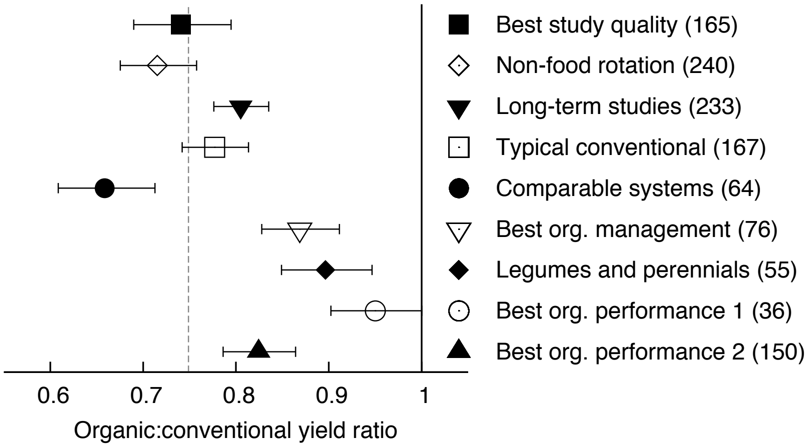

Figure 2.2. Sensitivity study of organic-to-conventional yield ratios. Best study quality, peer-reviewed studies using appropriate study design and making appropriate inferences; non-food rotation, studies where both systems have a similar duration of non-food crops; long-term studies, excludes very short duration and recently converted studies; typical conventional, restricted to commercial conventional systems with yields comparable to local averages; comparable systems, studies that use appropriate study design and make appropriate inferences, where both systems have the same non-food rotation length and similar N inputs; best org. management, excludes studies without best management practices or crop rotations; legumes and perennials, restricted to leguminous and perennial crops; best org. performance 1, rain-fed legumes and perennials on weak-acidic to weak-alkaline soils; best org. performance 2, rain-fed and weak-acidic to weak-alkaline soils. Values are mean effect sizes with 95% confidence intervals. The number of observations is shown in parentheses. The dotted line indicates the effect size across all studies.

Part of these yield responses can be explained by differences in the amount of nitrogen (N) input received by the two systems (Fig. 2.3a). When organic systems receive higher quantities of N than conventional systems, organic performance improves, whereas conventional systems do not benefit from more N. In other words, organic systems appear to be N limited, whereas conventional systems are not. Indeed, N availability has been found to be a major yield-limiting factor in many organic systems (Berry *et al.* 2002). The release of plant-available mineral N from organic sources such as cover crops, compost or animal manure is slow and often does not keep up with the high crop N demand during the peak growing period (Pang & Letey 2000; Berry *et al.* 2002). The better performance of organic legumes and perennials is not because they received more N, but rather because they seem to be more efficient at using N (Supplementary Table S2.7 and Supplementary Fig. S2.4). Legumes are not as dependent on external N sources as non-legumes, whereas perennials, owing to their longer growing period and extensive root systems, can achieve a better synchrony between nutrient demands and the slow release of N from organic matter (Crews & Peoples 2005).

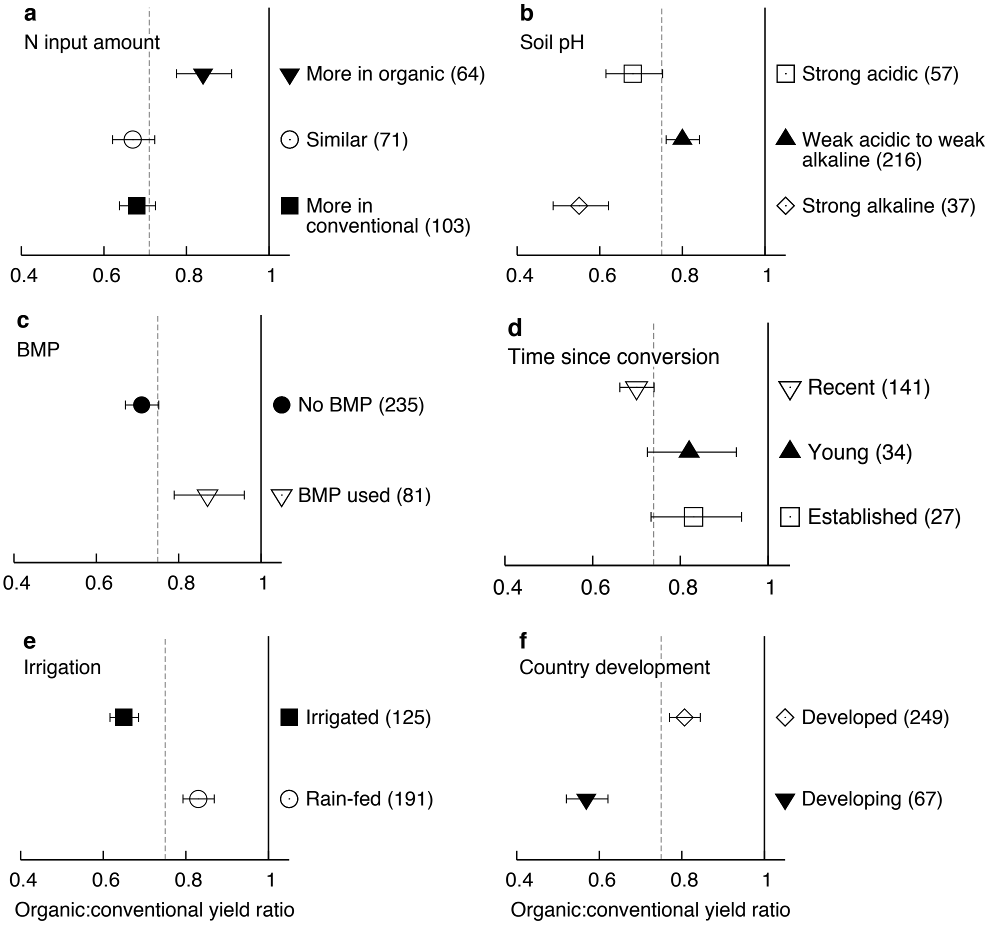

Figure 2.3. Influence of N input, soil pH, best management practices, time since conversion to organic management, irrigation and country development. a–f, Influence of the amount of N input (a), soil pH (b), the use of best management practices (BMP; c), time since conversion to organic management (d), irrigation (e) and country development (f) on organic-to conventional yield ratios. For details on the definition of categorical variables see Supplementary Tables S2.1–2.3. Values are mean effect sizes with 95% confidence intervals. The number of observations in each class is shown in parentheses. The dotted line indicates the cumulative effect size across all classes.

Organic crops perform better on weak-acidic to weak-alkaline soils (that is, soils with a pH between 5.5. and 8.0; Fig. 2.3b). A possible explanation is the difficulty of managing phosphorus (P) in organic systems. Under strongly alkaline and acidic conditions, P is less readily available to plants as it forms insoluble phosphates, and crops depend to a stronger degree on soil amendments and fertilizers. Organic systems often do not receive adequate P inputs to replenish the P lost through harvest (Oehl *et al.* 2002). To test this hypothesis we need further research on the performance and nutrient dynamics of organic agriculture on soils of varying pH.

Studies that reported having applied best management practices in both systems show better organic performance (Fig. 2.3c). Nutrient and pest management in organic systems rely on biological processes to deliver plant nutrients and to control weed and herbivore populations. Organic yields thus depend more on knowledge and good management practices than conventional yields. However, in organic systems that are not N limited (as they grow perennial or leguminous crops, or apply large N inputs), best management practices are not required (Supplementary Table S2.11).

It is often reported that organic yields are low in the first years after conversion and gradually increase over time, owing to improvements in soil fertility and management skills (Martini *et al.* 2004). This is supported by our analysis: organic performance improves in studies that lasted for more than two seasons or were conducted on plots that had been organic for at least 3 years (Fig. 2.2, Supplementary Fig. S2.5 and Supplementary Table S2.13). Water relations also influence organic yield ratios - organic performance is -35% under irrigated conditions, but only -17% under rain-fed conditions (Fig. 2.3e). This could be due to a relatively better organic performance under variable moisture conditions in rain-fed systems. Soils managed with organic methods have shown better water-holding capacity and water infiltration rates and have produced higher yields than conventional systems under drought conditions and excessive rainfall (Colla *et al.* 2000; Lotter *et al.* 2003) (see Supplementary Information). On the other hand, organic systems are often nutrient limited (see earlier), and thus probably do not respond as strongly to irrigation as conventional systems.

The majority of studies in our meta-analysis come from developed countries (Supplementary Fig. S2.1). Comparing organic agriculture across the world, we find that in developed countries organic performance is, on average, -20%, whereas in developing countries it is -43% (Fig. 2.3f). This poor performance of organic agriculture in developing countries may be explained by the fact that a majority of the data (58 of 67 observations) from developing countries seem to have atypical conventional yields (>50% higher than local yield averages), coming from irrigated lands (52 of 67), experimental stations (54 of 67) and from systems not using best management practices (67 of 67; Supplementary Fig. S2.10 and Supplementary Table S2.8). In the few cases from developing countries where organic yields are compared to conventional yields typical for the location or where the yield data comes from surveys, organic yields do not differ significantly from conventional yields because of a wide confidence interval resulting from the small sample size (n=8 and n=12 respectively, Supplementary Fig. S2.10a).

The results of our meta-analysis differ dramatically from previous results (Badgley *et al.* 2007). Although our organic performance estimate is lower than previously reported (Badgley *et al.* 2007) in developed countries (-20% compared to -8%), our results are markedly different in developing countries (-43% compared to +80%). This is because the previous analysis mainly included yield comparisons from conventional low-input subsistence systems, whereas our data set mainly includes data from high-input systems for developing countries. However, the previous study compared subsistence systems to yields that were not truly organic, and/or from surveys of projects that lacked an adequate control. Not a single study comparing organic to subsistence systems met our selection criteria and could be included in the meta-analysis. We cannot, therefore, rule out the claim (Scialabba & Hattam 2002) that organic agriculture can increase yields in smallholder agriculture in developing countries. But owing to a lack of quantitative studies with appropriate controls we do not have sufficient scientific evidence to support it either. Fortunately, the Swiss Research Institute of Organic Agriculture (FiBL) recently established the first long-term comparison of organic and different conventional systems in the tropics (Forster *et al.* 2013). Such well-designed long-term field trials are urgently needed.

Our analysis shows that yield differences between organic and conventional agriculture do exist, but that they are highly contextual. When using best organic management practices yields are closer to (-13%) conventional yields (Fig. 2.2). Organic agriculture also performs better under certain agroecological conditions—for example, organic legumes or perennials, on weak-acidic to weak-alkaline soils, in rainfed conditions, achieve yields that are only 5% lower than conventional yields (Fig. 2.2). On the other hand, when only the most comparable conventional and organic systems are considered the yield difference is as high as 34% (Fig. 2.2). In developed countries or in studies that use conventional yields that are representative of regional averages, the yield difference between comparable organic and conventional systems, however, goes down to 8% and 13%, respectively (see Supplementary Material S2.4).

In short, these results suggest that today's organic systems may nearly rival conventional yields in some cases—with particular crop types, growing conditions and management practices—but often they do not. Improvements in management techniques that address factors limiting yields in organic systems and/or the adoption of organic agriculture under those agroecological conditions where it performs best may be able to close the gap between organic and conventional yields.

Although we were able to identify some factors contributing to variations in organic performance, several other potentially important factors could not be tested owing to a lack of appropriate studies. For example, we were unable to analyse tillage, crop residue or pest management. Also, most studies included in our analysis experienced favourable growing conditions (Supplementary Fig. S2.8), and organic systems were mostly compared to commercial high-input systems (which had predominantly above-average yields in developing countries; Supplementary Figs 6b and 10a). In addition, it would be desirable to examine the total human-edible calorie or net energy yield of the entire farm system rather than the biomass yield of a single crop species. To understand better the performance of organic agriculture, we should: (1) systematically analyse the long-term performance of organic agriculture under different management regimes; (2) study organic systems under a wider range of biophysical conditions; (3) examine the relative yield performance of smallholder agricultural systems; and (4) evaluate the performance of farming systems through more holistic system metrics.

As emphasized earlier, yields are only part of a range of economic, social and environmental factors that should be considered when gauging the benefits of different farming systems. In developed countries, the central question is whether the environmental benefits of organic crop production would offset the costs of lower yields (such as increased food prices and reduced food exports). Although several studies have suggested that organic agriculture can have a reduced environmental impact compared to conventional agriculture (Bengtsson *et al.* 2005; Crowder *et al.* 2010), the environmental performance of organic agriculture per unit output or per unit input may not always be advantageous (Kirchmann & Bergström 2001; Leifeld & Fuhrer 2010). In developing countries, a key question is whether organic agriculture can help alleviate poverty for small farmers and increase food security. On the one hand, it has been suggested that organic agriculture may improve farmer livelihoods owing to cheaper inputs, higher and more stable prices, and risk diversification (Scialabba & Hattam 2002). On the other hand, organic agriculture in developing countries is often an export-oriented system tied to a certification process by international bodies, and its profitability can vary between locations and years (Raynolds 2004; Valkila 2009).

There are many factors to consider in balancing the benefits of organic and conventional agriculture, and there are no simple ways to determine a clear ‘winner’ for all possible farming situations. However, instead of continuing the ideologically charged ‘organic versus conventional’ debate, we should systematically evaluate the costs and benefits of different management options. In the end, to achieve sustainable food security we will probably need many different techniques - including organic, conventional, and possible ‘hybrid’ systems (NRC 2010) - to produce more food at affordable prices, ensure livelihoods for farmers, and reduce the environmental costs of agriculture.

2.4 METHODS SUMMARY

We conducted a comprehensive literature search, compiling scientific studies comparing organic to conventional yields that met our selection criteria. We minimized the use of selection criteria based on judgments of study quality but examined its influence in the categorical analysis. We collected information on several study characteristics reported in the papers and derived characteristics of the study site from spatial global data sets (see Supplementary Tables S2.1–S2.3 for a description of all categorical variables). We examined the difference between organic and conventional yields with the natural logarithm of the response ratio (the ratio between organic and conventional yields), an effect size commonly used in meta-analyses (Hedges *et al.* 1999). To calculate the cumulative effect size we weighted each individual observation by the inverse of the mixed-model variance. Such a categorical meta-analysis should be used when the data have some underlying structure and individual observations can be categorized into groups (for example, crop species or fertilization practices) (Rosenberg *et al.* 2000). An effect size is considered significant if its confidence interval does not overlap with 1 in the back-transformed response ratio. To test the influence of categorical variables on yield effect sizes we examined between-group heterogeneity (Q_B). A significant Q_B indicates that there are differences in effect sizes between different classes of a categorical variable (Rosenberg *et al.* 2000). All statistical analyses were carried out in MetaWin 2.0 (Rosenberg *et al.* 2000).

2.5 ACKNOWLEDGEMENTS

We are grateful to the authors of the 66 studies whose extensive fieldwork provided the data for this meta-analysis. Owing to space limitations our citations can be found in Supplementary Material. We would like to thank J. Reganold for useful comments on our manuscript. We are grateful to I. Perfecto, T. Moore, C. Halpenny, G. Seufert and S. Lehringer for valuable discussion and/or feedback on the manuscript and L. Gunst for sharing publications on the FiBL trials. D. Plouffe helped with the figures and M. Henry with compiling data. This research was supported by a Discovery Grant awarded to N.R. from the Natural Science and Engineering Research Council of Canada.

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SUPPLEMENTARY MATERIAL

S2.1 DETAILED METHODS

Literature search

We searched the literature on studies reporting organic-to conventional yield comparisons. First we used the references included in the previous study (Badgley *et al.* 2007) and then extended the search by using online search engines (Google Scholar, ISI Web of Knowledge) as well as reference lists of published articles. We applied several selection criteria to address the criticisms of the previous study (Badgley *et al.* 2007) and to ensure that minimum scientific standards were met. Studies were only included if they (1) reported yield data on individual crop species in an organic treatment and a conventional treatment, (2) the organic treatment was truly organic (that is, either certified organic or following organic standards), (3) reported primary data, (4) the scale of the organic and conventional yield observations were comparable, (5) data were not already included from another paper (that is, avoid multiple counting), and (6) reported the mean (X), an error term (standard deviation (s.d.), standard error (s.e.) or confidence interval) and sample size (n) as numerical or graphical data, or if X and s.d. of yields over time could be calculated from the reported data. For organic and conventional treatments to be considered comparable, the temporal and spatial scale of the reported yields needed to be the same, that is, national averages of conventional agriculture compared to national averages of organic agriculture or yields on an organic farm compared to yields on a neighbouring conventional farm—not included were, for example, single farm yields compared to national or regional averages or before–after comparisons. Previous studies (Johnston *et al.* 2009) have illustrated the danger of comparing yield data drawn from single plots and field trials to larger state and national averages.

The use of selection criteria is a critical step in conducting a meta-analysis. On the one hand, scientific quality and comparability of observations needs to be ensured. On the other hand, a meta-analysis should provide as complete a summary of the current research as possible. There is an ongoing debate about whether meta-analyses should adopt very specific selection criteria to prevent mixing incomparable data sets together and to minimize variation in the data set (Whittaker 2010) or whether, instead, meta-analyses should include as wide a range of studies as possible to allow for an analysis of sources of variation (Hillebrand & Cardinale 2010). We followed the generally recommended approach, trying to minimize the use of selection criteria based on judgments of study quality (Englund *et al.* 1999). Instead, we examined the influence of quality criteria empirically by evaluating the differences between observations with different quality standards. We did not therefore exclude yield observations from non-peer-reviewed sources or from studies that lacked an appropriate experimental design a priori. The quality of the study and the comparability of the organic and conventional systems were assessed by evaluating the experimental design of the study as well as the form of publication. Studies that were published in peer-reviewed journals and that controlled for the possible influence of variability in space and time on experimental outcomes through an appropriate experimental design were considered to follow high quality standards.

Categorical variables

In addition to study quality criteria, information on several other study characteristics like crop species, location and timescale, and on different management practices, was collected (see Tables S2.1–S2.3). We also wanted to test the effect of study site characteristics on yield ratios and we thus collected information on biophysical characteristics of the study site. As most studies did not report climate or soil variables we derived information on several agroecological variables that capture cropland suitability (Ramankutty *et al.* 2002), including the moisture index α (the ratio of actual to potential evapotranspiration) as an indicator of moisture availability to crops, growing degree days (GDD, the annual sum of daily mean temperatures over a base temperature of 5 °C) as an indicator of growing season length, as well as soil carbon density (C_{soil}, as a measure of soil organic content) and soil pH as indicators of soil quality from the latitude x longitude values of the study site and global spatial models/data sets at 5 min resolution (IGBP-DIS 1998; Deryng *et al.* 2011).

We derived the thresholds for the classification of these climate and soil variables from the probability of cultivation functions previously described (Ramankutty *et al.* 2002). This probability of cultivation function is a curve fitted to the empirical relationship between cropland areas, α, GDD or C_{soil}. It describes the probability that a location with a certain climate or soil characteristic is covered by cropland. Suitable locations with favourable climate and soil characteristics have a higher probability of being cultivated. Favourable climate and soil characteristics can thus be inferred from the probability of cultivation. For α, GDD and C_{soil} a probability of cultivation under 30% was classified as 'low' suitability, between 30% and 70% as 'medium' suitability, and above 70% as 'high' suitability (Table S2.3). Sites with low and medium suitable moisture indices are interpreted as having insufficient water availability, sites with low and medium GDD have short growing seasons, and sites with low and medium soil carbon densities are either unfertile because they have too small a C_{soil} and low organic matter content (and thus insufficient nutrients) or too high a C_{soil} in soils in wetlands where organic matter accumulates because they are submerged under water. For soil pH, instead, we defined thresholds based on expert judgment. Soil pH information was often given in the studies and we only derived soil pH values from the global data set if no soil pH value was indicated in the paper.

To assess whether the conventional yield values reported by studies and included in the meta-analysis were representative of regional average crop yields, we compared them to FAOSTAT yield data and a high-resolution spatial yield data set (Monfreda *et al.* 2008; FAO 2015). We used the FAO data (FAO 2015), which reports national yearly crop yields from 1961 to 2009, for temporal detail and a yield data set (Monfreda *et al.* 2008), which reports subnational crop yields for 175 crops for the year 2000 at a 5-min latitude by 5-min longitude resolution, for spatial detail. We calculated country average crop yields from FAO data for the respective study period and calculated the ratio of this average study-period yield to the year-2000 FAO national yield value. We derived the year-2000 yield value from the spatial data set through the latitude by longitude value of the study site and scaled this value to the study-period-to-year-2000 ratio from FAOSTAT. If the meta-analysis conventional yield value was more than 50% higher than the local yield average derived by this method it was classified as ‘above average’, when it was more than 50% lower as ‘below average’, and when it was within +/- 50% of local yield averages as ‘comparable’. We choose this large yield difference as a threshold to account for uncertainties in the FAOSTAT and global yield data set (Monfreda *et al.* 2008).

Meta-analysis

The natural log of the response ratio (Hedges *et al.* 1999) was used as an effect size metric for the meta-analysis. The response ratio is calculated as the ratio between the organic and the conventional yield. The use of the natural logarithm linearizes the metric (treating deviations in the numerator and the denominator the same) and provides more normal sampling distribution in small samples (Hedges *et al.* 1999). If the data set has some underlying structure and studies can be categorized into more than one group (for example, different crop species, or different fertilizer types) a categorical meta-analysis can be conducted (Rosenberg *et al.* 2000). Observations with the same or similar management or system characteristics were grouped together. We then used a mixed effects model to partition the variance of the sample, assuming that there is random variation within a group and fixed variation between groups. We calculated a cumulative effect size as weighted mean from all studies by weighting each individual observation by the reciprocal of the mixed-model variance, which is the sum of the study sampling variance and the pooled within-group variance. Weighted parametric meta-analysis should be used whenever possible to deal with heteroscedasticity in the sample and to increase the statistical power of the analysis (Gurevitch & Hedges 1999). The cumulative effect size is considered to be significantly different from zero (that is, the organic treatment shows a significant effect on crop yield) if its 95% confidence interval does not overlap zero.

To test for differences in the effect sizes between groups the total heterogeneity of the sample was partitioned into the within group (Q_W) and between group heterogeneity (Q_B) in a process similar to an analysis of variance (Hedges & Olkin 1985). The significance of Q_B was tested by comparing it against the critical value of the χ^2 distribution. A significant Q_B implies that there are differences among cumulative effect sizes between groups (Gurevitch *et al.* 1992; Rosenberg *et al.* 2000). Only those effects that showed a significant Q_B are presented in graphs. All statistical analyses were carried out using MetaWin 2.0 (Rosenberg *et al.* 2000). For representation in graphs effect sizes were back-transformed to response ratios.

Each observation in a meta-analysis is required to be independent. Repeated measurements in the same location over time are not independent. If yield values from a single experiment were reported over several years therefore the average yield over time was calculated and used in the meta-analysis. If the mean and variance of multiple years was reported, the weighted average over time was calculated by weighting each year by the inverse of its variance. Different experiments (for example, different tillage practices, crop species or fertilizer rates) from the same study are not necessarily independent. However, it is recommended to still include different experiments from the same study, as their omission would cause more distortions of the results than the lack of true independence (Gurevitch *et al.* 1992). We therefore included different experiments from a single study separately in the meta-analysis.

If data from the same experiment from the same study period were reported in several papers, the data were only included once, namely from the paper that reported the data in the highest detail (that is, reporting s.e./s.e. and n and/or reporting the longest time period). If instead data from the same experiment from different years were reported in separate papers, the data were included separately in the analysis (e.g., refs Liebhardt *et al.* 1989; Drinkwater *et al.* 2000).

In addition to potential within-study dependence of effect size data, there can also be issues with between-study dependence of data (Gurevitch & Hedges 1999) - data from studies conducted by the same author, in the same location or on the same crop species are also potentially non-independent. We addressed this issue by conducting a hierarchical, categorical meta-analysis (as described earlier), specifically testing for the influence of numerous moderators on the effect size. In addition, we examined the interaction between categorical variables through a combination of contingency tables and sub-categorical analysis (see Supplementary Material S2.4 for the results of this analysis and for a more detailed discussion of this issue).

We performed a sensitivity analysis (see Table S2.14) to compare the robustness of results under more strict quality criteria (see discussion of definition of study quality earlier) and to assess organic yield ratios under a couple of specific system comparisons.

S2.2 SUPPLEMENTARY FIGURES

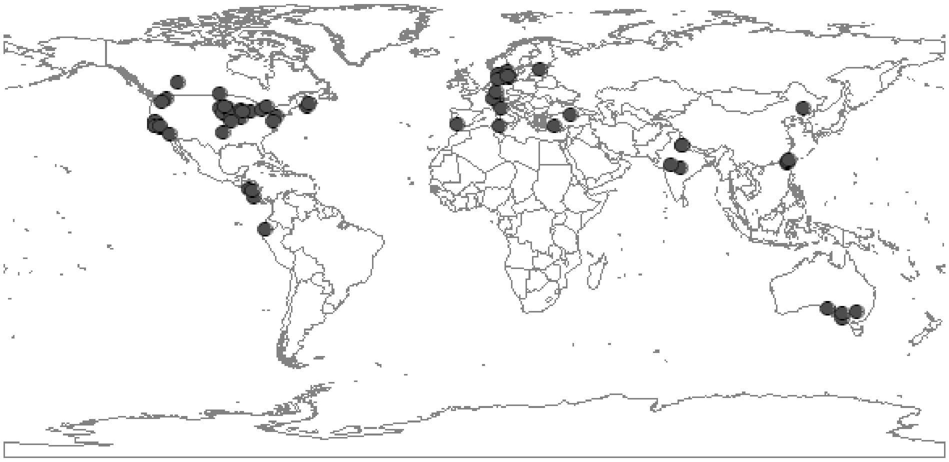

Figure S2.1. Map showing the 62 study sites that were included in the meta-analysis.

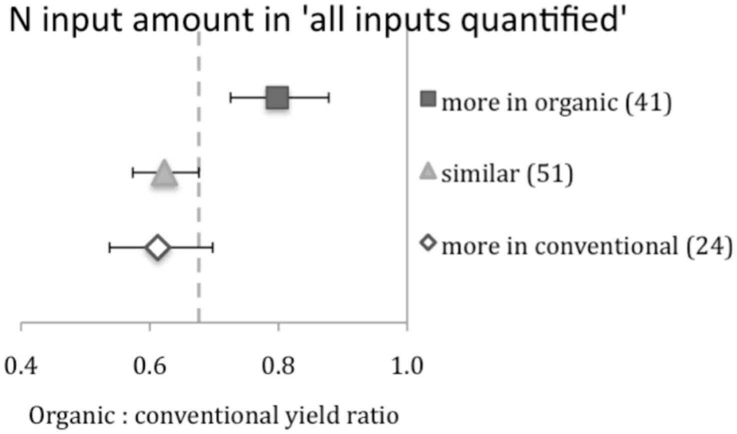

Figure S2.2. Influence of the amount of N inputs on organic-to-conventional yield ratios when only those studies quantifying all nutrient inputs (i.e. including green manure N inputs) are considered. Values are mean effect sizes with 95% confidence intervals (CI). A significant response is when the CI does not overlap 1. The number of yield observations in each class is shown in parentheses. The dotted line indicates the cumulative effect size across all classes.

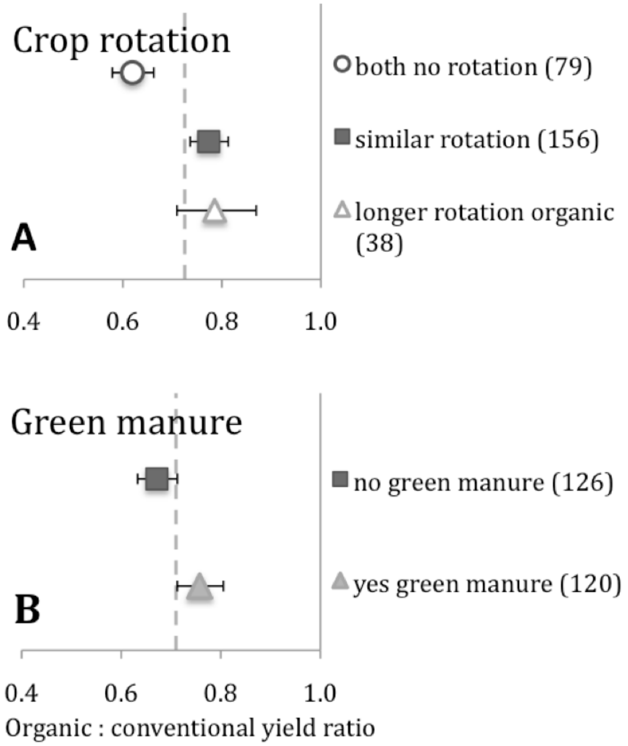

Figure S2.3. Influence of the use of crop rotation (A) and of whether or not green manure was applied to the organic system (B) on the organic-to-conventional yield ratios across all studies. Values are mean effect sizes with 95% confidence intervals (CI). A significant response is when the CI does not overlap 1. The number of yield observations in each class is shown in parentheses. The dotted line indicates the cumulative effect size across all classes.

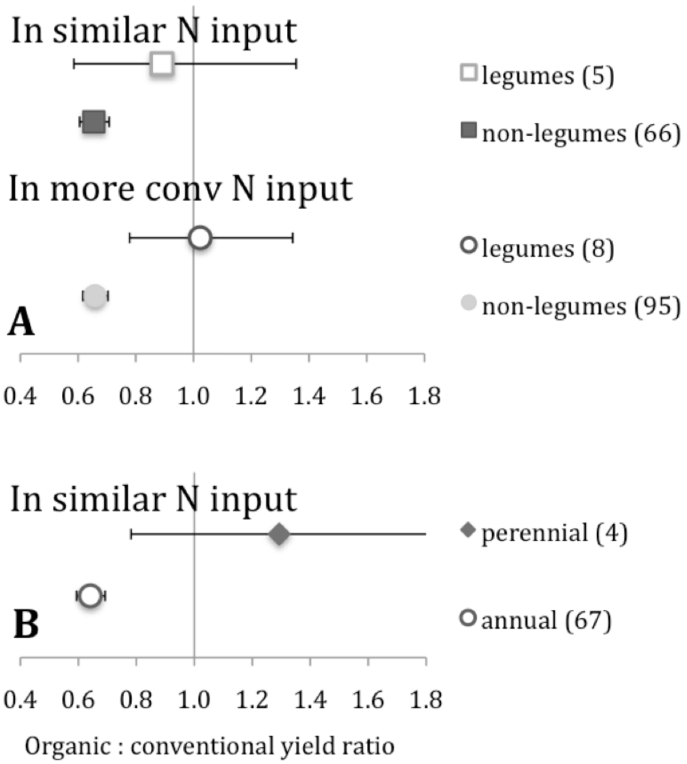

Figure S2.4. Influence of N_2-fixing capacity on organic-to-conventional yield ratios within studies in which the organic and conventional system received similar amounts of N inputs or in studies in which the conventional system received more N inputs (A) and the effect of perennial vs. annual growth form on organic-to-conventional yield ratios within studies in which the organic and conventional system received similar amounts of N inputs (B). Values are mean effect sizes with 95% confidence intervals (CI). A significant response is when the CI does not overlap 1. The number of yield observations in each class is shown in parentheses.

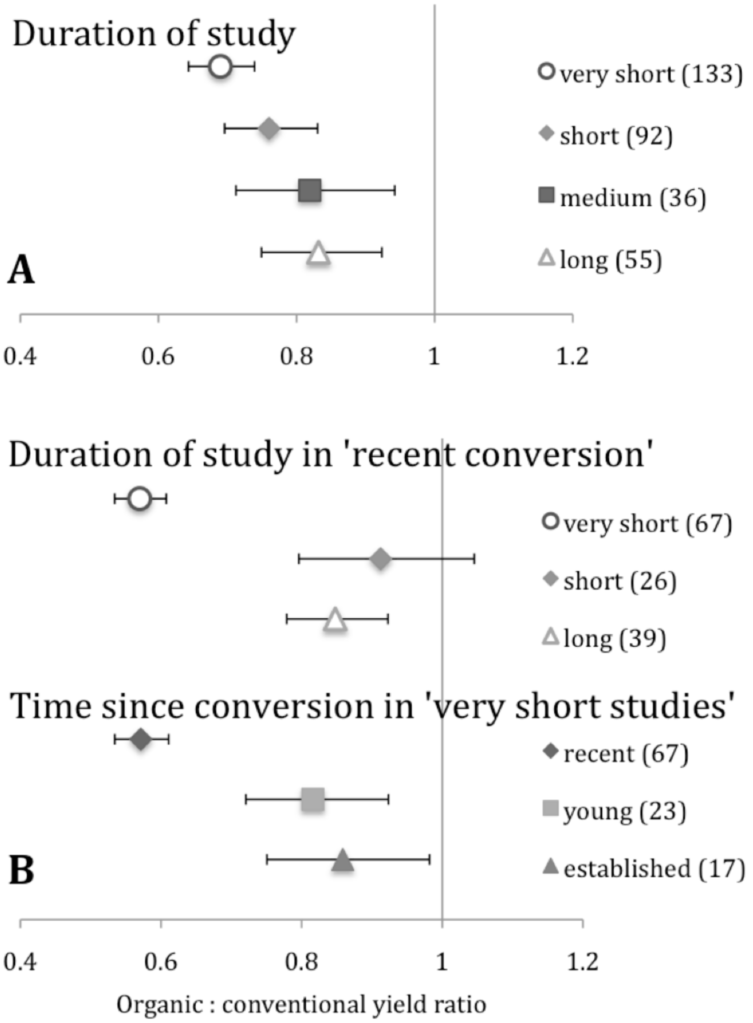

Figure S2.5. Influence of duration of study on organic-to-conventional yield ratios across all studies (A) and within studies where land had recently (i.e. less than 3 years ago) been converted to organic management (B, upper panel) as well as the effect of the time since the land had been converted to organic management in studies of very short study period (B, lower panel). Values are mean effect sizes with 95% confidence intervals (CI). A significant response is when the CI does not overlap 1. The number of yield observations in each class is shown in parentheses.

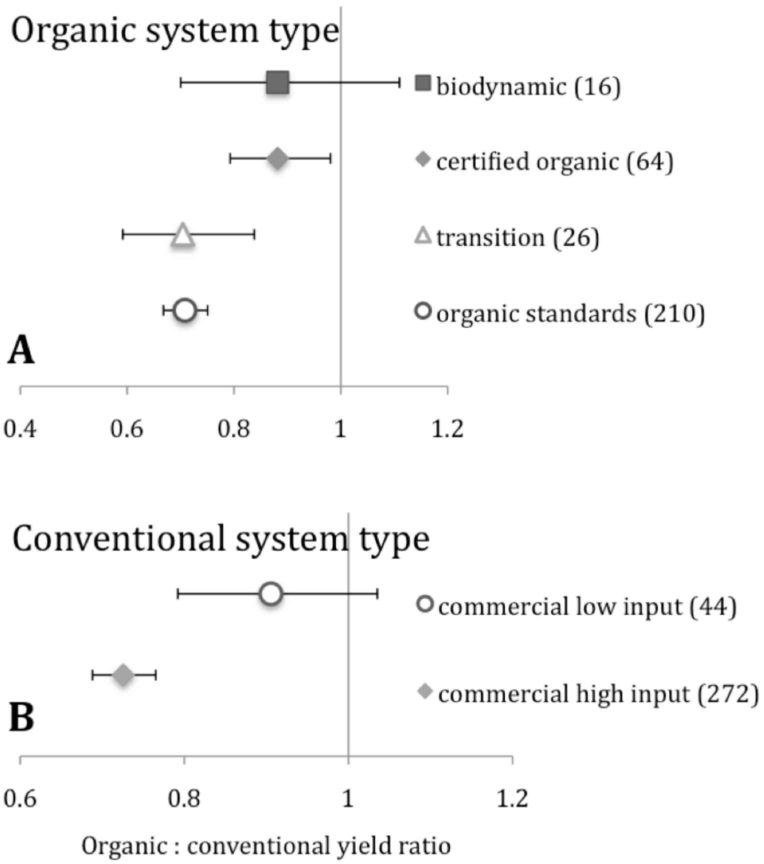

Figure S2.6. Influence of the organic (A) and the conventional system type (B) on organic-to-conventional yield ratios across all studies. Values are mean effect sizes with 95% confidence intervals (CI). A significant response is when the CI does not overlap 1. The number of yield observations in each class is shown in parentheses.

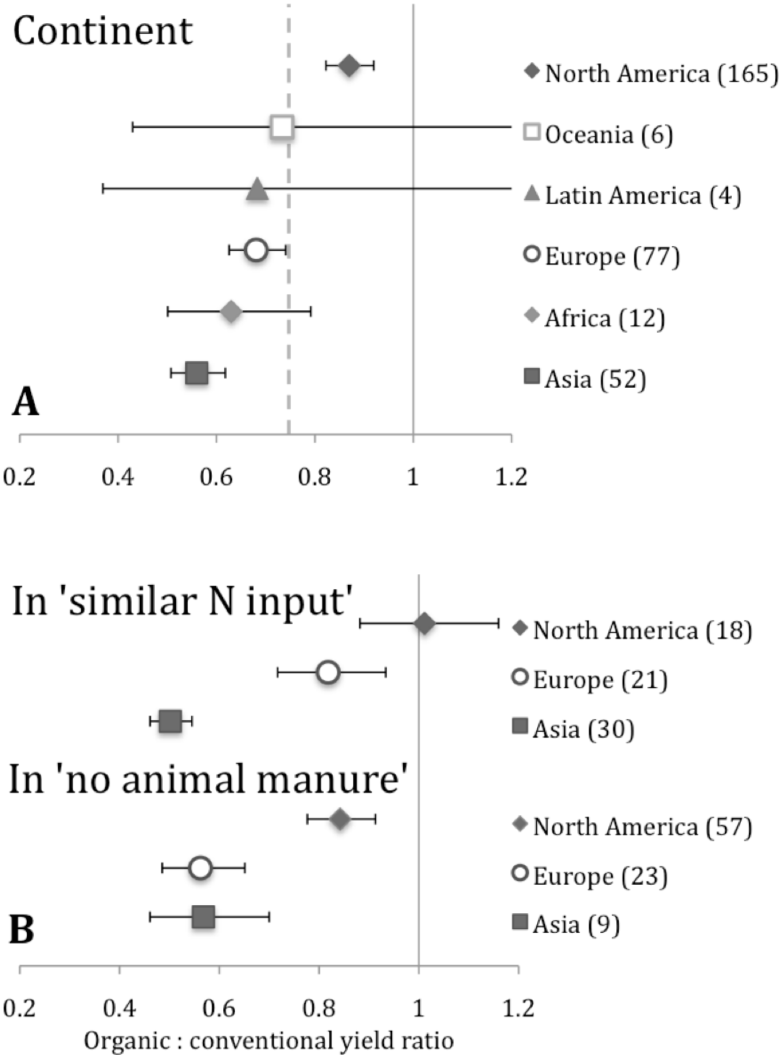

Figure S2.7. Influence of the continent of the study site on organic-to-conventional yield ratios across all studies (A) and within studies in which the organic and the conventional system received similar amounts of N inputs (B, upper panel) or in which the organic system received no animal manure (B, lower panel). Values are mean effect sizes with 95% confidence intervals (CI). A significant response is when the CI does not overlap 1. The number of yield observations in each class is shown in parentheses. The dotted line in A indicates the cumulative effect size across all classes.

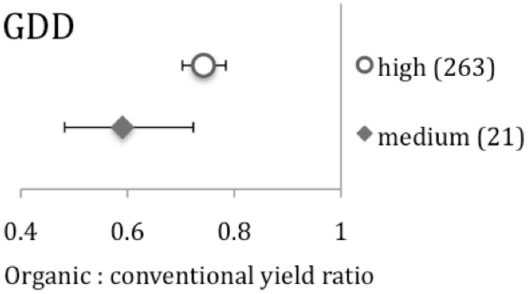

Figure S2.8. Influence of the growing degree days (GDD) on organic-to-conventional yield ratios across all studies. Values are mean effect sizes with 95% confidence intervals (CI). A significant response is when the CI does not overlap 1. The number of yield observations in each class is shown in parentheses.

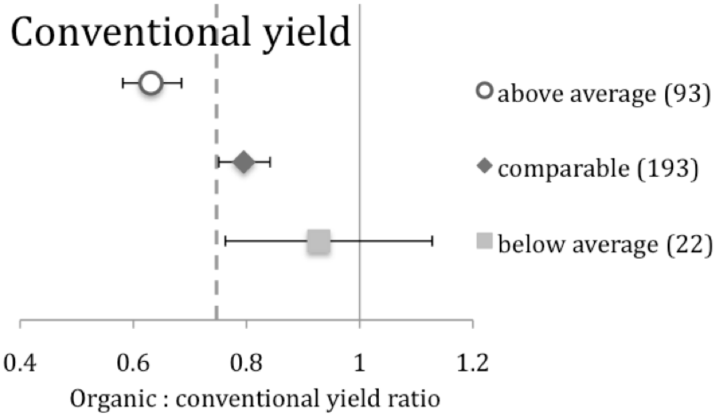

Figure S2.9. Influence of the comparability of conventional yields on organic-to-conventional yield ratios across all studies. Values are mean effect sizes with 95% confidence intervals (CI). A significant response is when the CI does not overlap 1. The number of yield observations in each class is shown in parentheses. The dotted line indicates the cumulative effect size across all classes.

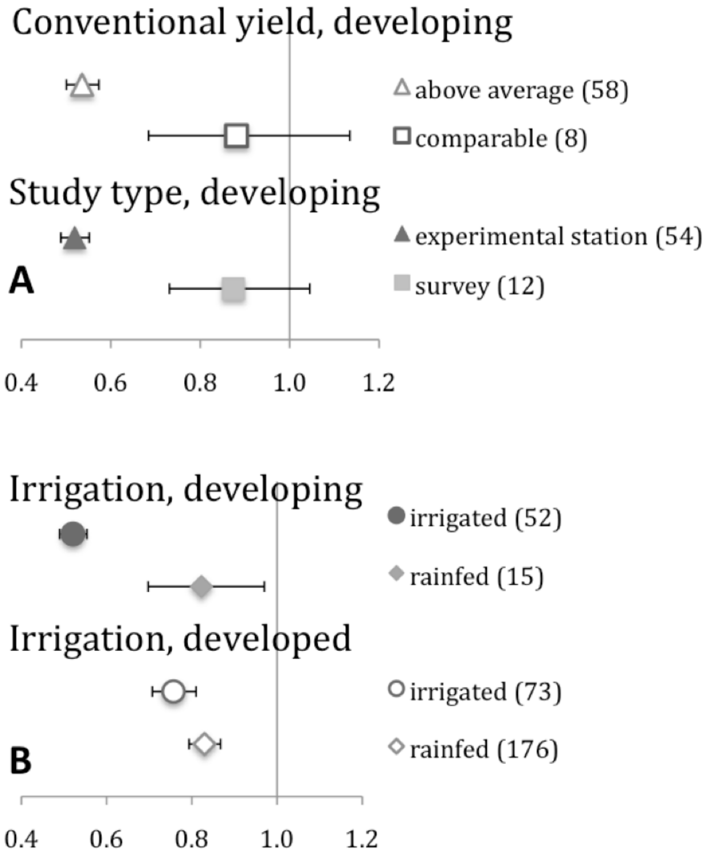

Figure S2.10. Influence of the comparability of the conventional yield with local yield averages (A, upper panel) and effect of the type of study (A, lower panel) on developing country yield ratios (A) as well as the effect of irrigation on organic-to-conventional yield ratios in developing (B, upper panel) and developed countries B, lower panel, B). Values are mean effect sizes with 95% confidence intervals (CI). A significant response is when the CI does not overlap 1. The number of yield observations in each class is shown in parentheses.

S2.3 SUPPLEMENTARY TABLES

Table S2.1. List of categorical variables describing system characteristics.

Category	Class	Definition
Country	Different countries	
Continent	North America Europe Oceania Asia Africa Latin America	
Country development	Developed Developing	‘very high’ Human Development Index (HDI) ‘high’, ‘medium’ & ‘low’ HDI
Latitude	Temperate Subtropical Tropical	30° - 66° 20° - 30° 0° - 20°
Crop species	Different crop species	
Crop type	Cereal Vegetable Roots and tubers Oilseed and oleaginous fruits Fruit Sugar crop Pulses Fibre crop Beverage crop Fodder crop	Following FAO definitions
Plant type 1	Legume Non-legume	N-fixing crop species of the Fabaceae family Not N-fixing crop species
Plant type 2	Perennial Annual	Perennial crop species Annual crop species
Study type	Experimental station On-farm trial Survey	Controlled field experiment Paired farms Diagnostic survey research
System comparability	Truly comparable Not truly comparable	Appropriate experimental design & appropriate inference Inappropriate experimental design & inappropriate inference
Duration of study	Very short Short Medium Long	1-2 seasons 3-5 seasons 6-10 seasons >10 seasons
Time since conversion	Recent Young Established	0-3 years 4-7 years >7 years

Conventional yield comparability	Above average	>50% higher than local average yield of crop species during study period
	Below average	>50% lower than local average yield of crop species during study period
	Comparable	Within +/-50% of local average yield of crop species during study period
Type conventional system	High-input	High-input commercial system
	Low-input	Any kind of low-input, integrated commercial system using conventional inputs but at low rates
	Subsistence	
Type organic system	Certified	Certified organic by certification bodies
	Transition	Transition: in transition period before certification
	Organic standards	Not certified but using organic standards
	Biodynamic	Biodynamic agriculture

Table S2.2. List of categorical variables describing management methods.

Category	Class	Definition
Best management practices (BMP)	Yes	BMP used for both systems
	No	No specification that BMP used
Multi-cropping	Monoculture	Both systems do monoculture (i.e. a single crop grown in a field in one season)
	Multi-cropping	Both systems do multi-cropping (i.e. more than 1 different crops grown in a field during one growing season)
	Multi-cropping organic	Conventional systems uses monoculture, organic system multi-cropping
	Multi-cropping conventional	Organic system uses monoculture, conventional system multi-cropping
Crop rotations	No rotation	Both systems apply no crop rotations
	Similar rotation	Both systems apply 2-year or longer crop rotations (i.e. at least 1 year lying between same crop being planted on a field)
	Longer rotation conventional	Conventional system applies longer crop rotation periods than organic
	Longer rotation organic	Organic system applies longer crop rotation periods than conventional

Non-food rotation	Both	Both systems have a non-food rotation
	No	Both systems do not have a non-food rotation
	Organic	Only the organic system has a non-food rotation
	Conventional	Only the conventional system has a non-food rotation
Type of organic fertilizer	Animal manure	Any type of animal manure, including cattle, chicken, swine & fish manure, as well as urine & slurry
	Plant	Green manure and/or compost
	Fertilizer	Commercial organic fertilizer
	Mixture	A mix of either animal or plant material or organic fertilizer
Animal manure	Yes	Animal manure applied to the organic system
	No	No animal manure applied to the organic system
Green manure	Yes	Green manure applied to the organic system
	No	No green manure applied to the organic system
N input amount	Similar	Organic and conventional received similar (i.e. in the range of +-50%) amounts of N per ha per year over the course of one rotation (or over the study period if the study period did not cover an entire rotation)
	More organic	Organic received >50% more than conventional
	More conventional	Conventional received >50% more than organic
Irrigation	Irrigated	Both systems irrigate crops
	Rainfed	Both systems do not irrigate crops
Tillage	Standard	Both systems use standard tillage (e.g. chisel or till ploughing)
	Conservation	Both systems use conservation tillage (i.e. reduced tillage, increased crop residues on soil surface)
	Conventional reduced	Conventional system uses reduced tillage
	No till	Both systems use no-till (i.e. no soil disturbance)
	Conventional no-till	Conventional system uses no-till
	Organic no-till	Organic system uses no-till

Table S2.3. List of categorical variables describing biophysical conditions.

Category	Class	Definition
Moisture index (α)	Low	$< 0.3\ \alpha$
	Medium	$0.3–0.4\ \alpha$
	High	$>0.4\ \alpha$
Growing degree days (GDD)	Low	< 1200 GDD
	Medium	1200-1500 GDD
	High	> 1500 GDD
Soil carbon density	Low	<3 & >22 kg C m^{-2}
	Medium	3-4 & 11-22 kg C m^{-2}
	High	4-11 kg C m^{-2}
Soil pH	Strong acidic	pH < 5.5
	Weak acidic to weak alkaline	pH 5.5-8
	Strong alkaline	pH > 8

Table S2.4. List of studies included in the meta-analysis, the country the study was conducted in, the crop species examined, whether the study was published in a peer-reviewed journal and whether it was included in the study by Badgley *et al.* (2007).

Study	**Country**	**Crops**	**Peer-reviewed**	**Included in Badgley *et al.***
Appireddy *et al.* (2008)	India	pepper	yes	no
Aronsson *et al.* (2007)	Sweden	barley, oat, wheat	yes	no
Bertschinger *et al.* (2004)	Switzerland	apple	yes	no
Besson *et al.* (1992)	Switzerland	barley	yes	no
Besson *et al.* (1993b)	Switzerland	cabbage	yes	no
Besson *et al.* (1993a)	Switzerland	sugar beet	yes	no
Blaise (2006)	India	cotton	yes	no
Cavigelli *et al.* (2009)	United States	maize, soybean, wheat	yes	no
Citak and Sinmez (2010)	Turkey	spinach	yes	no
Clark *et al.* (1999)	United States	bean, maize, safflower, tomato	yes	no
Delate & Cambardella (2004)	United States	maize, soybean	yes	yes
Demiryurek & Ceyhan (2008)	Turkey	hazelnut	yes	no
Denison (2004)	United States	maize, tomato	yes	no
Dobbs and Smolik (1997)	United Sates	maize, soybean	yes	yes
Doltra *et al.* (2010)	Denmark	barley, wheat	yes	no
Drinkwater *et al.* (1995)	United States	tomato	yes	yes
Drinkwater *et al.* (2000)	United States	maize	yes	no
Entz *et al.* (2005)	Canada	flax	no	no
Eyhorn *et al.* (2007)	India	chili, maize, pigon pea, sorghum, soybean, wheat, cotton	yes	no
Gelfand *et al.* (2010)	United States	maize, soybean, wheat	yes	no
Gliessman *et al.* (1996)	United States	strawberry	yes	no
Goldstein *et al.*	United States	maize	no	no
Gopinath *et al.* (2008)	India	wheat	yes	no
Hargreaves *et al.* (2008)	Canada	strawberry	yes	no
Herencia *et al.* (2007)	Spain	bean, chard, pumpkin, tomato	yes	no
Bachinger (1996)	Germany	rye	no	no
Järvan and Edesi (2009)	Estonia	potato	yes	no
Jimenez *et al.* (2007)	Ecuador	banana	yes	no
Juroszek *et al.* (2007)	Taiwan	tomato	yes	no
Kaut *et al.* (2009)	Canada	wheat	yes	no
Kirchmann *et al.* (2007)	Sweden	barley, wheat	yes	no
Kitchen *et al.* (2003)	Australia	wheat	yes	no
Liebhardt *et al.* (1989)	United States	maize, soybean	yes	no
Lockeretz *et al.* (1980)	United States	maize	yes	no
LTRAS	United States	maize, tomato	no	no
Lyngbaek *et al.* (2001)	Costa Rica	coffee	yes	no
Mäder *et al.* (2002b)	Switzerland	potato, wheat	yes	yes
Martínez-Sánchez (2008)	Nicaragua	coffee	no	no

Martini *et al.* (2004)	United States	maize, tomato	yes	no
Mazzoncini *et al.* (2006)	Italy	sunflower	yes	no
Mazzoncini *et al.* (2007)	Italy	wheat	no	no
Pezzarossa *et al.* (1995)	Italy	maize	yes	no
Pieper and Barrett (2009)	United States	tomato	yes	no
Polat *et al.* (2008)	Turkey	lettuce	yes	no
Porter *et al.* (2003)	United Sates	maize, oat, soybean, alfalfa	yes	yes
Posner *et al.* (2005)	United States	maize, soybean	no	no
Raupp (1996)	Germany	beetroot, carrot, potato, rye	no	yes
Raupp (1999)	Germany	rye	no	no
Reganold *et al.* (1987)	United States	wheat	yes	no
Reganold *et al.* (2001)	United States	apple	yes	yes
Riahi *et al.* (2009)	Tunisia	tomato	yes	no
Russo and Taylor (2006)	United States	cucumber, pepper, sweet corn, wheat	yes	no
Ryan *et al.* (2004)	Australia	wheat	yes	no
Sellen *et al.* (1996)	Canada	cabbage, bean, onion, sweet corn, tomato	yes	no
Stonehouse *et al.* (1996)	Canada	wheat	yes	no
Swezey *et al.* (1994)	United States	apple	yes	no
Swezey *et al.* (2007)	United States	cotton	yes	no
Teasdale *et al.* (2007)	United States	maize, wheat	yes	no
Torstensson *et al.* (2006)	Sweden	barley, oat	yes	no
Knudsen *et al.* (2010)	China	soybean	yes	no
Valkila (2009)	Nicaragua	coffee	yes	no
Wang *et al.* (2008)	United States	lettuce	yes	no
Warman and Havard (1997)	Canada	cabbage, carrot	yes	yes
Warman and Havard (1998)	Canada	sweet corn, potato	yes	yes
Welsh *et al.* (2009)	Canada	flax, wheat	yes	no
WICST (2007)	United States	maize, soybean, wheat	no	no

Table S2.5. The influence of categorical variables on *k* yield effect sizes. Significant influence of categorical variables is indicated by the between-group heterogeneity (Q_B) with df degrees of freedom. In some cases not all 316 yield observations could be included and the categorical analysis had to be restricted to the *k* effect sizes that reported information on the relevant categorical variable.

Categorical variable	***k***	**df**	**Q_B**
Author	305	47	411.91***
Study	303	52	414.90***
Study site	296	42	371.87***
Country	313	14	248.55***
Continent	316	5	71.15***
Country development	316	1	48.58***
Latitude	316	2	2.22
Crop type	316	10	32.76***
Crop species	304	23	236.89***
Perennial/annual	316	1	5.16*
Legume	316	1	7.15**
Legume or perennial	316	1	11.98***
Publisher	316	1	3.78
Study type	316	2	9.68**
Comparability	316	1	0.46
Drought	316	1	1.13
Duration of study	316	3	11.39*
Time since conversion	202	2	10.65**
Conventional system type	316	1	9.57**
Organic system type	316	3	15.83**
Conventional yield comparability	308	2	26.57***
Best management practices	316	1	13.21***
Crop rotation	277	3	31.11***
Multi cropping	265	3	4.25
Non-food rotation	270	2	5.40
Organic fertilizer type	292	3	5.80
Green manure	246	1	7.82**
Animal manure	292	1	0.35
N input amount	238	2	20.68***
Irrigation	316	1	46.41***
Tillage	152	3	3.32
Growing degree days	284	1	5.12*
Moisture index	284	2	0.14
Soil carbon	284	2	3.63
Soil pH	310	2	38.34***

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table S2.6. The significance of selected categorical variables in a sub-categorical analysis, with each class represented by *k* effect sizes. dev: country development, per: perennial & leg: leguminous growth form, irr: irrigation, BMP: best management practices, rot: crop rotation, N fert: N fertilizer amount, soil pH, yield conv: conventional yield comparability, study type. A significant effect (i.e. $p < 0.05$, of the between-group heterogeneity against the chi-squared distribution) is indicated by a "+", no significant effect (i.e. $p \geq 0.05$) by a "-" and combinations of classes and categories for which no sub-categorical analysis could be performed by a "/".

Category	Class	*k*	Dev	Per	Leg	Irrig	BMP	Rot	N fert	soil pH	Yield conv	Study type
Country development	Developed	249	/	+	+	+	+	-	+	-	-	-
	Developing	67	/	+	-	+	/	+	+	+	+	+
Crop type	Vegetables	82	+	/	/	+	+	+	+	+	+	-
	Cereals	161	+	/	/	+	+	-	+	+	+	+
Plant type I	Annual	291	+	/	/	+	+	+	+	+	+	+
	Perennial	25	-	/	/	+	-	-	+	/	-	+
Plant type II	Non-legume	282	+	/	/	-	+	+	+	+	+	+
	Legume	34	-	/	/	+	-	-	+	-	-	-
Irrigation	Irrigated	125	+	-	-	/	+	+	+	+	+	-
	Rainfed	191	-	+	+	/	-	+	+	-	-	+
BMP	BMP no	235	+	+	+	-	/	+	+	+	+	+
	BMP yes	81	/	-	-	+	/	-	-	/	+	-
Crop rotation	No rotation	79	+	+	/	+	-	/	-	+	+	+
	Longer org	38	/	/	-	/	-	/	-	-	-	-
	Similar	156	-	+	+	-	+	/	+	-	-	-
N fertilizer amount	Similar N	51	+	+	+	+	+	+	/	+	+	-
	More conv N	97	-	/	+	+	+	+	/	+	+	+
	More org N	61	+	-	-	+	-	+	/	+	+	/
Soil pH	Weak acidic to weak alkaline	114	+	+	+	-	+	-	+	/	+	+
	Strong acidic	57	+	/	-	+	/	+	+	/	-	/
	Strong alkaline	37	+	/	-	+	/	+	+	/	+	+
Duration of study	Very short	133	+	+	-	+	-	+	-	+	+	+
	Short	92	-	-	-	+	+	+	+	-	+	-
	Medium	36	/	-	-	-	-	-	-	-	-	-
	Long	55	/	-	+	-	-	-	+	/	-	/
Time since conversion	Recent	141	+	+	+	+	+	+	+	+	+	-
	Young	34	+	-	-	-	/	-	-	-	+	-
	Established	27	/	/	/	-	-	+	-	+	-	-

Table S2.7. Between-group heterogeneity (Q_B) for yield effect sizes of the categorical variables describing different plant and crop types within different 'N input amount' classes represented by *k* effect sizes with df degrees of freedom. Sub-categorical analysis indicated by a '/' could not be performed due to a lack of different classes of the categorical variable in the sub-sample.

In class	Categorical variable	*k*	df	Q_B
Similar N input	Legume/non-legume	71	1	3.89*
	Perennial/annual	71	1	18.58***
	Crop type	71	5	102.63***
More conv N input	Legume/non-legume	103	1	13.45***
	Perennial/annual	/	/	/
	Crop type	101	5	20.02**
More org N input	Legume/non-legume	64	1	0.54
	Perennial/annual	64	1	1.48
	Crop type	64	4	2.54

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table S2.8. Between-group heterogeneity (Q_B) for yield effect sizes of the categorical variable 'country development' within different classes describing management practices represented by *k* effect sizes with df degrees of freedom. Sub-categorical analysis indicated by a '/' could not be performed due to a lack of different classes of the categorical variable in the sub-sample.

In class	Categorical variable	*k*	df	Q_B
Irrigated	Country development	125	1	66.29***
No crop rotation		79	1	87.06***
No BMP		235	1	32.70***
Rainfed	Country development	191	1	0.09
Similar crop rotations		156	1	0.02
More org crop rotations		/	/	/
Yes BMP		/	/	/

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table S2.9. Contingency table between the categorical variables 'crop rotation' and 'green manure'.

Crop rotation	Green manure		
	Yes	No	Total
No rotation	0	72	72
Longer organic rotation	22	7	29
Longer conventional rotation	2	0	2
Similar rotation	95	45	140
Total	119	124	243

Table S2.10. Between-group heterogeneity (Q_B) for yield effect sizes of the categorical variables 'green manure' and 'crop rotation' within different 'crop rotation' and 'green manure' classes represented by *k* effect sizes with df degrees of freedom. Sub-categorical analysis indicated by a '/' could not be performed due to a lack of different classes of the categorical variable in the sub-sample.

Categorical variable	In class	*k*	df	Q_B
Green manure	No rotation	73	/	/
	Longer organic rot	29	1	0.27
	Longer conv rot	2	/	/
	Similar rotation	140	1	0.60
Crop rotation	No green manure	124	2	19.90***
	Yes green manure	119	2	0.16

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table S2.11. Between-group heterogeneity (Q_B) for yield effect sizes of different categorical variables within different 'best management practices' (BMP) classes and of the 'BMP' categorical variable within different plant type and 'N input amount' classes represented by *k* effect sizes with df degrees of freedom.

In class	Categorical variable	*k*	df	Q_B
No BMP	N input amount	167	2	10.43**
	Crop rotation	196	3	12.72**
	Legume/non-legume	235	1	4.22*
	Perennial/annual	235	1	6.46*
Yes BMP	N input amount	71	2	0.70
	Crop rotation	81	2	1.37
	Legume/non-legume	81	1	0.90
	Perennial/annual	81	1	0.05
Non-legumes	BMP	282	1	10.31**
Annuals		291	1	14.53***
Similar N input		71	1	18.59***
More conv N input		103	1	10.85***
Legumes	BMP	34	1	3.07
Perennials		25	1	0.10
More org N input		64	1	2.14

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table S2.12. Contingency table between the time categorical variables 'time since conversion' and 'duration of study'.

Duration of study	**Time since conversion**			
	Recent	**Young**	**Established**	**Total**
Very short	67	23	17	107
Short	26	4	7	37
Medium	9	4	3	16
Long	39	3	0	42
Total	141	34	27	202

Table S2.13. Between-group heterogeneity (Q_B) for yield effect sizes of the categorical variables 'duration of study' and 'time since conversion' within different 'time since conversion' and 'duration of study' classes represented by *k* effect sizes with df degrees of freedom.

Categorical variable	**In class**	***k***	**df**	**Q_B**
Duration of study	Recent conversion	141	3	79.75***
	Young conversion	34	3	0.54
	Established conversion	27	2	5.44
	Young & established conversion	61	3	2.94
Time since conversion	Very short duration	107	2	48.31***
	Short duration	37	2	0.30
	Medium duration	16	2	3.91
	Long duration	42	1	0.00
	Short, medium & long duration	95	2	0.97

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table S2.14. List of different sensitivity analysis.

Sensitivity analysis	Categories included	Categories excluded
Best study quality	Peer-reviewed; study design that allows system comparison	Grey literature; study design that does not allow system comparison
Non-food rotation	Both systems have non-food rotation, none of the systems has non-food rotation	Only organic has non-food rotation
Long-term studies	Short, medium & long duration; young & established conversion	Very short duration & recent conversion
Typical conventional	Commercial conventional system; comparable conventional yields	Low-input conventional system; above- or below-average conventional yields
Comparable systems	Study design that allows system comparison; both systems have non-food rotation, none of the systems has non-food rotation; same N fertilizer amount	Study design that does not allow system comparison; only organic has non-food rotation; more organic or more conventional N fertilizer amount
Best org management	Yes BMP; similar crop rotation or longer organic crop rotation	No BMP; no crop rotation
Legumes & perennials	Legumes or perennials	Annual non-legumes
Best org performance 1	Legumes or perennials; optimal or acidic soils; rainfed	Annual non-legumes; alkaline soils; irrigated
Best org performance 2	Optimal or acidic soils; rainfed	Alkaline soils; irrigated

S2.4 SUPPLEMENTARY DISCUSSION

Criticisms of the Badgley et al. study

The main criticisms of the analysis by Badgley *et al.* (2007) were: (i) The use of organic crop yields from systems receiving very large amounts of N from animal manure compared to lower N input in the conventional system (Cassman 2007; Connor 2008; Kirchmann *et al.* 2008); (ii) the use of unrepresentative low conventional crop yields in the comparison (Avery 2007); (iii) failing to consider reduction of yield over time due to rotations with non-food cover crops (Cassman 2007; Kirchmann *et al.* 2008); (iv) comparison of systems that did not receive the same amount of concern for optimization of management practices (Cassman 2007; Kirchmann *et al.* 2008); (v) inclusion of non-organic yields in the comparison (Avery 2007); (vi) multiple-counting of high organic yields (Avery 2007); (vii) inclusion of unverifiable sources from the grey literature and giving them equal weight to rigorous studies that adhered to scientific norms of experimental design and treatment replication (Avery 2007; Cassman 2007). We tried to address these issues either through careful study selection criteria (see main text), or through testing for those effects in a categorical analysis. As a result our dataset differs considerably from the data used by Badgley *et al.* (2007) – only 22 of the 316 yield ratios included in our analysis were also used by Badgley *et al.* (2007).

Sustainable vs. organic agriculture

Organic agriculture was developed in Western countries as a management system that tries to provide consumers with a certain degree of assurance that food is produced in an environmentally friendly way. Originally, the concept of organic agriculture is based on outcomes, not necessarily on specific methods. As these outcomes are however difficult to assess, the actual organic certification process requires specific management practices that are considered best environmental practices, e.g. enhanced crop rotations and crop diversity, use of organic fertilizers and biological pest control. Organic is thus closely tied to the certification and labelling process and to a set of prescribed management methods.

What distinguishes organic from 'sustainable' management is that organic practices are well-defined and in many countries regulated by laws. Considering the wealth of meanings and definitions of 'sustainable', agro-ecological or low-input agriculture it is important to adhere to these rules and standards when discussing organic agriculture (Rigby & Cáceres 2001). We therefore defined organic as certified organic management or non-certified organic management that follows the standards of organic certification bodies.

Farming system vs. management practice comparison

Organic-conventional system comparisons are intended to compare organic and conventional management "systems", i.e. a whole set of different management practices that is typical for the specific management system (including differing use of nutrient inputs, cover crops, crop rotations, weed management etc.) and not individual management "practices". If organic-conventional system comparisons implemented the same crop rotations, the same cover crop management etc. for both the organic and the conventional system and only varied the type of nutrient or pesticide input, this would not be an organic vs. conventional system comparison but a comparison of organic vs. conventional inputs. Organic management involves, however, more than a simple input replacement. Instead of using chemical fertilizers and pesticides it relies on organic nutrient inputs, more diverse crop rotations, multi-cropping and the use of leguminous crops for nutrient and pest management. All of these factors can and should vary between the organic and the conventional system in a valid system comparison.

Similarly, we believe that a valid organic vs. conventional system comparison does not necessarily need to ensure nutrient supply equivalence or a non-limiting nutrient supply in both systems. Instead, we believe that the often-observed differences in nutrient supply to organic and conventional systems are an important part of the system comparison as they capture a difference that might be inherent to the two systems. Our results suggest that the N-limitation of crops is common in typical organic systems. This different N-availability is a characteristic of the organic system that would not be visible if only studies with non-limiting nutrient supply were compared.

Instead of restricting our analysis to studies that implemented similar crop rotations and similar supply of nutrient inputs (which incidentally only very few studies did – only 14 out of the 316 yield observations in our database came from field experiments in which the organic and conventional systems had both similar crop rotations and similar N input quantities), we thus included studies that varied more than one management factor in their system comparison and then specifically tested for the influence of different management practices on the yield difference through the categorical analysis.

Crop rotation & green manure

Studies that did not use a crop rotation in both the conventional and the organic system showed a lower yield ratio than studies, in which the organic system used a crop rotation (Fig. S2.3a). Organic systems depend to a strong degree on crop rotations for nutrient management and crop productivity. The fact that lack of crop rotation disadvantaged organic performance thus also evidences the importance of good management practices for high organic yield performance. As all studies that did not use a crop rotation did not apply green manure (Table S2.9) we checked whether there was an interaction between the green manure (Fig. S2.3b) and the rotation effect (Fig. S2.3a). In a sub-categorical analysis the rotation effect did still show up in those studies applying no green manure, while the green manure effect did not show up in any of the rotation classes (Table S2.10). As the rotation effect thus appears more consistently in the sub-categorical analysis, the difference between studies applying green manure and those that did not is probably due to an underlying rotation effect (i.e. the higher yield ratio of the studies that did apply green manure is due to these studies having a crop rotation).

The nutrient inputs through green manure are difficult to quantify and not all studies included N sources from green manure in the estimate of the N input to the organic system. This could potentially lead to an underestimation of N inputs to the organic system and to a bias of the N input analysis. However, if the analysis was restricted to only those studies that quantified all inputs, the N input amount still had a significant effect on yield ratios ($Q_B = 18.86$, $n = 116$, $df = 2$, $p < 0.001$) and the analysis showed the same pattern as in all studies (Fig. S2.2).

Best management practices

When studies applied best management practices (BMP), the amount of N inputs or the use of crop rotations did not influence the yield ratios anymore, while the use of BMP did not show an effect in the case of legumes and, perennial crops or when the organic system received more N inputs than the conventional system (Table S2.11). The use of BMP thus appears to be only necessary when no other factors contribute to a high organic yield performance; and when BMPs are used, no perennial growth form, capacity for N fixation or large N inputs are required anymore for high organic yield performance.

Time scale

In very short studies, lasting only one or two seasons, and in studies where land had only been converted to organic management recently, i.e. less than three years before study begin, the organic yield ratio was -31% and -30% respectively, while in medium (spanning 6-10 growing seasons) and long (spanning >10 growing seasons) studies or young (converted to organic 4 to 7 years ago) and established organic plots (converted to organic >7 years ago) yield ratios were between -17% and -18% (Fig. 2.2d, Fig. S2.5a). The apparent similarity in the patterns between these two time categories could lead to the surmise that their respective classes co-varied. A contingency table, however, shows that recently converted plots are not necessarily represented by very short studies (Table S2.12). There is, however, still a relationship between the two categories, as in a sub-categorical analysis the time scale only shows up as significant within the class ‘recently converted’, while the time since conversion category only shows up in ‘very short’ studies (Table S2.13; Fig. S2.5b). This shows that both categories represent the same effect: very short studies on land that was recently converted to organic management underestimate organic yield ratios due to lower organic yields during this transition period. This is also evidenced in the lower organic yield ratio in studies on transitional organic systems (Fig. S2.6a).

Soil water processes

Our results suggest that the yield difference between organic and conventional farming systems is smaller in rainfed than in irrigated agriculture (see main article). This result appears to be unrelated to general low availability of water (see Table S2.5). We hypothesize that the better organic performance in rainfed systems could be due to better water-retention properties of soils managed with organic methods. Several studies have suggested that soils in organic systems can have higher water-holding capacities and water infiltration rates than conventionally managed soils (Droogers *et al.* 1996; Colla et al. 2000; Lotter et al. 2003). This has been attributed to the higher soil organic matter content and increased aggregate stability of soils managed with organic methods (Stockdale *et al.* 2001). Soil organic matter increases field capacity more strongly than the permanent wilting point, thus leading to increased available water capacity for crops (Hudson 1994). Organic management could thus, by increasing the soil organic matter content, provide benefits for water management under the variable conditions of rainfed agriculture. The category 'drought' (i.e. whether a drought occurred during the study period) did not, however, show a significant effect (Table S2.5), likely because of too few drought observations (n = 9). The drought-performance of organic agriculture thus needs further investigation.

Farm type

Yield ratios differed between different types of organic farms (Fig. S2.6a). Due to the wide error bars of biodynamic farms and farms in transition to organic management, the main difference is the difference between certified organic systems and systems that only used organic standards but were not certified by an organic certification body. This shows that the certification process increases organic performance, possibly by requiring good farmers knowledge on organic management methods.

The yield ratio does not only depend on organic yields but also on what type of conventional system is taken as comparison, depending e.g. on the input-intensity (Fig. S2.6b). When organic yields were compared to low-input conventional systems, organic yields were not significantly lower than conventional yields (-9%), whereas when they were compared to high-input conventional systems organic yields were 27% lower. In 19 out of the 28 cases from low-input system-comparisons, where the amount of nitrogen inputs were reported, the low-input conventional system received lower amounts of nitrogen than the organic system. The importance of the type of conventional reference system was also evidenced in the difference in yield ratios between studies, in which the conventional yields were representative of local yield averages (i.e. within +/- 50% of local yields) and studies, in which the conventional yields were higher than local averages (Fig. S2.9). This effect was especially pronounced in developing countries (Fig. S2.10a) but was not visible in developed countries (Table S2.6).

Continent

There was a significant difference in yield ratios between different continents – organic performance in North America was higher than in Europe and Asia (Fig. S2.7a). Kirchmann *et al.* (2008) hypothesized that organic yields in Europe and Australia are lower than in the United Sates because of limited purchase of animal manure or compost due to a more traditional understanding of organic agriculture. However, in our meta-analysis the continent effect and the difference between Europe and North America still showed up in studies where the conventional and organic systems received similar N inputs ($Q_B = 99.79$, $n = 71$, $df = 3$, $p < 0.001$) or in systems that did not use any animal manure ($Q_B = 33.76$, $n = 89$, $df = 2$, $p < 0.001$; Fig. S2.7b).

Experimental stations

Experimental stations often have yields that are considerably higher than typical yields achieved on farms under similar conditions. In developing countries this was true for 53 of the 54 conventional yield values from experimental stations, mainly due to 51 of them being irrigated. These high conventional yields in experimental stations in developing countries lead to a low organic yield ratio (-48%) that differed significantly from the yield ratio from surveys (Fig. S2.10a). In the few cases from developing countries where organic yields were compared to conventional yields typical for the location or where the yield data came from surveys, organic yields did not differ significantly from conventional yields because of a large uncertainty range (Fig. S2.10a). In developed countries instead, 154 of 195 experimental station conventional yields were comparable to local yield averages and only 24 were above average. In addition, neither the type of study nor the comparability of the conventional yield had any influence on the yield ratio in developed countries (Table S2.6). The yield ratio in developed countries is thus not biased due to untypically high conventional yields in experimental stations, while the developing country yield ratio appears to be underestimated because of over-representing irrigated experimental stations with above-average conventional yields.

Developing country interactions

Studies in developing countries had relatively similar characteristics, e.g. they were mostly irrigated, came from experimental stations, had above-average conventional yields and in addition they did not apply best management practices (BMP) and did not use crop rotations (as discussed in the main text). Because of this covariance of several relevant factors it is difficult to identify the one that is responsible for the poor organic performance in developing countries. We tried to examine potential interactions between categorical variables by conducting several sub-categorical analyses. Irrigation appears to be a strong effect as it shows up both in developed and developing countries (Table S2.6; Fig. S2.10b). Similarly, the BMP effect still shows up in developed countries and the crop rotation effect shows up within developing countries (Table S2.6). This implies that the irrigation, BMP and crop rotation effects are not due to an underlying developing/developed country effect. However, developing countries still have a lower yield ratio than developed countries in irrigated studies, in studies that do not apply BMP and in studies that do not use any crop rotation, while under rainfed conditions and similar crop rotations the developing country effect disappears (Table S2.8). This can be interpreted as showing that developing country yield ratios are similar to developed country yield ratios when they are rainfed or use a crop rotation, while they are lower than developed country yield ratios under irrigated conditions due to a lack of BMP and crop rotations and they are lower under 'no BMP' and 'no rotation' conditions due to irrigation.

This difficulty in dissecting the effect of different factors for developing countries is due to a relatively small sample size (67 yield ratios coming from 14 different studies) and the similarity between studies discussed above. To examine how our study selection criteria that studies had to report (or we could estimate) an error term and sample size influenced yield ratios, we compared the mean yield ratio of the data that was included in the meta-analysis with the data that met our basic selection criteria (i.e. selection criteria i to iv) but did not report an error term and sample size. The (unweighted) average organic-to-conventional yield ratio of the 316 yield observations that we included in our meta-analysis (see Supplementary Data 1) and the 268 yield ratios that met the basic selection criteria but did not report error term and sample size (see Supplementary Data 2) did not differ from each other (t-test, $t = 1.56$, $df = 582$, $p = 0.12$). When examining developed and developing countries separately, in developed countries the yield ratios included and the yield ratios excluded also did not differ (t-test, $t = 0.49$, $df = 445$, $p = 0.63$). In developing countries, instead, the yield ratios included in the meta-analysis were significantly lower than the yield ratios that were not included (t-test, $t = 4.60$, $df = 135$, $p < 0.001$). The restriction of the meta-analysis to studies that reported data in higher detail could thus contribute to the low organic performance observed in developing countries in our meta-analysis, by selecting for studies that were conducted under similar conditions that are unfavourable for organic crops. However, even within all 584 yield observations that met our basic study selection criteria (t-test, $t = 4.08$, $df = 582$, $p < 0.001$) or within those 268 yield observations that could not be included in the meta-analysis due to missing error term and sample size (t-test, $t = 1.92$, $df = 266$, $p < 0.05$) developing country yield ratios were significantly lower than developed country yield ratios.

The low organic yield ratio of developing countries also influences other results of the meta-analysis. We therefore examined how developing countries and the unrepresentative low conventional yields of some studies conducted in developing and developed countries influence some of the sensitivity analyses. If the 'comparable systems' sensitivity analysis is restricted to studies with conventional yields that are comparable to regional averages, then the yield ratio changes from the original 0.66 ($n = 64$) to 0.87 ($n = 26$) and if it is restricted to developed countries it changes to 0.92 ($n = 36$). The 'best org management' and 'best org performance 1' sensitivity analyses do, however, not change strongly under the same conditions – 'best org management' changes from 0.87 ($n = 76$) to 0.85 ($n = 65$) and to 0.87 ($n = 76$) respectively and 'best org performance 1' changes from 0.95 ($n = 36$) to 0.91 ($n = 22$) and 0.95 ($n = 35$) if restricted to comparable conventional yields or developed countries. This shows that most studies that fall into the 'best org management' or 'best org performance 1' category have conventional yields that are comparable to regional averages and are conducted in developed countries, while the yield ratio of the 'comparable systems' sensitivity analysis is as low also because of the inclusion of yield data from developing countries and from studies using unrepresentative conventional yields.

Biophysical growing conditions

It has been hypothesized that differences between organic and conventional yields increase, the better the biophysical conditions are (Halberg et al. 2006). Under unfertile conditions organic methods accordingly improve plant-available nutrients, while application of mineral fertilizers does not lead to substantial yield increases. Under fertile conditions instead, organic methods cannot match the high potential yields achieved by conventional systems. In this meta-analysis neither the moisture index (as an indicator of water availability), soil carbon content (as an indicator of soil fertility) nor the latitude showed any influence on yield ratios (Table S2.5). Soil pH (Fig. 2.2e) and growing degree days (GDD; Fig. S2.8) were the only biophysical variables that had an effect on organic yield ratios. However, these variables rather showed an opposite pattern: under unfavourable conditions, i.e. on strongly acidic and strongly alkaline soils or under a short growing season in northern latitudes, organic yield ratios were lower than under more favourable conditions. The majority of studies were, however, conducted on sites with favourable conditions and classified as being highly suitable according to the initial threshold definitions used (276 of 284 studies were classified as having high moisture index, 263 of 284 as having high GDD and 237 of 284 as having high soil carbon content). We therefore also tested a different categorization using different thresholds [i.e. 'low' being below 70%, 'medium' between 70% and 100% (90% for C_{soil}), and 'high' being a probability of cultivation of 100% (or higher than 90% for C_{soil})]. This did, however, not change the overall result (i.e. the small effect of GDD and the lack of effect of moisture index and soil carbon content; results not shown). To assess the hypothesis of better organic performance under unfavourable conditions, experimental field trials under a wider range of climatic and edaphic conditions need to be conducted.

Limitations

A common problem in meta-analysis is the lack of independence of data. To assess the independence of data from the same study, same study site or same author we included the variables 'study', 'study site' and 'author' in the meta-analysis. All of these variables showed up as strongly significant (see Table S2.5). This indicates that data coming from the same study, the same study site or from research conducted by the same principal author is not independent. This could be either because of identical study characteristics like management methods or the crop species tested or because of the characteristics of the study site. A categorical analysis, i.e. a meta-analysis with a hierarchical structure, is a way to deal with such non-independence. Some of the factors that make data non-independent could be captured by the categorical analysis, while others (e.g. yield measurement technique, machinery use, pesticide use, crop varieties) might have not been accounted for.

We tested for the effect of different management practices, study and site characteristics on the yield ratios. But again, different management practices and site and study characteristics might not be independent. Management practices are often part of a certain management system. Mixed crop-livestock systems might for example apply animal manure and include forage or fodder crops in their rotation, while plant-based systems might typically use compost and include cover crops and a fallow in their rotation. On the other hand, certain site characteristics might require certain management practices (e.g. vegetables in dry climates being often irrigated) or certain study characteristics might follow from other study characteristics (e.g. irrigated crops having often yields that are higher than local yield averages). We tried to dissect such interactions by performing sub-categorical analysis and by examining contingency tables (see e.g. discussion of green manure and crop rotation interaction).

To test the robustness of the results discussed in the paper we checked whether the effects of the different categorical variables also showed up in a sub-categorical analysis (Table S2.6) and whether the resulting pattern was similar in these sub-categories. Most of the effects discussed in the paper were confirmed in sub-categorical analysis. The difference between irrigated and rainfed yield ratios (i.e. rainfed yield ratio > irrigated yield ratio) for example showed up in all of the different latitude, study type and N input quantity classes. While the soil pH effect showed up in fewer classes (e.g. in developing, irrigated and no rotation but not in developed, rainfed and similar or longer organic rotation), it showed a similar pattern in these classes as in all studies. In the cases where the effect showed a different pattern in different classes in a sub-categorical analysis, this is discussed in the text.

Another common issue in meta-analysis and any published research is the bias to publish only significant results (publication bias). If the effect size is expected to vary across experiments, the fail-safe number is an appropriate method for testing for publication bias (Gurevitch & Hedges 1999). In the present meta-analysis the fail-safe number estimated with Rosenthal's method is that 660,526 studies with null-results (i.e. with an effect size of 0) would be needed to make the mean yield response non-significant. This is considerably higher than the critical value (5n + 10 = 1590, with n as the number of original studies included in the meta-analysis) suggested by Rosenthal (1979). It is thus unlikely that unpublished non-significant yield responses would overturn the significant negative yield ratio.

S2.5 SUPPLEMENTARY REFERENCES

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CONNECTING STATEMENT

In the previous chapter I examined the yield performance of organic systems. I concluded by identifying situations where organic yield performance is highest, as well as situations where it is lowest. In the following chapter I will move from an agronomic to an ecological analysis of organic agriculture, but asking a similar question about how different contexts influence the performance of organic agriculture. Specifically, I will to examine my research question 2, trying to identify how landscape context influences the biodiversity benefit of organic management. As in Chapter 2 I will use a global meta-analysis of the scientific literature to address this question. The study is situated within and contributes to the literature on landscape ecology.

3. LANDSCAPE CONTEXT CONTROLS THE BIODIVERSITY BENEFITS OF ORGANIC AGRICULTURE

“Utopia lies at the horizon. When I draw nearer by two steps, it retreats two steps. If I proceed ten steps forward, it swiftly slips ten steps ahead. No matter how far I go, I can never reach it. What, then, is the purpose of utopia? It is to cause us to advance.”

- Eduardo Galeano

In preparation for *Landscape Ecology*.

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3.1 ABSTRACT

The most important driver of biodiversity loss today is the conversion of natural habitats for human land uses, mostly for the purpose of food production. To address the current biodiversity crisis we need to develop more wildlife-friendly agricultural practices. Organic farming has been shown to typically host higher biodiversity than conventional farming. But how is the biodiversity benefit of organic management dependent on the landscape context farms are situated in? And what landscape characteristics influence the effectiveness of organic management for biodiversity preservation? We conducted a meta-analysis of the scientific literature to answer this question, compiling the most comprehensive database to date of studies that monitored biodiversity in organic versus conventional fields. We also characterized the landscape surrounding these fields using remote sensing datasets. Our analysis shows that organic management can improve biodiversity in agricultural fields substantially, but that the biodiversity benefit of organic farming is strongly dependent on landscape context. The type of landscape where organic management is most effective at preserving biodiversity varies, however, between different organism groups. Organic management is most effective for plants and arthropods in compositionally and configurationally homogeneous landscapes, for soil organisms in compositionally heterogeneous landscapes, and for birds in landscapes with high forest cover. Generally, organic management appears to have the strongest influence on species in situations where biodiversity is low. We further show, for the first time in a meta-analytic study, that landscape configuration has an effect on biodiversity in agricultural fields that is independent from the influence of composition.

3.2 INTRODUCTION

Species extinction rates today are much higher than they would be without human influence; and researchers recently suggested that we are already in the midst of a sixth mass extinction (Ceballos *et al.* 2015). The most important driver of this biodiversity loss is the conversion of natural habitats for human land uses, mostly for the purpose of food production (Pereira *et al.* 2012; Laurance *et al.* 2014). Accordingly, conservation efforts have typically focused on the preservation of natural habitats like forests in protected areas and have emphasized the reduction of deforestation rates as a key mechanism to reduce extinctions. The idea that species survive in forest islands surrounded by uninhabitable agricultural land, is, however, misguided (Mendenhall *et al.* 2014). Preservation of species on a human-dominated planet (Ellis & Ramankutty 2008) depends as much on the quality and hospitability of the agricultural matrix, as it does on the availability of sufficient natural habitat (Vandermeer & Perfecto 2007). We therefore need to pay equal attention to the development of more wildlife-friendly farming practices to protect biodiversity as to nature conservation through protected areas (Mendenhall *et al.* 2014).

Organic farming potentially constitutes such a wildlife-friendly farming system, as it has been shown to host higher biodiversity than conventional agriculture (Bengtsson *et al.* 2005; Crowder *et al.* 2010; Kennedy *et al.* 2013; Tuck *et al.* 2014). But beyond studying this overall pattern, it is also important to study underlying variations in the effectiveness of organic agriculture in preserving biodiversity. To implement organic farming as an effective means for protecting biodiversity we need to understand better under what conditions organic management is most beneficial for species.

One factor that strongly influences the relationship between agricultural management practices and biodiversity is landscape context. The survival of a species depends strongly on the amount and layout of suitable habitat in the surrounding for its different life stages (Benton *et al.* 2003; Tews *et al.* 2004; Fischer & Lindenmayer 2007). Numerous studies have already examined the influence of landscape context on the biodiversity benefits of organic management (e.g. Rundlöf & Smith 2006; Gabriel *et al.* 2010; Holzschuh *et al.* 2010; Jonason *et al.* 2012) or of agro-environmental management[5] (Concepcion *et al.* 2012). A couple of meta-analyses have also addressed

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[5] Although the terms ‘organic’, ‘agro-environmental’, ‘agro-ecological’, and ‘wildlife-friendly’ management are used almost interchangeably here, they are not entirely equivalent. Organic management denotes management following rules as laid out in organic regulations; agro-

the question in a more synthetic manner for both organic agriculture (Kennedy *et al.* 2013; Tuck *et al.* 2014), as well as more general agro-ecological management (Batáry *et al.* 2011).

Based on ecological theory Tscharntke *et al.* (2005) suggested a non-linear humpback-shaped relationship between landscape context and the effectiveness of agri-environmental schemes, where biodiversity is most strongly enhanced by management in landscapes with intermediate amount of non-cropped habitat. According to this theory, the effectiveness of agro-environmental management for biodiversity is low in cleared landscapes with little natural habitat, due to the limited species pool available to recolonize agricultural fields. While in highly complex landscapes with high quantity of natural habitat in the surrounding, management does not matter much as biodiversity is generally high. In landscapes with intermediate amount of habitat, instead, the species pool is sufficiently large so that wildlife-friendly management can provide a positive influence on biodiversity. Concepción *et al.* (2008, 2012) tested this theory using empirical data from several different regions across Spain and Europe, and found confirmation for the humpback-shaped response of the effectiveness of agro-environmental management along a gradient of habitat availability, as well as along a gradient of landscape connectivity, from cleared, to intermediate to more complex landscapes[6].

Other studies only distinguished between two different types of landscapes, omitting the separate category of cleared landscapes (or lumping it with intermediate habitat landscapes), and observed that organic or agro-environmental management only

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environmental management denotes management as supported by European Agro-Environmental Schemes (AES); agro-ecological management denotes any management practice following principles of agro-ecological agriculture (Altieri 2002); wildlife-friendly management denotes any management that results in higher biodiversity in agricultural fields.

[6] Although Tscharntke *et al.* (2005) used different terminology - describing landscapes with low (<1%) non-cropped habitat as 'cleared', landscapes with intermediate amount (1-20%) as 'simple' and landscapes with high amount (>20%) of non-cropped habitat as 'complex' - they refer to the same idea as the terms 'simple', 'intermediate', and 'complex' landscapes used by Concepcion *et al.* (2008, 2012).

enhanced biodiversity in simple and not in complex landscapes[7] (Roschewitz *et al.* 2005; Rundlöf & Smith 2006; Rundlöf *et al.* 2008b; Dänhardt *et al.* 2010; Smith *et al.* 2010; Batáry *et al.* 2011). But some other studies did not find any effect of landscape context on the effectiveness of organic management and concluded that landscape complexity influenced biodiversity in organically and conventionally managed fields in the same way (Weibull *et al.* 2000; Purtauf *et al.* 2005).

Many questions remain. Can we conclude that organic management only enhances biodiversity in homogeneous landscapes? What are the characteristics of such landscapes and which characteristics drive the pattern? Do we expect a humpback-shaped relationship between the effectiveness of organic management and landscape heterogeneity across all species and contexts? Or do different organism groups respond to organic management and landscape context differently? In this study we aim to re-assess the question of how the surrounding landscape influences the biodiversity benefits of organic management by examining all existing empirical data on the topic through a systematic quantitative review of the scientific literature.

A unique contribution of our study is that we specifically separate out landscape composition and landscape configuration effects, which most studies on the topic to date have failed to do (but see Concepción *et al.* 2008, and Kennedy *et al.* 2013; and more discussion in next paragraph). Landscape composition denotes the amount of different habitats in the surrounding landscape, while landscape configuration describes the connectivity of these habitats after controlling for the amount of habitat (Fahrig 2003). Landscape configuration both describes the spatial distribution of patches (i.e. placement of patches relative to each other, e.g. their connectivity, aggregation or subdivision), as well as the spatial characteristics of patches (i.e. their shape and size; see Fig. S3.2).

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[7] Note that in this paper we use the terms homogeneous for ‘simple’ landscapes, and heterogeneous to denote ‘complex’ landscapes. We define ‘homogeneous’ landscapes as landscapes that are uniform in composition or structure, while ‘heterogeneous’ landscapes are non-uniform in one of these qualities (Li and Reynolds 1995).

Landscape composition (i.e. habitat availability) and landscape configuration (i.e. habitat fragmentation) are difficult to separate out, as they are typically highly interrelated (see Supplementary Material S3.2). The vast majority of studies examining landscape influence on biodiversity in organic versus conventional fields have therefore only examined compositional heterogeneity, typically using the proportion of semi-natural habitat or the proportion of cropland in the surrounding as a measure of landscape heterogeneity (Roschewitz *et al.* 2005; Rundlöf *et al.* 2008b; Fischer *et al.* 2011b; Winqvist *et al.* 2011; Tuck *et al.* 2014). Some other studies did examine landscape configurational metrics but did not account for the interaction between composition and configuration (e.g. Weibull *et al.* 2003; Ekroos *et al.* 2008; Concepcion *et al.* 2012). Only very few studies to date have teased apart landscape composition and configuration effects on the effectiveness of organic or agro-environmental management (Concepción *et al.* 2008; Holzschuh *et al.* 2010; Kennedy *et al.* 2013).

We compiled the largest meta-analytic database to date on biodiversity in organic versus conventional fields to address the following questions:

1. How does the response of different organism groups to organic management vary according to landscape context?
2. How do landscape composition versus configuration effects drive the response?
3. Is the response humpback shaped, as previously hypothesized?

3.3 MATERIALS AND METHODS

We conducted a systematic literature review and searched the scientific literature for studies examining biodiversity in organically versus conventionally managed fields[8] (see

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[8] Organic management here represent management following the rules of organic regulations. Organic fields monitored by primary studies were typically certified organic, but not necessarily so. We thus excluded agroecological management practices or low-input systems that were not following rules of organic regulations. Conventional management represents management as dominantly practiced today. We excluded low-input or integrated pest management systems as there were not enough observations to allow for a separate category in the analysis.

Supplementary Material S3.1 for details) and after contacting authors to get more details, were able to include 92 studies in our analysis that provided information about study location as well as site-level biodiversity data, representing 49 different research projects and 290 study sites across North America and Europe (see Table S3.3 in Supplementary Material S3.1).

3.3.1 LANDSCAPE DESCRIPTION

Spatial scale is important in the assessment of species-landscape interactions (Jackson & Fahrig 2014). We therefore described landscape context at four different scales – 1, 2.5, 5 and 10km radius. In the choice of different scales we were limited at the lower end by the quality of the land cover data used, and at the upper end by the biodiversity data included in our analysis. At the lower end, the pixel resolution of the land cover datasets used (250m resolution) did not allow an analysis at a smaller scale than 2.5km. We therefore used a different approach (i.e. high-resolution satellite imagery from Google Earth) to describe landscape patterns at a smaller spatial scale of 1km (see details below). At the upper end, the scale was limited by spatial overlap between different study sites in adjacent regions.

Fragstat

We extracted several variables describing landscape composition and landscape configuration using the software FRAGSTAT v. 4 (McGarigal 2014) from regional 250m resolution land cover datasets (CORINE for Europe and NALCMS for North America, see Supplementary Material S3.1 for details).

There are hundreds of possible metrics available to describe landscapes. But many of these metrics are highly correlated and thus redundant (Riitters *et al.* 1995), making the choice of appropriate metrics a difficult but important step in landscape analyses (Schindler *et al.* 2015). The goal in choosing landscape metrics is to identify a small set of independent metrics that capture multiple biologically relevant characteristics of the landscape without being redundant (Turner *et al.* 2001).

We chose Fragstat variables that represented different aspects of the landscape while being uncorrelated to each other. Li and Reynolds (1994, 1995) proposed five different aspects of landscape heterogeneity: (1) proportion of each land cover type, (2) diversity of land cover types, (3) spatial arrangement of patches, (4) patch shape, and (5) contrast between neighbouring patches. We considered similar landscape aspects, distinguishing between four different groups of landscape characteristics:

I. Composition:
    Ia. %Land cover
    Ib. Land cover diversity
II. Configuration:
    IIa. Shape of patches
    IIb. Spatial arrangement of patches

We selected 2 Fragstat variables as indicators of each of the landscape characteristics Ib, IIa, and IIb (see Table 3.1 for an overview and Supplementary Material S3.1 for a more detailed description of Fragstat indicators used).

Google Earth

We also used high-resolution imagery from Google Earth to manually estimate agricultural area and trace field boundaries within a 1km circular buffer around study sites (see Supplementary Material S3.1 for more details) and extract information on several landscape parameters at higher spatial resolution (see Table 3.1 for an overview). Field boundaries not only provide important habitat for many species and enhance biodiversity (Benton *et al.* 2003), but field perimeter and field size also provide measures of fragmentation, and of the amount of agricultural land in the surrounding[9].

Study and regional variables

In addition to the landscape parameters we also included other study and regional variables in the analysis (see Table 3.2 for an overview). Study variables included for example information about the agricultural system type (arable, grassland, orchard), about the habitat sampled and the average field size of study sites. Unfortunately we were not able to examine the influence of other management practices, like pest or fertility management, as the majority of studies did not provide sufficient information about agricultural management. Even the simple management variables included (i.e. crop rotation and multicropping) contain many data gaps.

In order to control for potentially confounding regional factors like climate and soil, and for which study data were not available, we included variables that have been identified as simple indices of crop suitability (Ramankutty *et al.* 2002) from global 5-minute resolution datasets: soil characteristics from IGBPS-DIS (1998); climatic variables about the length of the growing season and water availability (Ramankutty *et al.* 2002; Deryng *et al.* 2011); slope from HydroSHEDS (Lehner *et al.* 2008) and from the Aster digital elevation model (ASTER GDEM) for latitudes north of 60 degrees (as high latitudes are not provided by HydroSHEDS); and yield gap, i.e. the difference between actual and potential yield, across 16 major crops (Monfreda *et al.* 2008; Licker *et al.* 2010) obtained from EarthStat (http://www.earthstat.org/).

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[9] Note that agricultural area derived from Google Earth includes all agricultural fields, including permanent and arable crops, as well as pastures, while cropland cover derived from Fragstat only includes permanent and arable crops, but does not include pasture (Table 3.1).

Table 3.1. Description of landscape variables included in the analysis.

Variable Name	Description
Fragstat variables (2.5, 5 & 10km)	
Composition - %Land cover	
%Cropland	Arable land and permanent crops
%Grassland	Pasture and natural grassland
%Forest	Forest and shrubland
%Water and wetland	Water bodies and wetland
%Artificial surfaces	Urban and industrial areas
Composition – Land cover diversity	
Patch Shannon Evenness Index (SHEI)	Distribution of the landscape area among different patch types
Patch Richness Density (PRD)	Number of different patch types present
Configuration – Patch shape	
Mean Patch Size (AREA_AM)	Area-weighted mean patch area
Edge Density (ED)	Total length of edges (i.e. patch boundaries) in the landscape
Configuration – Patch spatial arrangement	
Contagion Index (CONTAG)	Probability to find a cell of type i next to a cell of type j; measures the degree of intermixing of different land types (i.e. interspersion), as well as the contiguity of different patch types (i.e. dispersion)
Aggregation Index (AI)	Percentage of like adjacencies; measures the clumpiness of different patch types (i.e. measures dispersion only)
Google Earth variables (1km)	
Composition - %Land cover	
% Agricultural area	Total area covered by agricultural fields (includes arable fields, permanent crops like orchards, as well as pastures)
Configuration – Patch shape	
Field size (km^2)	Average field size
Field number	Number of fields
Total field perimeter (km)	Total length of field perimeter
Field area-perimeter ratio	Field area to field perimeter ratio

Table 3.2. Description of study and regional variables included in the analysis.

Variables	Description
Study variables	
Continent	Europe North America
System type	Arable Grassland Horticultural Orchard
Habitat	Both within and outside field Within field Outside field
Years since conversion	Number of years since conversion to organic management
Crop rotation[1]	No crop rotation Both organic and conventional crop rotation Only organic crop rotation Only conventional crop rotation
Multicropping[2]	No multicropping Both organic and conventional multicropping Only organic multicropping Only conventional multicropping
Study field size	Average size (ha) of fields sampled
Organism subgroup	Phylogenetic order
Regional variables	
Slope	
Moisture Index (Alpha)	Availability of water to plants, expressed as ratio of actual evapotranspiration to potential evapotranspiration
Growing Degree Days (GDD)	Annual sum of daily mean temperatures > 5°C
Soil pH	Regional soil pH from IGBP-DIS dataset
Soil Carbon Density	Regional soil carbon density from IGBP-DIS dataset
Yield Gap	Difference between actual yield (in t/ha, from census data) and potential yield (in t/ha, modelled)

[1] different crops grown in the same field in different years

[2] different crops grown in the same field in the same year

3.3.2 STATISTICAL ANALYSIS

In order to compare the influence of organic relative to conventional management on biodiversity we had to pair organic and conventional farms. We paired unpaired studies (concerning 150/812 biodiversity observations) based on similarity in management practices (if the study involved different treatments), as well as nearest distance (if the study involved different study sites). We checked the appropriateness of this pairing by examining whether farms within a pair showed lower variation in landscape characteristics than farms between pairs using ANOVA (see Supplementary Material S3.1 for more details). In the end (after exclusion due to site overlap, multipairing or ANOVA results, see Supplementary Material S3.1) we were able to include 290 study sites from the original 498 sites for which we had extracted landscape information.

We used the natural logarithm of the response ratio (i.e. the ratio of biodiversity in organic versus conventional farms), a common effect size measure used in meta-analyses (Hedges *et al.* 1999), as our response variable. Two biodiversity metrics were examined: species richness (S) and organism abundance (N).

Linear mixed models

We examined the influence of landscape characteristics on biodiversity in organic versus conventional fields using linear mixed models. We analysed arthropods, birds, plants and soil organisms separately. As we used the natural logarithm response ratio (Hedges *et al.* 1999), the response variable was approximately normally distributed and we therefore used general linear mixed models with Gaussian error distribution to analyse data. As some studies had multiple sites and some sites multiple observations we included study and study site as random effects in the models. Independent variables (see description above) were included as fixed effects.

We based model selection on Akaike Information Criterion (AIC). AIC provides information about the relative quality of a statistical model given a set of data. As AIC is based both on goodness of fit and the complexity of the model, it addresses issues of overfitting. AIC is generally recommended over likelihood ratio tests (LRTs) for inferences on fixed effects in mixed models (Bolker *et al.* 2009).

Cluster analysis

We conducted a hierarchical agglomerative cluster analysis on Fragstat variables using the Ward's method (Kaufman & Rousseeuw 2009) to examine whether clear landscape clusters could be distinguished. We then included identified landscape clusters in univariate models of biodiversity for each organism group at each scale, using dAIC to identify whether inclusion of landscape clusters improved model fit. However, this cluster analysis lumps together different landscape characteristics, and the binary landscape classification resulting from the cluster analysis might hide opposing response of biodiversity to individual landscape variables. This cluster analysis thus allows a preliminary exploration of the influence of broad landscape patterns on biodiversity but it does not identify the specific landscape characteristics driving the patterns.

Differentiating landscape composition from landscape configuration

One of the key goals of our study was to separate landscape composition from landscape configuration effects, as they can often be confounded. To do so, we examined linear as well as quadratic relationships between composition and configuration variables using mixed models including study as random effect. If the inclusion of landscape composition variables as a fixed effect in predicting configuration variables reduced AIC by more than 2 units compared to an intercept-only model, we used the residuals of this relationship as independent variables representing configuration in biodiversity models. The residuals allow us to statistically remove composition and isolate the configuration effect (McGarigal & McComb 1995; Villard *et al.* 1999).

Note that we are including two different field size variables in our analysis – study field size denotes the average field size of the study site, as indicated in the papers (Table 3.2), while the Google Earth variable field size indicates the average field size within a 1km radius around the study site, as derived from Google Earth (see Table 3.1). Field size is often related to compositional metrics like crop diversity (Belfrage *et al.* 2005) or agricultural area. For the Google Earth field size variable we are able to separate out the configurational effect of field size from the compositional effect of agricultural area. For the study field size variable, instead, we are not able to separate configurational from compositional effects due to limited information in studies about cropping patterns.

Repeated regressions

Our dataset includes many different independent variables: 14 study and regional variables (including several categorical ones, see Table 3.2), as well as 5 Google Earth variables and 11 Fragstat variables (or their residuals) at each of the three spatial scales (see Table 3.1). It was therefore impossible to examine all these variables in a single model simultaneously. To achieve some variable-pre-selection we therefore ran repeated univariate regressions on each independent variable. We used AIC to identify un-important variables, excluding them from any further analysis if their ΔAIC < 1.5 compared to the intercept-only model (see Supplementary Material S3.1). We chose this rather low threshold to ensure we did not exclude potentially important variables at this stage. The random-effects structure of study site nested within study was kept the same for all models in the repeated regressions.

For landscape variables (Table 3.1) we examined both linear as well as quadratic fits. To keep models as simple as possible, we only considered quadratic models if they reduced AIC by more than 2 units compared to linear models. We only tested residuals of configuration variables if the associated landscape composition variable reduced AIC by more than 1.5 units; otherwise the configuration variables were tested directly and the composition variable dropped from the model.

Multimodel inference

In ecology it is often not appropriate to assume the existence of a single 'true' model that best describes a complex multivariate biological process. In order to account for uncertainty in variable and model selection, we used multimodel-inference procedures that draw conclusions based on a 'confidence set' of plausible models (Burnham & Anderson 2002). Model selection was based on AIC. While we used first-order AIC for repeated regressions (as these were testing independent variables individually and thus had a small number of parameters, see above), we used second-order AIC (AICc) for multimodel inference, as the global and candidate models typically had a high number of estimated parameters (i.e. $n/K < 40$) (Burnham & Anderson 2002).

Due to high correlation between scales we only included the scale that showed the strongest decrease in AIC if a Fragstat variable was identified at multiple scales in repeated regressions. A global model including all variables identified in repeated regressions was fitted by maximum likelihood (ML) for each organism group (i.e. arthropods, plants, birds and soil organisms) and each response variable (i.e. S and N). Possible candidate models based on this global model were ranked based on AICc, and models with ΔAICc <4 from best model were included in the model set. Models in this set were then re-fitted with restricted maximum likelihood (REML), and the sum of Akaike weights, as well as model-averaged parameters were calculated from this subset of models. Continuous independent variables were standardized (i.e. scaled to have a standard deviation of one, and centred around zero) in order to make parameter coefficients comparable (Schielzeth 2010).

Unconditional model-averaged parameter estimates were calculated as averages across selected models in which the parameter appears. The sum of Akaike weights (w_j) for each parameter j across selected models allows assessing the relative importance of different explanatory variables and can be used for variable selection (Burnham & Anderson 2002). The sum of weights represents, however, only a relative measure of variable importance, and it does not tell anything about the overall model fit (Galipaud *et al.* 2014). We therefore also report conditional (i.e. variance explained by fixed and random effects) and marginal (i.e. variance explained by fixed effects only) R^2 values for mixed–effect models (Nakagawa & Schielzeth 2013) to assess overall model fit.

We considered variables to be important if their w_j was larger than 0.4 (Burnham & Anderson 2002) and if their model-averaged 95% confidence intervals (CIs) did not overlap zero. We checked global models as well as best-fitted models for homoscedasticity, normality and independence by examining residual versus fitted values of models, as well as QQ-plots.

All analyses were carried out in R v. 3.0.2 (R Development Core Team 2013) using the packages 'lme4' (Bates *et al.* 2013), 'MuMln' (Barton 2015), and 'cluster' (Maechler *et al.* 2015).

3.4 RESULTS

Literally all of the biodiversity studies that we could include in our analysis were situated in Europe and North America (see Fig. 3.1). There is very little available literature on the influence of organic farming on biodiversity in tropical or developing countries. The landscapes included in our analysis are dominated by cropland cover, with, on average, only 24% forest cover and 15% grassland (at 5km spatial scale, Fig. 3.2a, b & c). Due to the nature of the land cover products used (see Supplementary Material S3.1, Table S3.1), we were not able to distinguish pasture from natural grassland. Farms that have been monitored for biodiversity under organic versus conventional management are mostly located in wet climates (Fig. 3.2e). In Europe, study locations were mostly at higher latitudes, while in North America they were located at slightly lower latitudes with warmer climates and longer growing seasons (Fig. 3.2f). In general, the agricultural regions studied showed good growing conditions, and rather intensive agriculture with low yield gaps (Fig. 3.2g).

Figure 3.1. Map of study site locations across North America and Europe.

We were not able to include any studies on mammals, amphibians or molluscs in our analysis. Organism groups differed considerably in how they responded to organic management. Overall, organic management increased species richness by 23% for arthropods, 99% for plants, 20% for soil organisms and 16% (ns) for birds (Fig. 3.3). Organism abundance increased by 16% (ns) for arthropods, 124% for plants, 23% for soil organisms and decreased by 21% (ns) for birds (Fig. 3.3).

In general, most models showed a good fit with R^2 typically above 0.3, and up to 0.54 (Table 3.3 and 3.4). In most models it was important to account for the hierarchical structure of the data, as the marginal R^2 (which accounts only for fixed effects) was considerably lower than the conditional R^2 (which accounts for both random and fixed effects). If the marginal R^2 is lower than the conditional R^2, it suggests that there are additional differences between studies and study sites not accounted for by the independent variables included in the models.

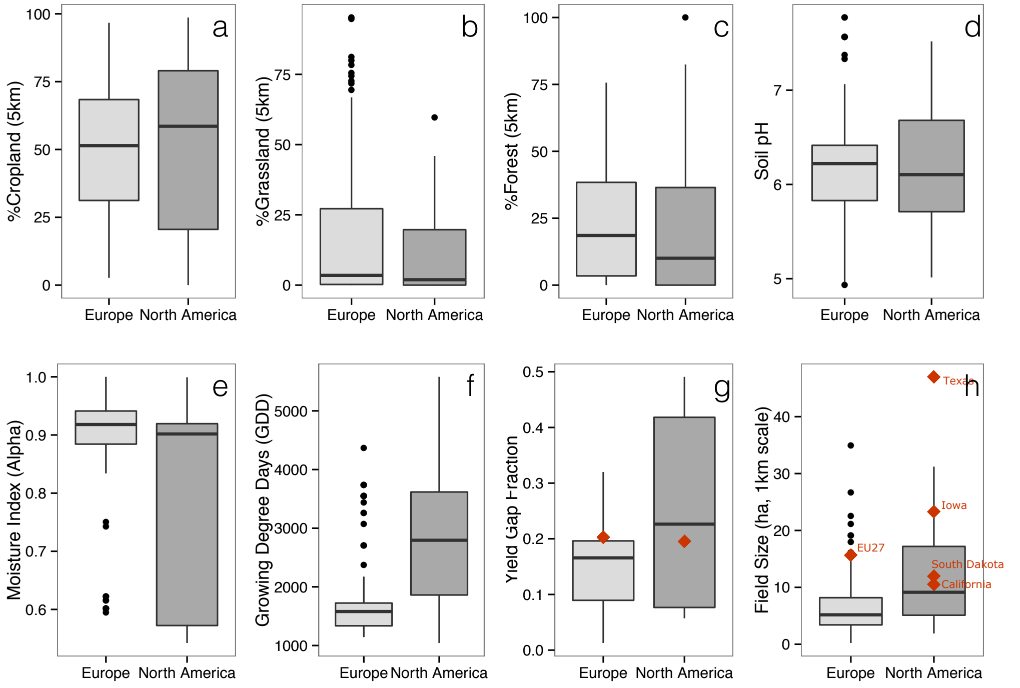

Figure 3.2. Characteristics of study sites in Europe (n=138) versus North America (n=36). Graphs show Tukey boxplots with median, upper and lower quartiles, as well as outliers. Whiskers represent the lowest and highest data points that are still within 1.5 times the interquartile range (i.e. length of the box) from the lower or higher quartiles respectively. In panel 3.2g, the average yield gaps across Europe (area-weighted average yield gap across EU28 countries minus Cyprus and Malta, but including Switzerland and Norway) and North America (including Canada and USA) are shown as red diamonds Panel 3.2h also includes typical field sizes (red diamonds) for Europe (represents area-weighted average field size across EU27 and Switzerland from Reuter and Eden (2008) and Borrelli *et al.* (2015)), as well as for several states in the US (taken from White and Roy (2015) for maize in Iowa, and from Yan and Roy (2014) for Texas, California and South Dakota).

Table 3.3. Results of multimodel inference for organism abundance, showing sum of Akaike weights (w_j), model-averaged partial regression coefficients (β) and unconditional 95% CIs. Akaike weights > 0.4 and CIs that do not overlap 0 are highlighted in bold.

	Soil organisms				Plants				Arthropods				Birds			
Explanatory variables	w	β	CI_{low}	CI_{up}	w	β	CI_{low}	CI_{up}	w	β	CI_{low}	CI_{up}	w	β	CI_{low}	CI_{up}
Study variables																
System type					**0.89**								**0.47**			
Habitat					**1.00**											
Study field size					**1.00**	**0.39**	**0.18**	**0.61**								
Organism subgroup									0.37							
Regional variables																
Soil moisture													0.30	-0.04	-0.93	0.85
GDD													0.36	**0.41**	**0.00**	**0.81**
SCD									0.09	-0.11	-0.25	0.03				
Google Earth variables																
% Agricultural area					0.06	0.01	-0.25	0.26	**0.85**	**0.19**	**0.05**	**0.33**				
Total field perimeter													0.02	0.03	-0.18	0.24
Total field perimeter^2													0.00	/	/	/
Fragstat variables																
%Grassland									0.14	-0.19	-0.50	0.13				
%Grassland^2									0.12	**0.20**	**0.04**	**0.36**				
%Forest	0.24	0.17	-0.06	0.41									**0.83**	**0.61**	**0.15**	**1.06**
%Water & wetland					**1.00**	**-0.54**	**-0.90**	**-0.18**	0.04	-0.07	-0.20	0.05				
SHEI	**0.40**	**0.23**	**0.01**	**0.45**	0.38	-0.21	-0.43	0.02	0.19	-0.13	-0.31	0.06	0.07	-0.11	-0.29	0.08
SHEI^2													<0.01	0.08	-0.07	0.24
ED					0.25	-0.18	-0.42	0.07								
AI	0.19	-0.13	-0.31	0.04												
AI-SHEI res													0.01	0.02	-0.13	0.18
AI-SHEI res^2													0.00	/	/	/

CONTAG					0.26	0.16	-0.14	0.45								
Conditional R^2	0.54				0.48				0.39				0.50			
Marginal R^2	0.09				0.48				0.12				0.43			

Table 3.4. Results of multimodel inference for species richness, showing sum of Akaike weights (w_j), model-averaged partial regression coefficients (β) and unconditional 95% CIs. Akaike weights > 0.4 and CIs that do not overlap 0 are highlighted in bold.

	Soil organisms				**Plants**				**Arthropods**				**Birds**			
Explanatory variables	***w***	**β**	**CI_{low}**	**CI_{up}**	***w***	**β**	**CI_{low}**	**CI_{up}**	***w***	**β**	**CI_{low}**	**CI_{up}**	***w***	**β**	**CI_{low}**	**CI_{up}**
Study variables																
System type					**1.00**								**0.84**			
Habitat					**1.00**				0.04							
Multicropping*													0.05			
Crop rotation*									0.32							
Study field size*					0.03	-0.02	-0.13	0.08					0.05	**0.03**	**0.00**	**0.05**
Organism subgroup									0.00							
Regional variables																
Soil moisture													0.21	-0.09	-0.28	0.10
Soil pH					**0.49**	**0.12**	**0.03**	**0.20**								
Google Earth variables																
% Agricultural area					**0.60**	**0.13**	**0.03**	**0.23**	0.00	0.03	-0.04	0.11				
% Agricultural area ^ 2									0.00	**0.04**	**>0.00**	**0.07**				
Area-perimeter ratio													0.03	0.02	-0.09	0.13
Area-perimeter ratio ^ 2													0.00	0.07	-0.04	0.18
Total field perimeter													0.07	-0.06	-0.16	0.04
Total field													0.02	**0.09**	**0.01**	**0.17**

perimeter ^ 2																
Fragstat variables																
%Grassland									0.05	-0.08	-0.18	0.02				
%Grassland ^ 2									0.05	**0.10**	**0.02**	**0.17**				
%Water & wetland													0.19	-0.09	-0.18	0.00
SHEI	0.23	0.11	-0.03	0.26					**0.95**	**-0.09**	**-0.16**	**-0.02**				
SHEI ^ 2	0.04	-0.13	-0.27	0.01												
PRD					0.09	-0.06	-0.15	0.02								
AREA_AM					0.05	0.03	-0.08	0.15								
ED					0.11	-0.07	-0.16	0.02								
ED-SHEI res									**1.00**	**-0.09**	**-0.14**	**-0.04**				
AI					**1.00**	**0.16**	**0.07**	**0.25**								
CONTAG-SHEI res									0.00	-0.01	-0.11	0.08				
Conditional R^2	0.36				0.45				0.29				0.13			
Marginal R^2	0.07				0.44				0.12				0.10			

*Covariates were tested in separate models with smaller sample size due to large number of missing values.

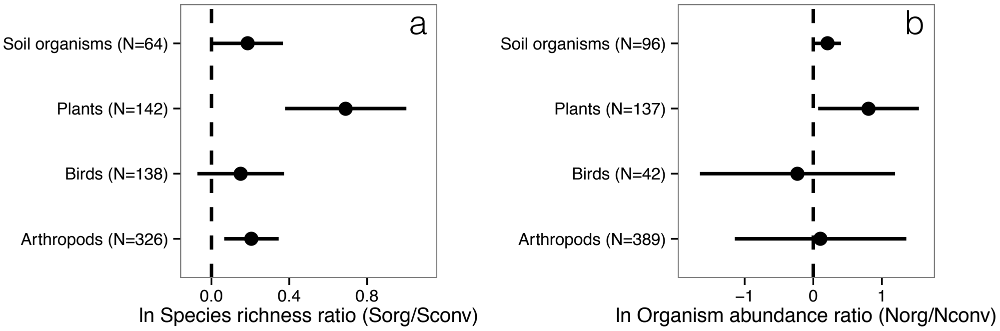

Figure 3.3. Effectiveness of organic management for species richness (a) and organism abundance (b) of different organism groups. Values represent model-averaged intercepts as well as unconditional 95% CIs from the set of best models for each organism group (see Table 3.3 for organism abundance and Table 3.4 for species richness). The number of observations for each organism group is shown in parentheses. The effect of organic management is considered to be significantly different from zero if CIs do not overlap zero. Note that biodiversity ratios are represented as natural logarithms and not back-transformed.

The study variables that regularly showed high Akaike weights were 'System Type' (i.e. arable versus grassland) and 'Habitat' (i.e. biodiversity sampled within fields, outside fields or across whole farms, Table 3.3, 3.4, Supplementary Fig. S3.4, S3.5). Here we focus on the discussion of landscape results, but see Supplementary Material S3.4 for a more in-depth discussion of these general results.

A cluster analysis of landscape variables showed a strong clustering into two different landscape types (Agglomerative Coefficient AC=0.99 at 2.5km, AC=0.98 at 5km, and AC=0.98 at 10km scale; AC values close to 1 indicate that a clear structure has been found, Kaufman & Rousseeuw 2009). The homogeneous landscapes (Fig. 3.4a) are dominated by agricultural land cover (on average 70%), have low forest cover (6.7%), high aggregation (i.e. CONTAG and AI), low edge density, and large average patch sizes. The heterogeneous landscapes, instead, have higher forest cover (32%), lower agricultural cover (45%), lower aggregation, higher edge density and smaller average patch sizes (Fig. 3.4b).

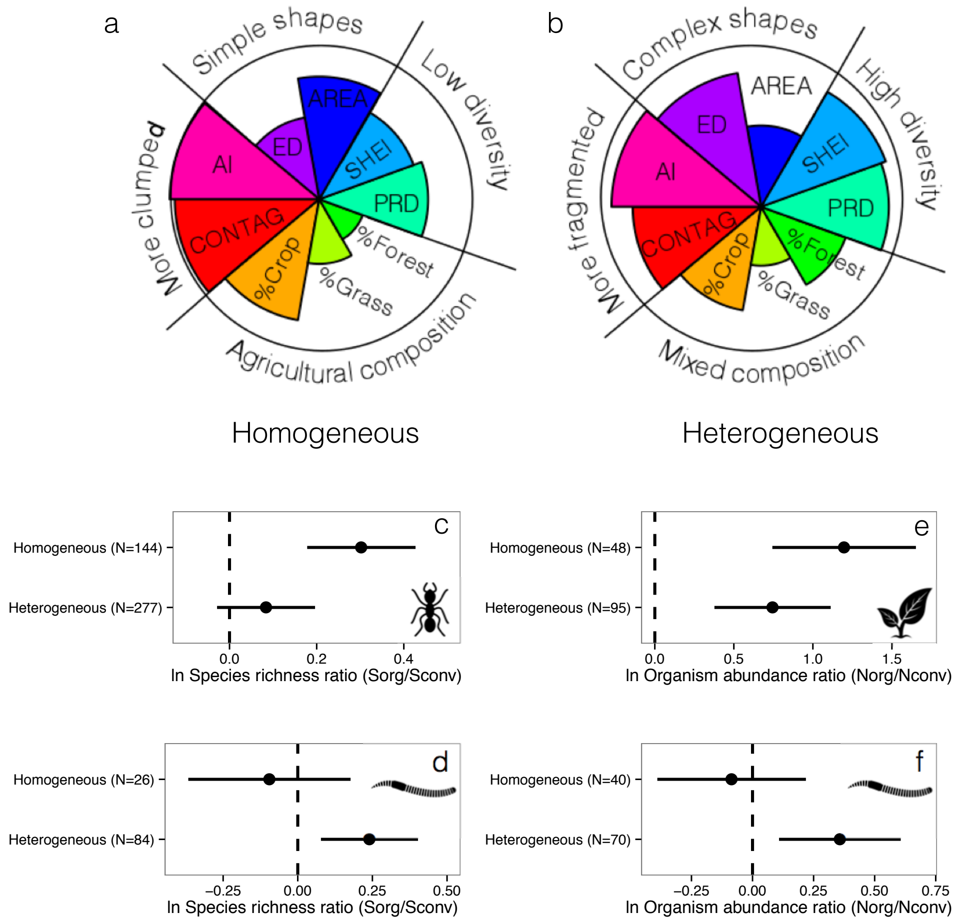

Figure 3.4. The homogeneous and heterogeneous landscape clusters identified. Upper two panels show average landscape characteristics (relative to maximum, non-outlier values across all study sites) for homogeneous landscapes (a) and heterogeneous landscape clusters (b). See Table 3.1 for variable description. The lower panels show influence of these landscape clusters on the effect of organic management on species richness of arthropods (c), soil organisms (d), and on organism abundance of plants (e) and soil organisms (f). Note that biodiversity ratios are represented as natural logarithms and not back-transformed.

The landscape clusters identified were able to explain biodiversity differences between organically and conventionally managed fields for soil organism and arthropod species richness (Supplementary Table S3.5, Fig. 3.4c, 3.4d), as well as for plant and soil organism abundance (Supplementary Table S3.5, Fig. 3.4e, 3.4f). Arthropods and plants showed higher biodiversity in organic fields in homogeneous landscapes, while soil organisms benefitted more from organic management in heterogeneous landscapes.

Examining different components of landscape heterogeneity individually showed that for arthropod richness and soil organism abundance the diversity of land cover types was of importance (Fig. 3.5b, 3.6d). We also observed, however, a strong influence of individual land cover types on the effectiveness of organic management – plant richness and arthropod abundance were influenced by the amount of agricultural area, plant abundance by the amount of water and wetlands, and bird abundance by forest cover (Fig. 3.5, 3.6).

Examining the relationship between landscape composition and landscape configuration metrics in order to separate these effects, we observed strong linear and/or quadratic relationships between SHEI, PRD and landscape configuration variables at 2.5, 5, and 10km scale, as well as between Total Agricultural Area, and landscape configuration at 1km scale (see Supplementary Table S3.4 and Fig. S3.2). Beyond the effect of landscape composition, landscape configurational variables showed an influence on the effect of organic management on species richness of plants and arthropods (Fig. 3.5). The abundance of plants was also influenced by study field size, a configurational metric (Fig. 3.6).

Generally, the analysis of individual landscape variables confirmed the results of the cluster analysis. Organic management increased biodiversity of arthropods and plants more in homogeneous landscapes with high coverage of agricultural area, with low land cover diversity, low edge density, and high clumpiness (i.e. aggregation index, Fig. 3.5, 3.6). The abundance of soil organisms, instead, benefitted more from organic management in more heterogeneous landscapes with high SHEI (Fig. 3.6d). The effectiveness of organic management for birds was, instead, not dependent on landscape heterogeneity (birds did not show any response to landscape clusters, Fig. 3.4), but bird abundance benefitted most from organic management in highly forested landscapes (Fig. 3.6c).

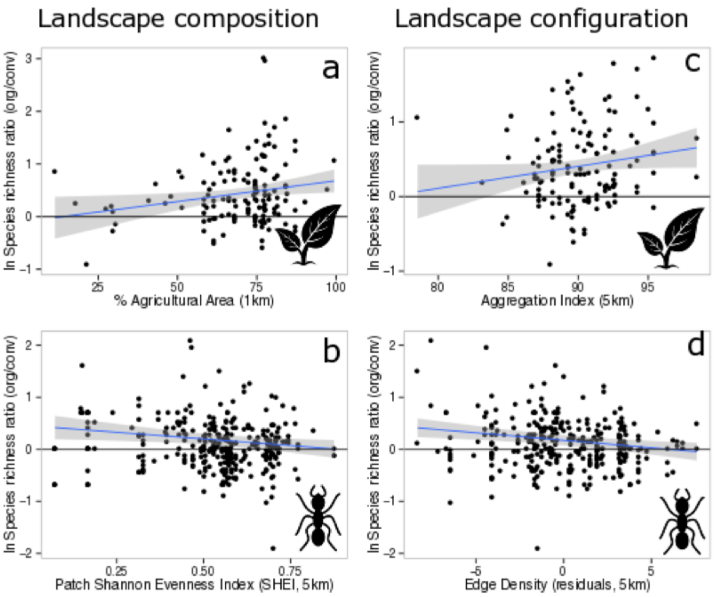

Figure 3.5. Effectiveness of organic management for species richness of different organism groups depending on landscape composition (panels a and b) and landscape configuration (panels c and d). The graphs depict regression lines from univariate mixed models (i.e. not accounting for other independent variables), as multivariate models are difficult to depict in two dimensions. Only relationships with independent variables where the 95% CI of model-averaged partial regression coefficients does not overlap 0, and where Akaike weights > 0.4 (see Table 3.4) are shown. Shaded area represents 95% CI. Note that biodiversity ratios are represented as natural logarithms and not back-transformed.

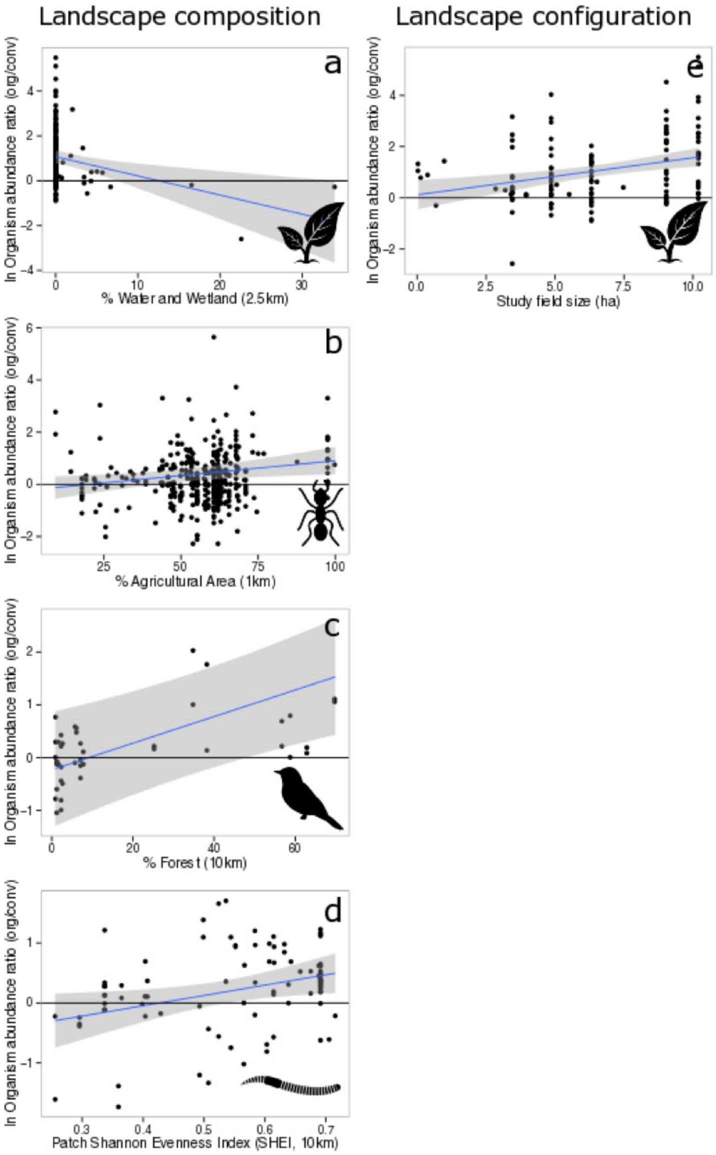

Figure 3.6. Effectiveness of organic management for organism abundance of different organism groups depending on landscape composition (panels a-d) and landscape configuration (panel e). The graphs depict regression lines from univariate mixed models (i.e. not accounting for other independent variables), as multivariate models are difficult to depict in two dimensions. Only relationships with independent variables where the 95% CI of model-averaged partial regression coefficients does not overlap 0, and where Akaike weights > 0.4 (see Table 3.3) are shown. Shaded area represents 95% CI. Note that biodiversity ratios are represented as natural logarithms and not back-transformed.

3.5 DISCUSSION

Numerous primary studies have concluded that landscape context matters more for biodiversity than management (Weibull *et al.* 2000; Belfrage *et al.* 2005; Purtauf *et al.* 2005; Isaia *et al.* 2006; Piha *et al.* 2007; Boutin *et al.* 2009; Boutin *et al.* 2011; Jonason *et al.* 2012). Here we show across multiple regions, multiple organism groups, and multiple studies that under certain landscape conditions organic management has a significant positive impact on biodiversity for all organism groups (note that the regression lines in Fig. 3.5 and 3.6 are significantly different from zero, as the CIs do not overlap zero, at some point along the curve in all graphs; also note that none of the CIs go below zero, suggesting that biodiversity in conventional fields is never significantly higher than in organic fields.). Despite the large variation in how biodiversity and the effectiveness of organic management for biodiversity respond to landscape context (see Supplementary Fig. S3.7 for an overview of relationships observed in primary studies) we find consistent landscape patterns and conclude that the effectiveness of organic management for biodiversity of all organism groups depends to some extent on landscape characteristics (see Fig. 3.7 for an overview).

Our study shows that plants and arthropods generally benefit most from organic management in homogeneous landscapes (Fig. 3.4, 3.5 and 3.6). This is consistent with primary studies that have often observed this pattern of higher effectiveness of organic management in homogeneous landscapes (Supplementary Fig. S3.7). The response can be explained by one of three possible patterns: (1) a stronger increase in biodiversity in conventional than organic fields with increasing landscape heterogeneity (Fig. 3.8a), (2) an increase in biodiversity from homogeneous to heterogeneous landscapes in conventional fields alone (Fig. 3.8b), and/or (3) by a decrease in biodiversity from homogeneous to heterogeneous landscapes in organic fields alone (Fig. 3.8c).

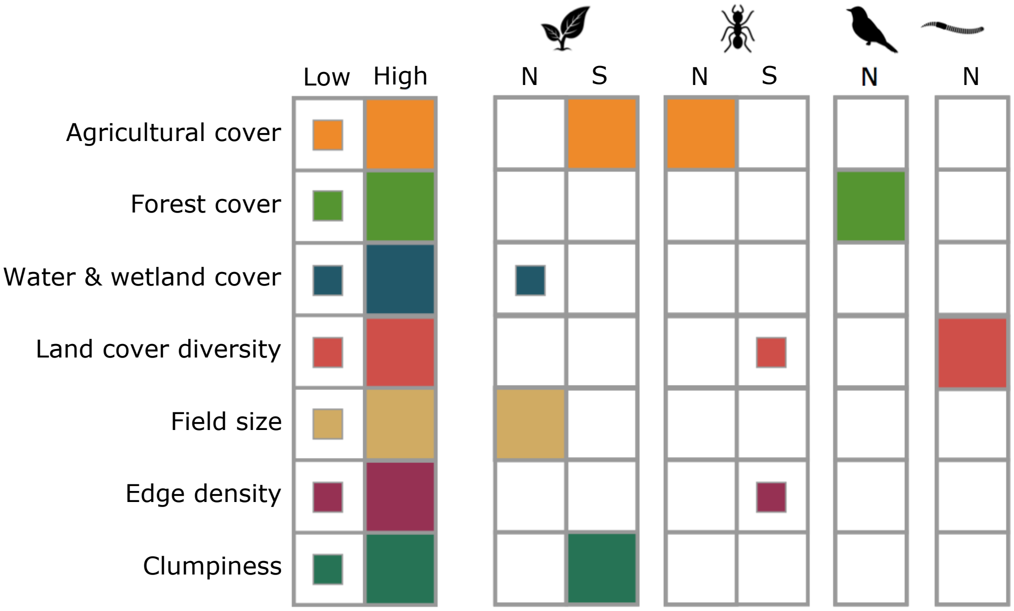

Figure 3.7. Landscape context in which organic management is most effective at increasing organism abundance (N) or species richness (S) of different organism groups. This represents a summary of all results depicted in Fig. 3.5 and 3.6. Empty cells indicate that the landscape variable did not have an influence on organic effectiveness.

Our paired farm study design did not allow us to examine the relationship between landscape context and absolute biodiversity in organic versus conventional fields (sampling methods and organisms sampled would differ too much between sites to allow any useful comparison of absolute biodiversity values). Given that primary studies have found all three types of responses (see Supplementary Fig. S3.7g, h, u, w for pattern a, Supplementary Fig. S3.7j, z, aa, ab, af, ag for pattern b, and Supplementary Fig. S3.7j, aa, af, ag for pattern c), it is difficult to draw conclusions about what drives this relationship between landscape pattern and the effectiveness of organic management. In order to conduct a meta-analytical comparison of absolute biodiversity values that would be able to address this question more conclusively, the sampling designs of experimental studies would need to be standardized (like e.g. in Geiger *et al.*

2010; Schneider *et al.* 2014) or the analysis would need to be constrained to a more detailed taxonomic group (like e.g. bees, Kennedy *et al.* 2013).

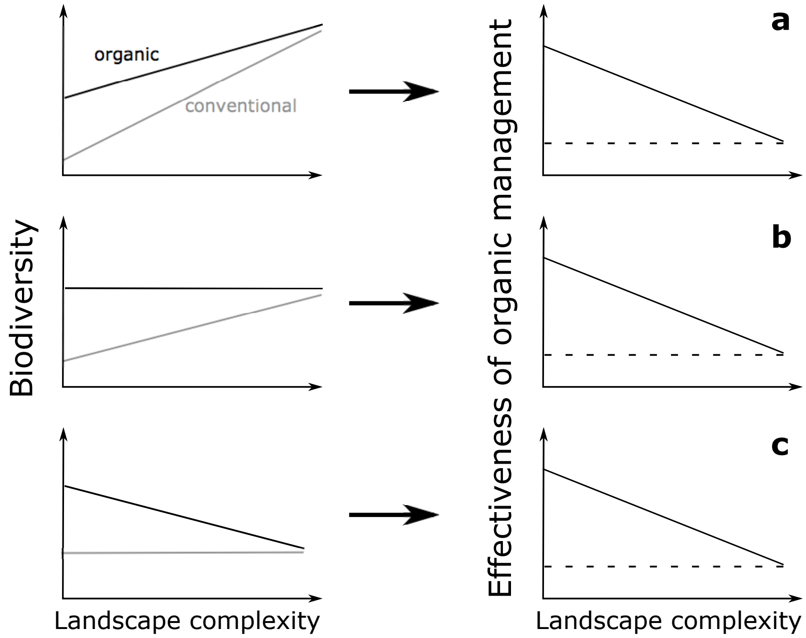

Figure 3.8. The relationship between landscape complexity and the effectiveness of organic management (dotted line represents zero effect of organic management), as observed in this study for plants and arthropods (right panels), and the three hypothetical relationships between landscape complexity and absolute biodiversity in organic (black line) and conventional fields (grey line) that these observed curves could be based on (left panels).

Despite not being able to make strong conclusions on whether changes of biodiversity in organic or conventional fields drive the response of the effectiveness of organic management to landscape context, we are still able to formulate hypotheses as to the most likely explanations for these patterns. In the following we will discuss each result of our analysis and formulate hypothesis as to the most likely driver of this pattern based on our understanding of ecological processes.

3.5.1 INFLUENCE OF LANDSCAPE COMPOSITION

The effectiveness of organic management is often best explained by the presence of specific land cover types. For example, arthropod abundance and plant richness benefit most from organic management in landscapes with high agricultural land cover at a 1km radius (Fig. 3.5a, 3.6b). Agricultural land cover represents the sum of all fields in the surrounding, including arable cropland, permanent crops like orchards as well as managed grasslands and pastures. At a larger spatial scale of 2.5km, the effectiveness of organic management for plant abundance depends on the amount of water and wetland in the surrounding - organic management only increases plant richness in landscapes with no or very little water or wetland cover (Fig. 3.6a; note that this relationship was still strong if the zero values were excluded from the analysis, result not shown). The presence of wetlands typically enhances biodiversity (Zedler 2003), and it is thus likely that the plant response to % water and wetland is due to plant richness being higher in conventional fields when wetlands are present (i.e. pattern Fig. 3.8a or 3.8b).

Generally, plants and arthropods benefit most from organic management in landscapes with very low amounts of natural habitat (Fig. 3.5a, 3.6a, 3.6b) and with very low land cover diversity (Fig. 3.5b). Given that almost no primary study shows a decline of plant or arthropod biodiversity in organic fields with increasing compositional heterogeneity (i.e. Fig. 3.8c; see Supplementary Fig. S3.7)[10], we hypothesize this pattern is most likely due to a stronger positive impact of landscape heterogeneity on biodiversity in conventional than in organic fields (i.e. Fig. 3.8a or 3.8b). Previous studies have explained this pattern through a stronger dependence of diversity in conventional fields on surrounding habitat refuges, while organic fields can provide better quality habitat themselves, and are thus more self-sustaining (Roschewitz *et al.* 2005; Holzschuh *et al.* 2007).

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[10] With the exception of Holzschuh *et al.* (2007), who observe lower bee richness in landscapes with less cropland cover (Fig. S3.7j), but who do not provide an explanation for this pattern.

For birds we find, instead, a pattern that is opposite to the patterns observed for plants and arthropods – organic management is most effective for bird abundance in landscapes with high forest cover, i.e. landscapes that have more natural habitat (Fig. 3.6c). This pattern can be caused either by (I) increased bird abundance in organic fields with increased forest land cover, (II) decreased bird abundance in conventional fields with increased forest cover, or (III) faster increase of bird abundance in organic relative to conventional fields with increasing forest cover. Bird species observed in agricultural fields or on farms are typically open-habitat species, i.e. species that do not necessarily require forest habitat for their life cycle (Virkkala *et al.* 2004). Farmland birds typically depend on the presence of semi-natural grassland, pasture or agricultural habitats in the surrounding rather than forest cover (Pärt & Söderström 1999; Heikkinen *et al.* 2004; Virkkala *et al.* 2004)[11]. Because of this, the biodiversity of farmland birds has been observed to decrease with increasing forest land cover (Heikkinen *et al.* 2004; Desrochers *et al.* 2011; Rüdisser *et al.* 2015). In addition, some studies have shown that organic management only increases the abundance of bird species that are highly dependent on crop fields (Piha *et al.* 2007). We therefore hypothesize that organic management increases bird abundance most efficiently (and especially for crop-dependent farmland birds) in forested landscapes with generally lower farmland bird abundances (i.e. following either pattern II or III above). In order to test this hypothesis the influence of forest versus grassland versus cropland cover on open habitat versus forest bird species in organic and conventional fields would need to be examined in more detail.

Another result of our study that appears baffling at first is the interaction between landscape and organic management for soil organisms. Not only is landscape

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[11] Although in our study open habitats individually (i.e. %cropland, %grassland, or %agricultural area) did not show any effect on the effectiveness of organic management for birds (see Supplementary Table S3.6, S3.7, S3.8, S3.9), and the combined open habitats (i.e. %cropland + %grassland cover, result not shown) did not show as strong of an influence as forest cover.

influence stronger at larger spatial scales (Supplementary Table S3.6), but it is also a contrary pattern to that observed for plants and arthropods – i.e. the influence of organic management on soil organisms is highest in heterogeneous landscapes (Fig. 3.4, 3.6). Soil organisms in our study comprise a rather diverse group of organisms, including nematodes, earthworms, mycorrhizal fungi, and microbes. Soil arthropods like isopoda or collembolan were included in the arthropod and not in the soil organism group.[12]

The influence of landscape characteristics on local soil characteristics or on soil organisms has not received a lot of research, and landscape characteristics have often been found to be of no (Williams & Hedlund 2013; Lüscher *et al.* 2014) or less importance (Da Silva *et al.* 2012) than plot characteristics for soil organisms. But other studies indicate that large-scale landscape characteristics can have important influences on soil communities (Ponge *et al.* 2003; Sousa *et al.* 2006; Culman *et al.* 2010; Diekötter *et al.* 2010).

Diekötter *et al.* (2010)[13] observed that organic management only had an effect on arthropod soil decomposers in landscapes dominated by conventional farms. This pattern was caused by higher abundance of soil decomposers in conventional fields in landscapes with higher amount of organic farmland (and thus presumably more heterogeneous structures). A study on earthworms and soil microbes in Germany[13] also does align with the typical pattern of increased influence of organic management in homogeneous landscapes (Flohre *et al.* 2011), Supplementary Fig. S3.7af, ag). Flohre *et al.* (2011) suggested higher predatory pressure on earthworms in organic fields in heterogeneous landscapes as an explanation for this pattern but said that empirical evidence for this explanation is still lacking.

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[12] Results did not, however, change when below-ground arthropods (i.e. Collembola, Isopoda) were included as soil organisms rather than arthropods (results not shown).

[13] Data from these studies could not be included in our analysis, as they did not provide information about location of study sites nor site-level biodiversity data.

In most organism groups landscape heterogeneity typically increases absolute biodiversity. In soil organisms, however, the opposite has sometimes been observed, with local diversity decreasing with increasing landscape heterogeneity (Ponge *et al.* 2003; Sousa *et al.* 2006). It has been hypothesized that this pattern could be explained by more frequent land use change and thus disturbances to the soil community taking place in heterogeneous landscapes (Ponge *et al.* 2003; Ponge *et al.* 2006). Land-use history can have strong influences on soil organisms (Ponge *et al.* 2006; Renard *et al.* 2013), and land use history should be considered when examining the relative benefits of different management practices (von Wehrden *et al.* 2014). We hypothesize that the higher impact of organic management in homogeneous landscapes observed in our study could be attributed to land use legacies, potentially due to more frequent land use changes and thus lower soil biodiversity in conventional fields in heterogeneous landscapes (i.e. the reverse of the pattern in Fig. 3.8a or 3.8b). It is important to note that in our study we are only examining alpha diversity within local habitats, not beta diversity across habitats. Alpha diversity of sedentary and specialized soil organisms can be negatively affected by landscape heterogeneity, despite positive effects of landscape heterogeneity on beta-diversity (Sousa *et al.* 2006).

3.5.2 INFLUENCE OF LANDSCAPE CONFIGURATION

Even though compositional heterogeneity and configurational heterogeneity are often correlated in real landscapes (see discussion in Supplementary Material S3.2), they can influence ecological processes in different ways and can have differing influences on different species (Fahrig 2003; Fahrig *et al.* 2011). Not many studies to date have examined the influence of configurational heterogeneity on farmland biodiversity, while controlling for landscape composition (but see Concepción *et al.* 2008; Kennedy *et al.* 2013), and some of these studies have found weak effects of landscape configuration on biodiversity in agricultural land (Kennedy *et al.* 2013). Several studies in agricultural landscapes have examined configurational metrics, but did not control for the interaction between composition and configuration and may therefore have confounded composition with configuration (Weibull *et al.* 2003; Heikkinen *et al.* 2004; Ekroos *et al.* 2008; Liira *et al.* 2008; Holzschuh *et al.* 2010). Whereas studies that examined the influence of landscape configuration on biodiversity while controlling for landscape composition have typically been limited to natural habitats and to forest- or natural-grassland-dwelling species (McGarigal & McComb 1995; Villard *et al.* 1999; Guerry & Hunter 2002).

Our study is thus one of the first to find a strong influence of landscape configuration (that is separate from landscape composition) on biodiversity in agricultural lands. While we show that the effectiveness of organic management depends on compositional characteristics like agricultural land, wetland, and forest cover, the importance of configurational effects was often on par to compositional effects (with Akaike weights of 1.00 for AI for plant richness, and 0.86 for ED for arthropod richness, Table 3.4). The effectiveness of organic management for arthropod richness is, for example, negatively influenced by the density of edges in the landscape, i.e., organic management enhances arthropod richness in less spatially heterogeneous landscapes. While the effect of organic management on plant richness is stronger in landscapes where patches are highly clumped (Fig. 3.5c), and not influenced by any measure of large-scale compositional heterogeneity.

Another result of our study that is potentially related to a configurational effect is the influence of study field size on the effectiveness of organic management for plant abundance (Fig. 3.6e). This corresponds with a previous study showing that organic management increased bird, butterfly and plant diversity considerably more in large farms than in small farms (Belfrage *et al.* 2005). This pattern was due to the strong negative effects of farm size on absolute biodiversity - in small farms general biodiversity was so high that the management, i.e. organic versus conventional, did not make a big difference, while in large farms organic management considerably enhanced biodiversity. Belfrage *et al.* (2005) hypothesize that the strong impact of farm size on biodiversity is due to higher crop species diversity and smaller field sizes of small farms. We were unfortunately not able to separate a potential compositional effect of crop diversity from the configurational effect of field size.

Configurational heterogeneity is often equated with habitat fragmentation and thus with negative impacts on biodiversity (Fahrig 2003). This 'habitat fragmentation' hypothesis is strongly based on the habitat-matrix paradigm, which assumes that a landscape can be divided into islands of habitable semi-natural land cover and a matrix of inhabitable agricultural or human-dominated land cover. In agricultural landscapes the 'matrix' can, however, be as important for species survival as surrounding semi-natural ecosystems (Fischer & Lindenmayer 2007; Vandermeer & Perfecto 2007; Fahrig *et al.* 2011; Mendenhall *et al.* 2014). Given that farmland species often do not depend on a single habitat to survive, and given that the diversity of species often increases with the presence of heterogeneous structures, environmental gradients and edge effects (Benton *et al.* 2003; Fischer & Lindenmayer 2007), it is most likely that configurational heterogeneity, like compositional heterogeneity, typically increases biodiversity in agricultural landscapes.

Concepcion *et al.* (2008), the only other study to separate composition and configuration effects and finding an influence on farmland biodiversity, showed that the biodiversity of birds, plants and grasshoppers in cereal fields increased with increasing configurational heterogeneity. They also showed that the decreased effectiveness of agri-environmental management with increasing configurational heterogeneity of the landscape was related to a faster increase of biodiversity in conventional than organic fields with increasing landscape complexity (Concepción *et al.* 2008). Accordingly, we hypothesize that the lower effectiveness of organic management in configurationally heterogeneous landscapes observed in our study for arthropods and plants is driven by higher biodiversity in conventional fields in these landscapes (i.e. Fig. 3.8a or 3.8b). Landscapes with a high density of edges, as well as landscapes with small field sizes and a mosaic of different land cover types probably host already such high plant and arthropod biodiversity that organic management does not provide much of an additional benefit anymore.

3.5.3 SHAPE OF THE ORGANIC MANAGEMENT-LANDSCAPE RELATIONSHIP

Several studies have suggested a humpback shaped response of the effectiveness of wildlife-friendly management to landscape structure, where the effectiveness is highest in intermediately complex landscapes, and lower in highly cleared and in complex landscapes (Tscharntke *et al.* 2005; Concepción *et al.* 2008; Concepcion *et al.* 2012). Our analysis shows, instead, mostly linear effects of both compositional and configurational landscape complexity, even though our dataset includes a wide range of different landscapes including highly agriculturally dominated ones. While we did observe non-linear quadratic relationships between landscape characteristics and the effectiveness of organic management for several organism groups in univariate models (Supplementary Table S3.6, S3.7, S3.8 and S3.9), none of these non-linear relationships were significant in multivariate multimodel inference (Table 3.3 and 3.4). An examination of the relationships of effectiveness of organic management and landscape complexity in primary studies (Supplementary Fig. S3.7) also does not reveal a single humpback-shaped relationship[14].

The suggestion that the effectiveness of wildlife-friendly practices responds to landscape context in a humpback-shaped pattern is based on the hypothesis that in extremely simplified and cleared landscapes there is not enough of a species pool to repopulate fields managed in a more wildlife-friendly manner (Tscharntke

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[14] Concepcion *et al.* (2008, 2012) examined agri-environmental schemes and not organic agriculture.

et al. 2005; Concepcion *et al.* 2012). Our result that organic management increases biodiversity even in landscapes with 100% agricultural land cover (Fig. 3.5a, 3.6b) suggests, instead, that the type of biodiversity found in agricultural fields does not depend on the presence of non-agricultural habitats. We propose instead (differently than Tscharntke *et al.* (2005) and Concepcion *et al.* (2008), see Supplementary Fig. S3.6) - that biodiversity in agricultural fields (and consequently the effectiveness of organic management for biodiversity) responds in a linear fashion to both compositional and configurational landscape heterogeneity. We suggest that with increasing landscape heterogeneity the positive effects of organic management are counter-balanced by the stronger positive effects of landscape heterogeneity on biodiversity, so that at high landscape heterogeneity management does not matter anymore (Fig. 3.8a or 3.8b).

3.5.4 LIMITATIONS OF THE STUDY DESIGN

The influence of landscape context on species is strongly scale-dependent and it is important to capture landscape patterns at a scale that is of relevance for different organisms (Bradter *et al.* 2013; Jackson & Fahrig 2014). Due to the transcontinental scale of our study we were not able to examine landscape context at scales smaller than 1km around study sites. Most primary studies examining the interaction of landscape and organic management to date have characterized landscapes at scales smaller than 1km (Geiger *et al.* 2010; Holzschuh *et al.* 2010; Fischer *et al.* 2011a, b; Flohre *et al.* 2011; Batáry *et al.* 2012) or up to 1km (Roschewitz *et al.* 2005; Clough *et al.* 2007; Holzschuh *et al.* 2007; Winqvist *et al.* 2011; Kehinde & Samways 2012; Klein *et al.* 2012), and rarely above 1km (Schmidt *et al.* 2005; Brittain *et al.* 2010). It is thus possible that we might have observed even stronger and potentially different patterns at smaller spatial scales (Jackson and Fahrig (2015) find that many species respond strongly to landscape at scales below 1km). The fact that despite the rather large-scale characterization of landscapes we still find strong influences of landscape patterns on all organism groups suggests, however, that landscape context influences organism across large spatial scales (up to 10km surrounding fields), and that future studies should include larger spatial scales in their analysis (Jackson & Fahrig 2014).

Although we hypothesize that differences in management practices (like crop diversity, crop rotations, or tillage practices), as well as small-scale farm-level heterogeneity (like hedgerows, woody habitats, or set-aside land) are responsible for a substantial portion of the variation in how effective organic management is in conserving biodiversity (see discussion in Supplementary Material S3.4), in this study we were unfortunately not able to examine the influence of more specific management practices or farm characteristics. The studies included in our analysis were mostly carried out by ecologists and published in ecological journals and they often did not provide detailed information on agricultural management practices. In addition, management practices vary a lot and it is often difficult in a meta-analysis to find management categories that are broad enough to fit all the different studies and farms, but also specific enough to capture biologically relevant differences in practices. To better understand the influence of different organic management practices and farm structural characteristics on biodiversity outcomes, empirical studies need to explicitly examine and provide more detailed information on organic farm management.

Many current studies could be underestimating the influence of organic management on biodiversity due to limitations of the paired farm study design (Bengtsson *et al.* 2005). Researchers typically pair organic and conventional farms that are situated close to each other, that grow similar crops and have similar farm size. Such a study design thus often excludes very intensive large-scale conventional farms due to the absence of comparable large-scale organic farms in the vicinity. The average field size in a 1km radius around sampled farms was 6.7 ha for European study sites and 11.5 ha for North American study sites (see Fig.

3.2h). In both Europe and the US these field sizes are at the lower end of typical field sizes – in Europe the average field size across the countries of the European Union is 16 ha (Reuter & Eden 2008), while typical (i.e. median) field sizes for several agricultural US states range from 12 to 47 ha (Yan & Roy 2014; White & Roy 2015) (Fig. 3.2h). In terms of intensity of farming practices, however, studies were more representative of European and North American agriculture (Fig. 3.2g).

Another caveat to consider when interpreting results of studies comparing biodiversity in organic versus conventional farms is the density of organic versus conventional farms. Typically, the organic farms studied are surrounded by conventional farms, and any positive effect of local organic management practices might therefore be counteracted by conventional management in neighbouring farms. A few studies have, however, been able to compare the influence of organic management on biodiversity in so-called ‘hotspots’ of organic farming with a higher density of organic farms (Gabriel *et al.* 2009), thus allowing to examine the influence of organic management at the local as well as at the landscape scale (Rundlöf *et al.* 2008a; Gabriel *et al.* 2010; Rundlöf *et al.* 2010). These studies typically observed that a higher density of organic farms increases the biodiversity benefit of organic management.

3.6 CONCLUSIONS

Our meta-analysis across 17 countries and 2 continents shows persistent influence of landscape context on the effectiveness of organic management. Despite a large variability in patterns in primary studies, we still find clear signals across multiple studies and multiple regions. Plants and arthropods benefit most from organic management in both compositionally and configurationally homogeneous landscapes. For soil organisms, instead, organic management is most effective in highly heterogeneous and for birds in more forested landscapes. We hypothesize that these patterns are driven by a general pattern where organic management increases biodiversity most strongly in situations where the general levels of biodiversity are lower, whereas in situations where biodiversity is already high (e.g. plant and arthropod biodiversity in heterogeneous landscapes or farmland bird biodiversity in non-forested landscapes) organic management does not provide much of an additional benefit for biodiversity. In addition, we show that the effectiveness of organic management responds in a linear fashion to landscape context – being highest for plants and arthropods in very homogeneous landscapes rather than at intermediate levels of landscape complexity, as previously suggested.

Our results suggest that the effectiveness of organic management for increasing biodiversity depends on the landscape context farms are situated in, but that the specific type of response differs between organism groups. It is thus not possible to draw conclusions about organic management and landscape context that are valid across all organism groups. Organic management can provide benefits for some type of organisms in a wide range of different landscapes, but it generally appears to be most effective in situations where farmland biodiversity levels are low.

Future studies on the influence of landscape context on biodiversity in organic versus conventional fields should (1) consider configurational heterogeneity more explicitly, (2) focus on under-studied regions (i.e. tropical and subtropical latitudes, dry climates, developing countries, and intensive agricultural landscapes with large field and farm sizes), (3) and on under-studied organism groups (i.e. mammals, molluscs, amphibians), as well as (4) focus on organism groups for which landscape influence and interaction with management is less well understood (i.e. birds and soil organisms).

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SUPPLEMENTARY MATERIAL

S3.1 SUPPLEMENTARY METHODS

Literature search

We searched the scientific literature using the search engines Google Scholar, Scopus and ISI Web of Knowledge by using different combinations of keywords, including *organic* AND *agriculture*, and either one of the following words: *biodiv**, *landscape*, *“landscape context”*, *“landscape configuration”*, *“landscape connectivity”*, *“landscape structure”*, *“landscape heterogeneity”*, *“landscape complexity”*, *hedgerow**, *scale*, *hotspot**, *bird**, *insect**, *mammal**, *invertebrate**, *pollinator**, *weed**, *plant**, *earthworm**, *butterfly**, *moth**. We also searched the reference lists of published studies, especially of the existing quantitative reviews on biodiversity and agro-ecological management (Bengtsson *et al.* 2005; Hole *et al.* 2005; Crowder *et al.* 2010; Batáry *et al.* 2011; Crowder *et al.* 2012; Tuomisto *et al.* 2012; Winqvist *et al.* 2012; Kennedy *et al.* 2013; Birkhofer *et al.* 2014; Tuck *et al.* 2014; Wilcox *et al.* 2014). We screened abstracts of studies identified through this search, and selected those studies that appeared to measure biodiversity in organic versus conventional farms. In the next step we examined the 487 studies identified this way closer and narrowed studies down further to those that (1) provided either a measure of species richness (S), organism abundance (N), Shannon Diversity Index (SHDI), Shannon Evenness Index (SHEI), or Simpsons Diversity Index (SIDI), (2) measured biodiversity in both organically and conventionally managed fields[15], and (3) reported primary data. This lead to the identification of 262 studies, which were included in the general analysis. In order to include studies in the landscape analysis we also required (4) information about location of study sites, and (5) site-level biodiversity data. We therefore contacted authors of 194 of the identified studies for which some of this additional information was missing,

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[15] See main text for definition of organic and conventional management.

and received additional data for 52 studies. In the end we were able to include 92 studies in the landscape analysis that met all of the 5 selection criteria (see Table S3.3). One study was excluded even though it met all selection criteria (Schon *et al.* 2011; Schon *et al.* 2012), as it was the only study in Oceania and would have required the use of a separate land cover dataset.

Study sites

We collected landscape information from regional land cover products for 498 study sites for which we had coordinates. If we had coordinates for multiple blocks within a single site (e.g. multiple plots, or multiple fields), we extracted landscape information for each block, and afterwards averaged landscape information as well as biodiversity data across blocks for each site (e.g. Cárdenas *et al.* 2006). If multiple coordinates were given (e.g. for different fields within a farm) but only 1 biodiversity sample reported, we used the averaged coordinates at farm level.

Land cover datasets

Because of the lack of sufficiently high resolution global land cover datasets (the highest resolution multi-class global land cover dataset is the MODIS 500m product (Friedl *et al.* 2010), and a preliminary assessment of the recently released 30m GlobeLand30 dataset produced by the National Geomatics Center of China (NGCC) (Gong *et al.* 2013) showed some data quality issues), we used the most high-resolution regional land cover datasets available. For Europe we used 250m resolution CORINE dataset, which is available for the years 1999, 2000, and 2006 (EEA 2014). For North America we used the 250m resolution North American Land Change Monitoring System (NALCMS) dataset, which covers Canada, Mexico and the Unites States, and which is available for the year 2005 (CEC 2014). We used the 13 intermediate (level 2) CORINE classes, as these were most comparable to the 19 NALCMS classes. Land cover classes between the two land cover datasets differed quite substantially – CORINE has much higher detail in agricultural and artificial land cover classes, while NALCMS has much higher detail in forest land cover classes (Table S3.1). As these differences reflect real differences in European (where agricultural land cover is more dominant) and North American (where forest land cover is more dominant) landscapes, we decided to keep these differences (rather than aggregating classes into comparable classes and loosing important information) and to run Fragstat analysis on these original classes. To compare landscape composition (i.e. proportion of landscape covered by agriculture versus forests etc.) we afterwards aggregated land cover classes into comparable broader categories (see Table S3.1).

For Europe, where land cover data was available for multiple years, we always used the year that was closest to the year in which the study was conducted. Temporal inconsistency between study year and date of land cover data was on average 2 years for Europe (ranging from 5 years before and 10 years after the sampling date) and 8 years for North America (ranging from 4 years before and 31 years after the sampling date; temporal inconsistency was higher for North America due only a single date being available for NALCMS).

Table S3.1. Land cover classes used in the analysis and their equivalent classes in the two land cover datasets used.

Original land cover class	Category	CORINE	NALCMS
Arable land	Cropland	x	
Cropland	Cropland		x
Heterogeneous agricultural areas	Cropland	x	
Permanent crops	Cropland	x	
Industrial commercial and transport	Artificial surfaces	x	
Mine, dump and construction sites	Artificial surfaces	x	
Urban and built-up	Artificial surfaces		x
Urban fabric	Artificial surfaces	x	
Forests	Forests & shrublands	x	
Mixed forests	Forests & shrublands		x
Open spaces with little or no vegetation	Forests & shrublands	x	
Shrubland or herb	Forests & shrublands	x	
Temperate broadleaf deciduous	Forests & shrublands		x
Temperate needleleaf forest	Forests & shrublands		x
Temperate shrubland	Forests & shrublands		x
Tropical broadleaf evergreen	Forests & shrublands		x
Artificial non-agricultural vegetated areas	Grasslands	x	
Pastures	Grasslands	x	
Temperate grassland	Grasslands		x
Coastal wetlands	Water & wetlands	x	
Inland waters	Water & wetlands	x	
Inland wetlands	Water & wetlands	x	
Water	Water & wetlands		x
Wetland	Water & wetlands		x

Fragstat variables

We chose Fragstat variables that represented different aspects of landscapes (see main text for description of the four different groups of landscape characteristics), that were as uncorrelated with each other as possible within each group[16] (see Table S3.2 for correlation coefficients between variables included at each of the 3 spatial scales examined), and that represented landscape characteristics whose

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[16] We were not concerned about high correlation between variables from different groups of landscapes characteristics (especially between compositional and configurational variables), as we expected these to be correlated but still representing different aspects of the landscape (see discussion in Supplementary Material 3.2).

biological relevance is easily interpretable[17]. Land cover diversity was represented by Patch Richness Density (PRD) and Shannon Evenness Indicator (SHEI). PRD represents patch richness (i.e. the number of different patch types present) standardized to a per unit area basis. SHEI represents the distribution of the landscape area among different patch types. SHEI isolates the evenness component of the Shannon diversity index, which is a common diversity indicator based on information theory, controlling for the contribution of richness (McGarigal 2014).

We included mean patch size (AREA_AM) and edge density (ED) as metrics describing patch shape. AREA_AM represents the area-weighted mean patch area, quantifying the average area of each patch across the landscape, weighted by the different area of patches (i.e. larger patches contribute more strongly to the overall landscape value than smaller patches). AREA_AM provides a more landscape-centric perspective on landscape structure than the un-weighted mean patch area would (McGarigal 2014). ED represents the total edge length of all patches in the landscape standardized to a per unit area basis. Landscapes with higher values of ED have a higher number of different patches, and thus more patch boundaries. Edge and area metrics are good metrics to quantify landscape configuration, as they capture the shape of patches across the landscape, but they are not spatially explicit.

The Contagion Index (CONTAG) and the Aggregation Index (AI), instead, capture the spatial arrangement of patches relative to each other. The Contagion Index is a commonly used indicator that quantifies the clumpiness of the landscape (Li & Reynolds 1993; Turner *et al.* 2001). It measures the probability of finding a cell of type i next to a cell of type j, and captures both dispersion (i.e. the spatial distribution of an individual patch type) as well as interspersion (i.e. the degree to which patches of different land cover types are intermixed) (McGarigal 2014).

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[17] For example excluding variables like AREA_CV (i.e. the coefficient of variation of patch size) whose biological meaning is difficult to interpret.

Table S3.2. Pearson correlation coefficients between different Fragstat variables included in the analysis at 3 spatial scales. See text as well as Table 3.1 in main text for description of variables. Correlation coefficients higher than 0.7 are highlighted in green, higher than 0.8 in yellow and higher than 0.9 in red.

	% Land cover					**Land cover diversity**		**Shape of patches**		**Arrangem patches**	
	AGRI	**ARTI**	**FORS**	**GRAS**	**WAWE**	**PRD**	**SHEI**	**ED**	**AREA_AM**	**CONTAG**	**AI**
2.5 km											
AGRI_2.5	/										
ARTI_2.5	-0.12	/									
FORS_2.5	-0.49	-0.17	/								
GRAS_2.5	-0.47	-0.11	-0.39	/							
WAWE_2.5	-0.35	-0.10	0.31	-0.07	/						
PRD_2.5	-0.32	0.07	0.36	-0.06	0.34	/					
SHEI_2.5	-0.50	0.20	0.52	-0.06	0.22	0.39	/				
ED_2.5	-0.41	-0.05	0.59	-0.09	0.25	0.61	0.72	/			
AREA_AM_2.5	0.53	-0.13	-0.56	0.09	-0.23	-0.62	-0.87	-0.81	/		
CONTAG_2.5	0.48	-0.17	-0.53	0.05	-0.17	-0.24	-0.97	-0.67	0.78	/	
AI_2.5	0.47	-0.02	-0.61	0.08	-0.18	-0.21	-0.74	-0.68	0.66	0.86	/
5 km											
AGRI_5	/										
ARTI_5	-0.16	/									
FORS_5	-0.51	-0.17	/								
GRAS_5	-0.44	-0.10	-0.42	/							
WAWE_5	-0.30	-0.03	0.21	-0.09	/						
PRD_5	-0.28	0.12	0.19	0.02	0.24	/					
SHEI_5	-0.40	0.16	0.48	-0.13	0.21	0.25	/				
ED_5	-0.36	-0.03	0.48	-0.06	0.05	0.49	0.65	/			
AREA_AM_5	0.44	-0.09	-0.50	0.09	-0.16	-0.54	-0.86	-0.81	/		
CONTAG_5	0.40	-0.13	-0.50	0.12	-0.13	-0.09	-0.96	-0.62	0.78	/	
AI_5	0.46	-0.05	-0.54	0.06	-0.06	-0.12	-0.69	-0.66	0.67	0.83	/
10 km											
AGRI_10	/										
ARTI_10	-0.13	/									

FORS_10	-0.49	-0.21	/								
GRAS_10	-0.37	-0.06	-0.50	/							
WAWE_10	-0.27	-0.09	0.24	-0.08	/						
PRD_10	-0.27	0.05	0.11	0.11	0.07	/					
SHEI_10	-0.27	0.15	0.48	-0.28	0.12	0.17	/				
ED_10	-0.29	-0.05	0.49	-0.16	-0.03	0.50	0.60	/			
AREA_AM_10	0.34	-0.03	-0.51	0.24	-0.04	-0.47	-0.82	-0.79	/		
CONTAG_10	0.31	-0.14	-0.53	0.29	-0.10	-0.06	-0.96	-0.61	0.79	/	
AI_10	0.43	-0.01	-0.52	0.15	-0.08	-0.14	-0.60	-0.62	0.67	0.77	/

Higher values indicate landscapes that have larger contiguous patches, as well as landscapes in which patches of different types are not strongly interspersed. AI, instead, isolates the dispersion aspect of aggregation (and does not measure interspersion, as the Contagion Index does), and is better able to assess aggregation in some landscapes than the Contagion Index (He *et al.* 2000). The calculation of AI is based on a matrix of like adjacencies (i.e. whether cells are surrounded by cells of the same type or not), and quantifies the percentage of observed like adjacencies relative to the maximum possible number of like adjacencies (McGarigal 2014). Low values of AI indicate a highly fragmented, high values a very contiguous landscape.

Google Earth

Google Earth imagery is collected from different satellite imagery or aerial photography sources, and resolution and image quality varies between locations, but in Europe and North America the resolution is typically 15m or higher. In ArcMap we delineated a circular buffer with a radius of 1km around each study site, exported this buffer to Google Earth, where we manually traced individual field boundaries within this buffer, and saved these as polygons. Field boundaries were identified based on physical barriers between crops (e.g. hedgerows, roads, fences) to allow identification of fields even if fields were not planted during the time the image was taken (e.g. during winter). This means that fields were defined using physical structures that delineated field boundaries, and not based on land cover, or land use (i.e. not distinguishing between pasture and arable land, or between different types of crops).

We used historical images as available in Google Earth, using the image date closest in time *before* the time the study was conducted (as biodiversity is influenced by historical and not by future landscape patterns). Temporal inconsistency between study year and date of Google Earth image used was on average 7 years, ranging between 6 years before and 20 years after the sampling date.

Field polygons were processed using the website http://www.earthpoint.us/shapes.aspx to calculate area and perimeters of polygons. Field boundaries in orchards, olive grooves or vineyards were difficult to assess due to the large size of fields with permanent crops.

Site pairing

Different studies measured biodiversity of different organism groups with a large variety of methods, and even sampling strategies for the same organism group differed widely. Lepidoptera were, for example, sampled using light traps located in hedgerows and in the centres of fields on six trap nights over five sampling months by Boutin *et al.* (2011), using pitfall traps in a randomized block design across an olive orchard on a single sampling day by Cotes *et al.* (2010a), or using 100m line transects along the edge and centre of fields across three sampling days over three months by Power and Stout (2011). Due to this large variety of sampling methods it would not have been appropriate to compare the absolute biodiversity values of studies with each other. We therefore paired organic and conventional farms within each study, and used the biodiversity in organic farms relative to conventional farms as our response variable.

Most studies (i.e. 662/812 observations) already provided a paired study design in which authors had paired organic and conventional farms to control for landscape, management (e.g. farm size, main crops in rotation) or regional (e.g. soil, slope) characteristics. We trusted farm pairing conducted by authors of primary studies, assuming that authors are better able to assign appropriate pairs than any potential posteriori pairing, and we did therefore not further test the study author's pairing. For the remaining unpaired studies we first paired organic and conventional sites according to nearest distance. To ensure that farms within a pair were situated in the 'same' landscape, we examined whether the within-pair heterogeneity of pairs assigned by us was smaller than the between-pair heterogeneity in each unpaired study through a one-way ANOVA on one composition and one configuration Fragstat variable (i.e. %AGRI, and AREA_AM, see Table 3.1 for variable description) at each of the three spatial extents respectively. If the ANOVA showed that the within-pair heterogeneity was higher than the between-pair heterogeneity (i.e. $p > 0.05$) for more than 1 of the 6 comparisons tested (i.e. the two Fragstat variables at the three spatial extents) we ran a post-hoc Tukey test to identify the combination of pairs that did not show a significant difference, and removed those pairs that were not significantly different from each other (i.e. $p > 0.05$).

Often studies sampled farm pairs that were located quite close to each other in neighbouring regions or municipalities. In some cases even different studies by different researchers were conducted in the same region, for example in California (Hesler *et al.* 1993; Clark 1999; Kremen *et al.* 2002) in Nebraska (Neher & Olson 1999; Wortman *et al.* 2010) or in southern England (Alvarez *et al.* 2001; Bending *et al.* 2004; Gibson *et al.* 2007; Gabriel *et al.* 2010; van der Gast *et al.* 2011). This did not only limit the highest spatial scale we could use in our analysis (i.e. 10km radius), but it also lead to the exclusion of several farm pairs that had a very strong spatial overlap (e.g. from Gibson *et al.* (2007) or Girvan *et al.* (2003)).

In the end we were able to include 290 study sites, while 208 of the 498 sites for which we extracted landscape data had to be excluded due to (1) multi-pairing (i.e. the number of conventional farms/treatments not matching with the number of organic farms/treatments), (2) site overlap (i.e. too strong spatial overlap with another study site) or (3) because sites were situated in landscapes that were too different according to ANOVA tests.

Biodiversity data

When data was reported in primary studies for multiple points in time (sampling weeks, sampling seasons or years) we took an average over time. When data was reported for multiple samples across a single sampling unit (e.g. multiple soil cores within a sampling block) observations were pooled within blocks but averaged across blocks[18]. Many studies did not provide information on sample size (371/812 observations) or an estimate of variance (319/812 observations), and we were therefore not able to calculate a weighted effect size. If biodiversity data was provided at the species level we calculated species richness and organism abundance for each phylogenetic order. To deal with zero values while calculating the natural logarithm of the response ratio we added +1 to both denominator and numerator if the denominator was zero.

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[18] As an example: for Alvarez *et al.* (2001) multiple suction samples of Collembola across a single field were pooled, while the three fields samples were treated as replicates, and measures were averaged across fields within the same farm.

Table S3.3. Overview of studies included in the meta-analysis. *Beng* denotes Bengtsson *et al.* (2005), *Tuck* denotes Tuck *et al.* (2014), *Crow* denotes Crowder *et al.* (2012), *Kenn* denotes Kennedy *et al.* (2013), and *Batar* denotes Batáry *et al.* (2011).

									Included in				
Study #	**Study Code**	**Authors**	**Continent**	**Country**	**Organism Group**	**Organism Subgroup**	**# Sites**	**Sent data**	**Beng**	**Tuck**	**Crow**	**Kenn**	**Batar**
1	S01	Alvarez *et al.* (2001)	Europe	UK	Arthropods	Collembola	3	yes	no	no	no	no	yes
2	S02	Andersen *et al.* (2004)	Europe	Norway	Arthropods	Diptera	6	yes	no	no	no	no	no
3	S03	Balezentiene (2011)	Europe	Lithuania	Plants	/	1	no	no	no	no	no	no
4	S04	Belfrage *et al.* (2005)	Europe	Sweden	Arthropods	Hymenoptera, Lepidoptera	4	yes	no	no	no	no	no
					Birds	Passeriformes, Piciformes							
					Plants	/							
5	S05	Bending *et al.* (2004)	Europe	UK	Soil org	Microbes	2	yes	no	no	no	no	no
6	S06	Boutin *et al.* (2011)	North Am	Canada	Arthropods	Lepidoptera	13	no	no	yes	no	no	no
7	S07	Bouvier *et al.* (2011)	Europe	France	Birds	Columbiformes, Passeriformes	2	yes	no	no	no	no	no
8	S08	Bruggisser *et al.* (2010)	Europe	Switzerl.	Arthropods	Araneae, Orthoptera	2	yes	no	yes	yes	no	no
					Plants	/							
9	S09	Bulluck III *et al.* (2002)	North Am	USA	Soil org	Nematoda	2	no	no	no	no	no	no
10	S10	Cárdenas *et al.* (2006)	Europe	Spain	Arthropods	Araneae	2	yes	no	no	yes	no	no
11	S11	Clark *et al.* (2006)	North Am	USA	Arthropods	Coleoptera	1	yes	no	no	yes	no	no
12	S12	Cordero-Bueso *et al.* (2011)	Europe	Spain	Soil org	Microbes	1	yes	no	no	no	no	no

									Included in				
Study #	**Study Code**	**Authors**	**Continent**	**Country**	**Organism Group**	**Organism Subgroup**	**# Sites**	**Sent data**	**Beng**	**Tuck**	**Crow**	**Kenn**	**Batar**
13	S13	Cotes *et al.* (2010a)	Europe	Spain	Arthropods	Coleoptera	12	yes	no	no	no	no	no
14		Cotes *et al.* (2009)			Arthropods	Coleoptera		no	no	no	yes	no	no
15		Cotes *et al.* (2010b)			Arthropods	Dermaptera, Dictyoptera, Diptera, Embioptera, Hemiptera, Hymenoptera, Lepidoptera, Neuroptera, Orthoptera, Psocoptera, Thysanoptera, Trichoptera, Zygentoma		no	no	no	no	no	no
16	S14	Culliney & Pimentel (1986)	North Am	USA	Arthropods	Araneae, Coleoptera, Collembola, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Neuroptera, Thysanoptera	1	yes	no	no	no	no	no
17	S15	Edesi *et al.* (2012)	Europe	Estonia	Plants	/	1	yes	no	no	no	no	no
18	S16	Gabriel *et al.* (2010)	Europe	UK	Arthropods	Diptera, Hymenoptera	32	no	no	yes	no	no	no
19		Gabriel *et al.* (2013)			Birds	Columbiformes, Passeriformes		no	no	no	no	no	no
20		Sutherland *et al.* (2012)			Soil org	Annelida		no	no	no	no	no	no

Study #	Study Code	Authors	Continent	Country	Organism Group	Organism Subgroup	# Sites	Sent data	Included in				
									Beng	Tuck	Crow	Kenn	Batar
					Plants	/							
21	S17	Gibson *et al* (2007)	Europe	UK	Plants	/	18	yes	no	no	no	no	no
22		Macfadyen *et al.* (2009a)			Arthropods	Diptera,		no	no	no	no	no	no
23		Macfadyen *et al.* (2009b)				Hymenoptera,		yes	no	yes	yes	no	no
24		Macfadyen *et al.* (2011a)				Lepidoptera		yes	no	no	no	no	no
25		Macfadyen *et al.* (2011b)						yes	no	no	no	no	no
26	S18	Girvan *et al.* (2003)	Europe	UK	Soil org	Microbes	2	no	no	no	no	no	no
27	S19	Glover *et al.* (2000)	North Am	USA	Soil org	Annelida, Microbes	1	yes	no	no	no	no	no
28	S20	Gosme *et al.* (2012)	Europe	France	Arthropods	Hemiptera	1	yes	no	no	no	no	no
					Plants	/							
29	S21	Hesler *et al.* (1993)	North Am	USA		Araneae, Coleoptera, Decapoda, Diptera, Ephemeroptera, Hemiptera, Odonata	2	no	no	yes	yes	no	no
30	S22	Hyvönen *et al.* (2003)	Europe	Finland	Plants	/	30	yes	no	yes	no	no	no
31		Ekroos *et al.* (2010)						yes	no	yes	no	no	no
32	S23	Isaia *et al.* (2006)	Europe	Italy	Arthropods	Araneae	4	yes	no	no	no	no	no
33	S24	Jonason *et al.* (2011)	Europe	Sweden	Arthropods	Lepidoptera	21	yes	no	yes	no	no	no
34		Jonason *et al.* (2012)						yes	no	no	no	no	no
	S25	**KBS (LTER site)**	North Am	USA	Arthropods	Coleoptera	1						
35		Buckley & Schmidt (2001)			Plants	/		no	no	no	no	no	no
36		Clark *et al.* (1997)			Soil org	Annelida,		yes	no	no	no	no	no
37		Colunga-Garcia & Gage (1998)				Microbes, Nematoda		no	no	no	no	no	no
38		Costamagna & Landis (2006)						no	no	no	no	no	no

Study #	Study Code	Authors	Continent	Country	Organism Group	Organism Subgroup	# Sites	Sent data	Included in Beng	Tuck	Crow	Kenn	Batar
		Davis *et al.* (2005)											
39		Freckman & Ettema (1993)						yes	no	no	no	no	no
40		Maredia *et al.* (1992)						no	no	no	yes	no	no
41		Menalled *et al.* (2001)						no	no	no	no	no	no
42		Menalled *et al.* (2007)						yes	no	yes	no	no	no
43		Smith *et al.* (2008)						no	no	no	no	no	no
44		Xue *et al.* (2013)						no	no	no	no	no	no
45		Bhardwaj *et al.* (2011)						no	no	no	no	no	no
46								no	no	no	no	no	no
47	S26	Kremen *et al.* (2002)	North Am	USA	Arthropods	Hymenoptera	16	no	no	yes	no	yes	yes
48		Kremen *et al.* (2004)						no	no	no	no	no	no
49	S27	Kromp (1990)	Europe	Austria	Arthropods	Coleoptera	1	no	yes	yes	no	no	no
50	S28	Marinari *et al.* (2006)	Europe	Italy	Soil org	Microbes	1	no	no	no	no	no	no
51	S29	Mates *et al.* (2012)	North Am	USA	Arthropods	Hymenoptera	2	yes	no	no	no	no	no
52	S30	Melero *et al.* (2006)	Europe	Spain	Soil org	Microbes	1	no	no	no	no	no	no
53	S31	Miñarro *et al.* (2009)	Europe	Spain	Arthropods	Araneae, Coleoptera, Hymenoptera	1	yes	no	no	no	no	no
54	S32	Neher & Olson (1999)	North Am	USA	Soil org	Microbes, Nematoda	1	no	no	no	no	no	no
55	S33	Nelson *et al.* (2011)	North Am	Canada	Soil org	Microbes	1	no	no	no	no	no	no
56	S34	Overstreet *et al.* (2010)	North Am	USA	Soil org	Nematoda	1	no	no	no	no	no	no
57	S35	Pelosi *et al.* (2009)	Europe	France	Soil org	/	1	no	no	yes	yes	no	no
58	S36	Pollnac *et al.* (2009)	North Am	USA	Plants	/	1	no	no	yes	no	no	no
59	S37	Power & Stout (2011)	Europe	Ireland	Arthropods	Diptera, Hymenoptera, Lepidoptera	20	yes	no	yes	no	no	no
60	S38	Rendón *et al.* (2006)	North Am	Mexico	Plants Arthropods	/ Araneae	2	no	no	no	no	no	no

Study #	Study Code	Authors	Continent	Country	Organism Group	Organism Subgroup	# Sites	Sent data	Included in Beng	Tuck	Crow	Kenn	Batar
61	S39	Ruano *et al.* (2004)	Europe	Spain	Arthropods	Acari, Araneae, Coleoptera, Collembola, Diptera, Formicidae, Heteroptera, Homoptera, Hymenoptera, Isopoda, Lepidoptera, Neuroptera, Psocoptera, Thysanoptera	2	yes	no	no	yes	no	no
62	S40	Rundlöf & Smith (2006)	Europe	Sweden	Arthropods	Lepidoptera	24	no	no	yes	no	no	yes
63		Rundlöf *et al.* (2008b)				Hymenoptera		no	no	yes	no	no	yes
64		Smith *et al.* (2010)			Birds	Anseriformes, Charadriiformes Columbiformes, Falconiformes, Galliformes, Gruiformes, Passeriformes, Piciformes		no	no	yes	no	no	no
65	S41	Rundlöf *et al.* (2008a)	Europe	Sweden	Arthropods	Lepidoptera	16	no	no	no	no	no	yes
66	S42	Schjønning *et al.* (2002)	Europe	Denmark	Soil org	Microbes	6	yes	yes	no	no	no	no
67	S43	Tello *et al.* (2012)	Europe	Spain	Soil org	Microbes	2	no	no	no	no	no	no

Study #	Study Code	Authors	Continent	Country	Organism Group	Organism Subgroup	# Sites	Sent data	Included in				
									Beng	Tuck	Crow	Kenn	Batar
	S44	**Therwil (2000)**	Europe	Switzerl.	Arthropods	Araneae,	1						
68		Birkhofer *et al.* (2008a)				Coleoptera		no	no	no	no	no	no
69		Birkhofer *et al.* (2008b)			Soil org	Annelida,		yes	no	no	no	no	no
70		Birkhofer *et al.* (2012)				Microbes,		yes	no	no	no	no	no
71		Fließbach *et al.* (2000)				Nematoda		no	no	no	no	no	no
72		Fließbach *et al.* (2007)						no	no	no	no	no	no
73		Fließbach & Mäder (2000)						no	yes	no	no	no	no
74		Hartmann *et al.* (2006)						no	no	no	no	no	no
75		Mäder *et al.* (2002)						no	no	yes	no	no	no
76		Oberson *et al.* (1993)						no	no	no	no	no	no
77		Oehl *et al.* (2004)						no	no	no	yes	no	no
78		Pfiffner & Mäder (1997)						yes	yes	yes	no	no	no
79		Pfiffner & Niggli (1996)						no	yes	yes	yes	no	no
80		Widmer *et al.* (2006)						no	no	no	no	no	no
	S45	**UC Davis (SAFS)**	North Am	USA	Arthropods	Coleoptera	1						
81		Bossio *et al.* (1998)			Plants	/		no	no	no	no	no	no
82		Clark (1999)			Soil org	Microbes,		yes	yes	no	no	no	no
83		Ferris *et al.* (1996)				Nematoda		no	yes	no	no	no	no
84		Gunapala & Scow (1998)						no	yes	no	no	no	no
85		Jaffee *et al.* (1998)						no	no	no	no	no	no
86		Lundquist *et al.* (1999)						no	no	no	no	no	no
87		Robert Norris (LTRAS)						yes	no	no	no	no	no
88		Scow *et al.* (1994)						no	no	no	no	no	no
89	S46	van Der Gast *et al.* (2011)	Europe	UK	Soil org	Microbes	16	no	no	yes	no	no	no
90	S47	Verbruggen *et al.* (2012)	Europe	Netherl.	Soil org	Microbes	6	no	no	no	no	no	no
91	S48	Wander *et al.* (1995)	North Am	USA	Soil org	Microbes	1	no	no	no	no	no	no
92	S49	Wortman *et al.* (2010)	North Am	USA	Plants	/	1	yes	no	yes	no	no	no

S3.2 LANDSCAPE COMPOSITION VERSUS CONFIGURATION

Landscape composition describes the quantities of different land cover types present in a landscape. *Landscape configuration*, instead, denotes the specific arrangement of these land cover types. These two characteristics of a landscapes are typically not independent of each other – when you increase the number of different land cover types present in a landscape, you typically also increase the structural arrangement of these land cover types. However, landscape ecology is based on the premise that the structural arrangement of spatial elements in a landscape matters for ecological processes, even when landscape composition is held constant (Turner *et al.* 2001). Fig. S3.1 illustrates several cases of potential differences in configuration in landscapes with the same composition.

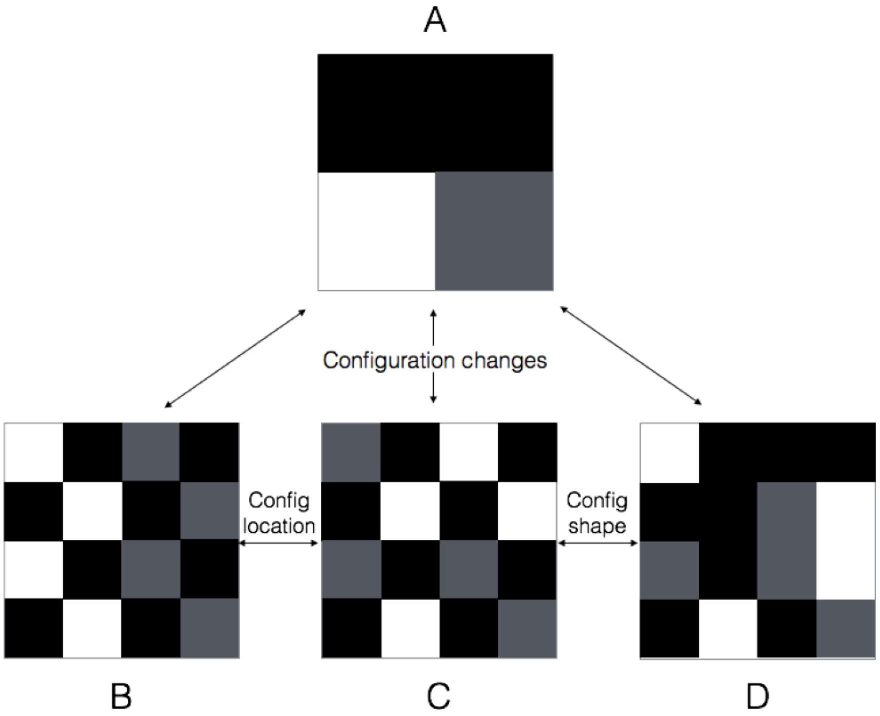


Figure S3.1. Illustration of configurational changes to how patches are arranged within a landscape independent of landscape composition. All example landscapes (different colours represent different patch types) have the same landscape composition, but differ in landscape configuration. In addition, landscapes B and C differ in locational configuration (i.e. how patches are arranged relative to each other), while landscapes C and D differ in their shape configuration (i.e. the shape of patches)

Table S3.4. Results of landscape composition versus landscape configuration models. Models with dAIC < 1.5 are highlighted in yellow, models with dAIC < 2 are highlighted in red. Models that were used to derive residuals are highlighted in bold. Quadratic models were only chosen if they reduced AIC by >2 compared to linear model.

Composition variable	Configuration variable		dAIC		
			2.5km	5km	10km
SHEI	AREA_AM				
		linear	**-187.6**	**-192.0**	**-163.7**
		quadratic	-188.2	-190.2	-161.8
	ED				
		linear	**-123.4**	-111.6	-87.1
		quadratic	-125.3	**-122.9**	**-98.4**
	CONTAG				
		linear	**-537.4**	-509.3	-514.7
		quadratic	-535.9	**-512.1**	**-519.0**
	AI				
		linear	**-99.6**	-86.2	-73.2
		quadratic	-98.1	**-88.2**	**-77.5**
PRD	AREA_AM				
		linear	**-43.8**	**-37.5**	**-18.6**
		quadratic	-42.8	-35.6	-16.7
	ED				
		linear	-42.6	-35.2	-35.7
		quadratic	**-51.4**	**-40.6**	**-41.5**
	CONTAG				
		linear	-4.1	**-5.7**	-1.9
		quadratic	**-13.3**	-6.8	-0.2
	AI				
		linear	**-5.2**	**-3.9**	-1.2
		quadratic	-4.8	-1.9	-0.1
Total Agricultural Area	Field Number				
		linear	1.5		
		quadratic	2.7		
	Mean Field Size				
		linear	**-52.8**		
		quadratic	-51.4		
	Total Field Perimeter				
		linear	-27.7		
		quadratic	**-38.0**		
	Area-Perimeter Ratio				
		linear	**-56.7**		
		quadratic	-55.3		

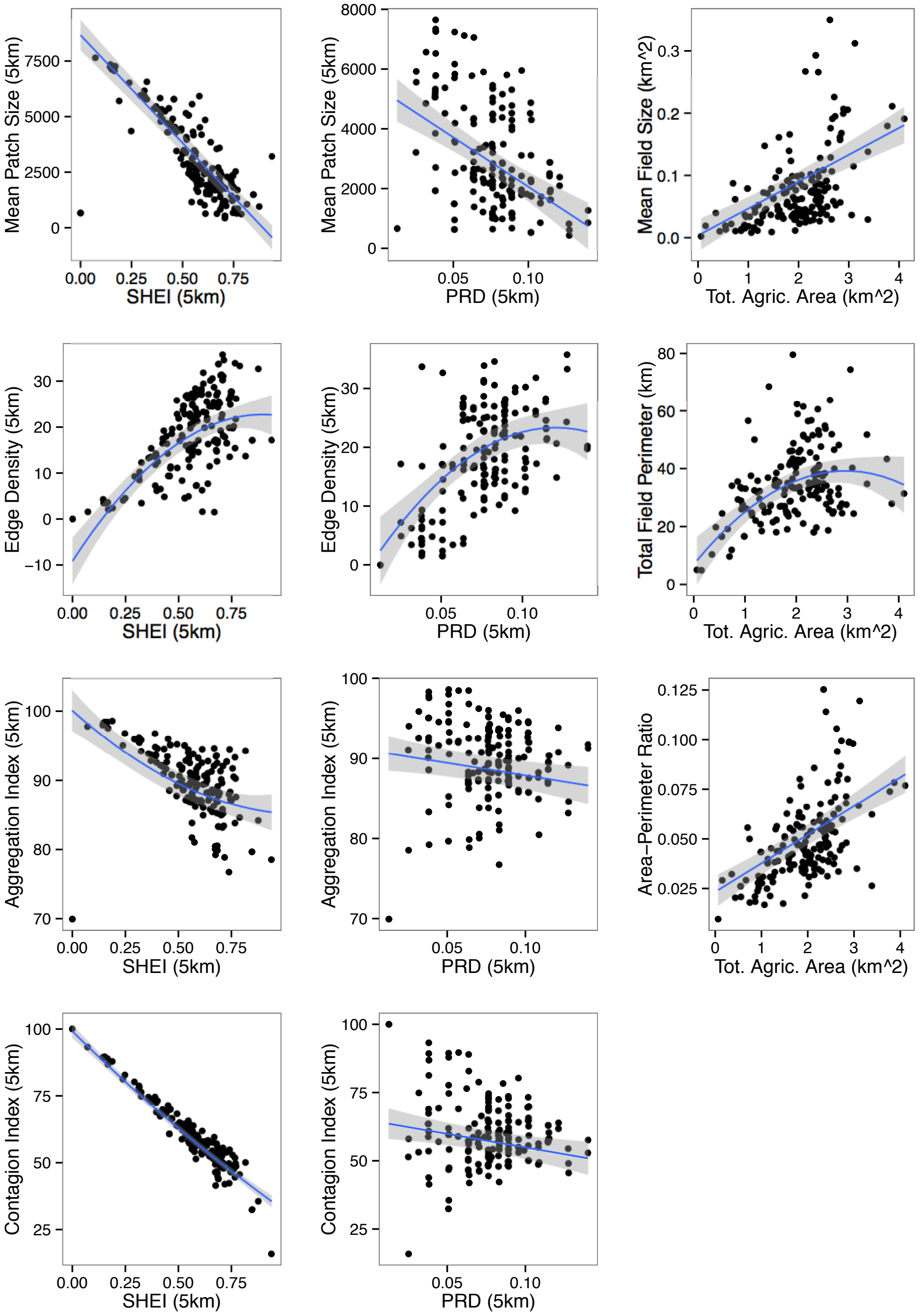


Figure S3.2. Relationships between landscape composition (SHEI, PRD, and Total Agricultural Area) and landscape configuration variables (see Table 3.1 in main text for a description of variables). For Fragstat metrics only relationships at 5km scale are shown. Blue line shows regression line from linear (or quadratic) mixed models (see Table S3.4), grey shaded area shows the 95% confidence interval.

S3.3 RESULTS OF UNIVARIATE MODELS

Due to the high number of explanatory variables included in our analysis we used univariate repeated regressions to do a variable-pre-selection (similar as Bradter *et al.* 2013). Several variables that reduced AIC of models by more than 1.5 units by themselves (see Tables S3.6, S3.7, S3.8 & S3.9) were not selected anymore during the subsequent multimodel inference (Table 3.3 & 3.4, main text). This thus suggests that some variables only improved model fit in univariate models due to their relationship with other covariates (which were accounted for in multivariate models). It thus also suggests that univariate models are inadequate for making conclusions on the importance of covariates. We therefore did not use univariate models for variable selection, but only used them to exclude unimportant variables.

This approach of variable pre-selection does account for positive interactions between covariates, but it does not account for potential negative interactions between covariates (i.e. covariates not increasing model fit in univariate models as their effect is cancelled out by a correlated variable). Due to the high number of covariates in our analysis we are, however, not able to include all covariates in a multivariate analysis – the only solution to address negative interactions.

Table S3.5. Univariate biodiversity models (i.e. with ln Biodiversity ratio (org/conv) as response variable) with landscape clusters at the three spatial scales as explanatory variables. Models with dAIC < 1.5 are highlighted in yellow, models with dAIC < 2 are highlighted in red. Models represented in graphs in main text are highlighted in bold.

	dAIC			
	Plants	**Soil organisms**	**Arthropods**	**Birds**
Species richness				
2.5km	1.27	**-2.16**	-0.29	1.35
5km	-0.62	0.22	**-9.34**	1.50
10km	-1.34	-2.12	-3.69	0.20
Abundance				
2.5km	1.47	-0.11	0.70	1.97
5km	**-1.97**	**-2.85**	0.44	1.97
10km	0.51	-2.49	1.29	2.00

Table S3.6. Results of repeated regressions of Fragstat variables for organism abundance (i.e. with ln Organism abundance ratio (org/conv) as response variable) at the 3 spatial scales. Models with dAIC < 1.5 are highlighted in yellow, models with dAIC < 2 are highlighted in red. Covariates that were included in multimodel inference are highlighted in bold. If covariates reduced AIC >1.5 at multiple scale, only the scale with the highest reduction in AIC was included in global models. Quadratic variables were only chosen if they reduced AIC by >1.5 compared to linear variables.

	Soil organisms			**Plants**			**Arthropods**			**Birds**		
	dAIC			**dAIC**			**dAIC**			**dAIC**		
	2.5 km	5km	10km	2.5 km	5km	10km	2.5 km	5km	10km	2.5 km	5km	10km
Landscape composition – %Land cover												
%Cropland												
linear	1.59	1.11	1.25	1.96	1.97	2.00	2.00	1.98	2.00	-0.92	-0.08	0.47
quadratic	1.53	2.14	1.80	2.16	0.56	0.84	0.61	1.32	3.07	0.97	1.69	2.26
%Grassland												
linear	1.31	1.37	1.08	1.67	1.59	1.67	1.55	1.29	1.11	1.71	2.00	1.99
quadratic	2.93	2.66	3.08	3.05	2.45	2.65	**-3.04**	-2.11	0.62	3.68	2.21	0.82
%forest												
linear	-0.16	-1.04	**-2.04**	1.41	0.99	0.45	1.53	1.59	1.02	-1.87	-4.31	**-6.86**
quadratic	1.81	0.92	-0.05	-0.65	2.31	2.05	3.53	3.51	2.91	-0.17	-2.53	-6.83
%water or wetland												
linear	1.90	1.41	1.34	**-7.26**	-3.74	-0.35	1.90	-0.59	**-1.81**	-0.64	0.99	0.65
quadratic	3.15	1.90	3.31	-8.36	-3.22	1.38	2.75	-0.37	-2.73	1.17	0.89	2.44
%artificial surfaces												
linear	1.52	1.05	1.37	1.99	2.00	1.99	2.00	2.00	1.93	1.93	1.77	0.73
quadratic	0.87	1.25	1.89	3.99	3.88	3.66	3.62	3.96	3.93	3.86	3.11	1.91
Landscape composition – Land cover diversity												
SHEI												
linear	0.49	-1.34	**-3.10**	-1.64	**-2.48**	-1.26	-2.35	**-2.81**	-0.55	0.55	1.47	1.65
quadratic	1.90	0.63	-3.42	-0.93	-1.71	-0.38	-2.89	-1.85	0.91	2.31	3.24	**-1.98**
PRD												

linear	1.22	1.39	1.90	0.75	1.97	1.84	0.84	1.94	0.68	1.99	1.82	1.80
quadratic	3.19	3.25	3.78	0.86	3.68	3.62	2.73	3.81	2.61	3.70	1.28	1.19
Landscape configuration – Patch shape												
AREA_AM												
linear	0.05	-0.11				-0.77			1.20	1.08	1.93	
quadratic	1.80	1.42				1.23			1.53	2.80	3.75	
AREA_AM-SHEI res												
linear			1.95	0.80	1.49		1.93	1.85				0.95
quadratic			3.29	2.78	3.47		0.04	3.23				2.41
AREA_AM-PRD res												
linear												
quadratic												
ED												
linear	-0.11	1.28				-1.89			1.62	1.97	1.30	
quadratic	0.16	2.39				-0.33			2.39	2.78	2.34	
ED-SHEI res												
linear			1.64	1.40	1.99		1.73	1.98				1.76
quadratic			3.40	3.06	3.37		0.64	1.26				0.41
ED-PRD res												
linear												
quadratic												
Landscape configuration – Patch spatial arrangement												
AI												
linear	-1.76	-0.30				0.44			1.04	1.99	1.28	
quadratic	0.10	1.32				-0.60			2.55	2.72	2.26	
AI-SHEI res												
linear			1.21	0.64	2.00		1.58	1.87				1.74
quadratic			2.55	1.64	3.30		0.95	1.62				-3.21
AI-PRD res												
linear												

quadratic												
CONTAG												
linear	0.21	-0.83				-1.71			-0.91	0.99	1.88	
quadratic	1.98	1.16				-1.46			0.69	2.96	3.81	
CONTAG-SHEI res												
linear			1.27	-0.70	2.00		0.38	1.77				1.38
quadratic			1.09	-0.41	2.77		-1.29	3.29				-0.75
CONTAG-PRD res												
linear												
quadratic												

Table S3.7. Results of repeated regressions of Fragstat variables for species richness (i.e. with ln Species richness ratio (org/conv) as response variable) at the 3 spatial scales. Models with dAIC < 1.5 are highlighted in yellow, models with dAIC < 2 are highlighted in red. Covariates that were included in multimodel inference are highlighted in bold. If covariates reduced AIC >1.5 at multiple scale, only the scale with the highest reduction in AIC was included in global models. Quadratic variables were only chosen if they reduced AIC by >1.5 compared to linear variables.

	Soil organisms			**Plants**			**Arthropods**			**Birds**		
	dAIC			**dAIC**			**dAIC**			**dAIC**		
	2.5 km	5km	10km	2.5 km	5km	10km	2.5 km	5km	10km	2.5 km	5km	10km
Landscape composition – %Land cover												
%Cropland												
linear	1.29	0.44	1.14	1.58	1.78	1.62	1.62	1.69	1.76	1.83	1.99	1.79
quadratic	1.69	1.43	1.00	0.95	-0.21	-0.95	0.34	0.82	1.97	2.41	3.39	3.62
%Grassland												
linear	2.00	1.87	1.94	1.63	1.75	1.88	2.00	1.99	1.95	-0.41	0.22	0.06
quadratic	3.76	3.48	1.50	3.63	3.56	3.19	**-4.29**	-3.37	-4.01	-0.01	1.61	1.11

%forest												
linear	1.57	1.30	1.75	0.98	1.79	1.83	1.62	0.71	0.63	1.78	1.95	1.85
quadratic	3.09	2.56	3.43	2.80	3.68	3.62	2.30	2.52	2.62	3.63	3.36	2.32
%water or wetland												
linear	2.00	1.99	1.99	-0.11	-0.39	0.03	1.57	1.92	1.32	1.81	**-2.30**	-1.75
quadratic	3.98	3.91	3.87	1.67	0.71	2.01	-0.16	3.31	2.75	2.94	-0.66	0.25
%artificial surfaces												
linear	1.58	1.58	1.45	1.63	1.64	0.69	1.98	1.97	1.86	1.90	0.83	0.80
quadratic	1.63	2.93	1.32	3.63	3.25	2.13	3.89	3.40	2.81	3.89	0.90	2.75
Landscape composition – Land cover diversity												
SHEI												
linear	1.52	0.37	-1.15	0.99	0.84	-0.42	-2.19	**-3.33**	-3.31	1.43	1.81	1.87
quadratic	3.17	1.94	**-2.00**	2.41	2.76	0.84	-0.20	-1.63	-1.34	3.41	2.62	2.40
PRD												
linear	-0.77	-0.27	0.36	-0.88	0.64	**-2.05**	1.99	1.89	0.86	1.81	1.81	1.94
quadratic	1.05	1.71	2.34	-0.67	2.64	-0.71	3.93	3.36	2.20	3.69	1.44	2.09
Landscape configuration – Patch shape												
AREA_AM												
linear	1.08	0.33	-1.01	**-2.93**	-2.37					1.38	1.47	1.87
quadratic	3.08	2.31	0.17	-1.88	-0.38					3.35	1.25	1.89
AREA_AM-SHEI res												
linear			0.83				1.19	0.40	-1.03			
quadratic			2.64				0.01	2.36	0.94			
AREA_AM-PRD res												
linear						0.71						
quadratic						-1.07						
ED												
linear	0.55	1.13		-2.07	**-4.56**					0.41	1.77	1.76
quadratic	2.47	3.06		-1.63	-3.46					2.19	3.54	3.66
ED-SHEI res												

linear			1.98				-1.18	**-7.52**	-4.32			
quadratic			1.59				-0.50	-5.53	-4.33			
ED-PRD res												
linear						-1.44						
quadratic						0.15						
Landscape configuration – Patch spatial arrangement												
AI												
linear	1.71	1.86		-0.04	-2.01	**-2.85**				0.35	1.81	1.88
quadratic	3.45	3.85		1.14	-2.71	-3.93				2.17	3.57	3.81
AI-SHEI res												
linear			1.96				-1.05	**-6.99**	-3.67			
quadratic			0.66				0.14	-5.02	-3.47			
AI-PRD res												
linear						/						
quadratic						/						
CONTAG												
linear	1.76	1.21		1.27	0.84	-0.89				1.16	1.83	1.87
quadratic	3.69	3.12		3.26	2.64	-0.26				3.03	3.00	2.43
CONTAG-SHEI res												
linear			1.86				-0.78	**-4.23**	-1.93			
quadratic			1.06				-1.33	-2.52	-3.52			
CONTAG-PRD res												
linear						/						
quadratic						/						

Table S3.8. Results of repeated regressions of Study, Regional and Google Earth variables for organism abundance (i.e. with ln Organism abundance ratio (org/conv) as response variable). Models with dAIC < 1.5 are highlighted in yellow, models with dAIC < 2 are highlighted in red. Covariates that were included in multimodel inference are highlighted in bold. Quadratic variables were only chosen if they reduced AIC by >1.5 compared to linear variables.

Explanatory variables	**dAIC**			
	Soil organisms	**Plants**	**Arthropods**	**Birds**
Study variables				
Continent	1.86	1.86	1.87	/
System type	4.48	**-4.90**	3.50	**-5.81**
Habitat	/	**-41.40**	1.04	/
Years since conversion	1.92	/	1.28	/
Multicropping	3.37	/	2.12	0.58
Crop rotation	3.43	1.79	3.29	/
Study field size	1.63	**-9.51**	-1.40	0.34
Organism subgroup	2.79	/	**-8.01**	3.75
Regional variables				
Slope	1.27	-0.09	0.42	1.76
Soil moisture	1.85	1.73	1.05	**-10.59**
GDD	1.00	1.99	1.63	**-2.69**
Soil pH	2.00	1.81	-1.01	-0.35
Soil Carbon Density	1.81	1.52	**-2.12**	1.76
Yield Gap	1.96	-0.69	1.09	-1.44
Google Earth variables				
% Agricultural area				
linear	**-3.78**	-0.77	**-3.41**	-0.58
quadratic	-2.74	-0.37	-4.41	-0.01
Field number				
linear	1.55	1.96	1.32	1.50
quadratic	3.29	3.74	3.32	**-4.09**
Field size				
linear		1.92		1.95
quadratic		2.87		3.53
Field size-res				
linear	1.33		1.45	
quadratic	2.19		3.39	
Area-perimeter ratio				
linear		1.72		1.71
quadratic		3.71		3.70
Area-perimeter ratio-res				
linear	1.59		1.51	

quadratic	1.27		3.48	
Total field perimeter				
linear		1.90		1.98
quadratic		3.80		**-3.31**
Total field perimeter-res				
linear	1.47		0.18	
quadratic	3.47		2.17	

Table S3.9. Results of repeated regressions of Study, Regional and Google Earth variables for species richness (i.e. with ln Organism species richness ratio (org/conv) as response variable). Models with dAIC < 1.5 are highlighted in yellow, models with dAIC < 2 are highlighted in red. Covariates that were included in multimodel inference are highlighted in bold. Quadratic variables were only chosen if they reduced AIC by >1.5 compared to linear variables.

	dAIC			
Explanatory variables	**Soil organisms**	**Plants**	**Arthropods**	**Birds**
Study variables				
Continent	1.26	1.57	1.13	/
System type	**-21.11**	4.88	0.06	**-7.97**
Habitat	**-19.63**	/	**-1.55**	/
Years since conversion	/	1.12	1.58	/
Multicropping	/	1.04	**-4.37**	/
Crop rotation	/	-0.95	2.92	**-3.25**
Study field size	**-2.77**	1.77	1.61	**-2.88**
Organism subgroup	/	2.71	**-1.96**	3.86
Regional variables				
Slope	1.15	0.86	-1.26	1.96
Soil moisture	1.99	1.09	1.53	**-5.88**
GDD	1.87	1.26	-0.88	-1.21
Soil pH	**-2.58**	1.12	1.57	1.75
Soil Carbon Density	0.83	1.78	0.04	1.99
Yield Gap	1.80	1.74	1.42	1.99
Google Earth variables				
% Agricultural area				
linear	**-3.53**	1.91	-1.40	0.39
quadratic	-1.63	2.82	**-3.00**	1.25
Field number				
linear	1.98	1.73	1.02	1.91
quadratic	2.33	2.66	2.44	**-8.32**
Field size				

linear		1.74		1.22
quadratic		3.73		0.54
Field size-res				
linear	2.00		1.40	
quadratic	2.19		2.37	
Area-perimeter ratio				
linear		1.92		1.53
quadratic		3.29		-2.84
Area-perimeter ratio-res				
linear	1.99		0.92	
quadratic	1.48		2.29	
Total field perimeter				
linear		1.91		1.81
quadratic		2.82		-6.50
Total field perimeter-res				
linear	1.88		1.47	
quadratic	3.76		2.96	

S3.4 GENERAL RESPONSE TO ORGANIC MANAGEMENT

Comparison to other meta-analyses

Our meta-analysis found that organic management significantly increases species richness of plants, arthropods, and soil organisms, as well as the abundance of soil organisms and plants. The influence of organic management on bird richness or bird abundance was not significant due to high uncertainty and wide confidence intervals. Interestingly, even the response of arthropod abundance was not significantly differently from zero, despite a rather high sample size (n=389).

The values found in our analysis for species richness are similar to values found by Tuck *et al.* (2014) (see Fig. S3.3). But previous meta-analyses have typically found higher impact of organic management on organism abundance than on species richness (Bengtsson *et al.* 2005; Crowder *et al.* 2012). In our study this pattern, which is visible in univariate models (result not shown), disappears when covariates are taken into account, suggesting that the effect of organic management on organism abundance varies considerably, for example between different arthropod orders, different system types or different landscapes. This is especially the case in arthropods and birds, where multivariate models show a very high confidence interval around the mean abundance effect.

Differences between organisms

Birds in general do not appear to benefit from organic management, neither in terms of species richness nor in terms of abundance (Fig. 3.3, main text). This result is consistent with many primary studies that have observed little to no effects of organic management on birds (Chamberlain *et al.* 1999; Fuller *et al.* 2005; Jones *et al.* 2005; Piha *et al.* 2007; Kragten & de Snoo 2008). Other studies have, however, found consistently higher occurrences of birds in organically managed fields (Christensen *et al.* 1996; Freemark & Kirk 2001; Beecher *et al.* 2002; Geiger *et al.* 2010; Winqvist *et al.* 2011), particularly for bird species that spend most of their time within fields (Christensen *et al.* 1996; Chamberlain *et al.* 1999; Piha *et al.* 2007). While we did thus not observe a significant effect of organic management on bird biodiversity across all studies, this could be different for individual bird species, or in different organic farms with a different set of management practices (see discussion below).

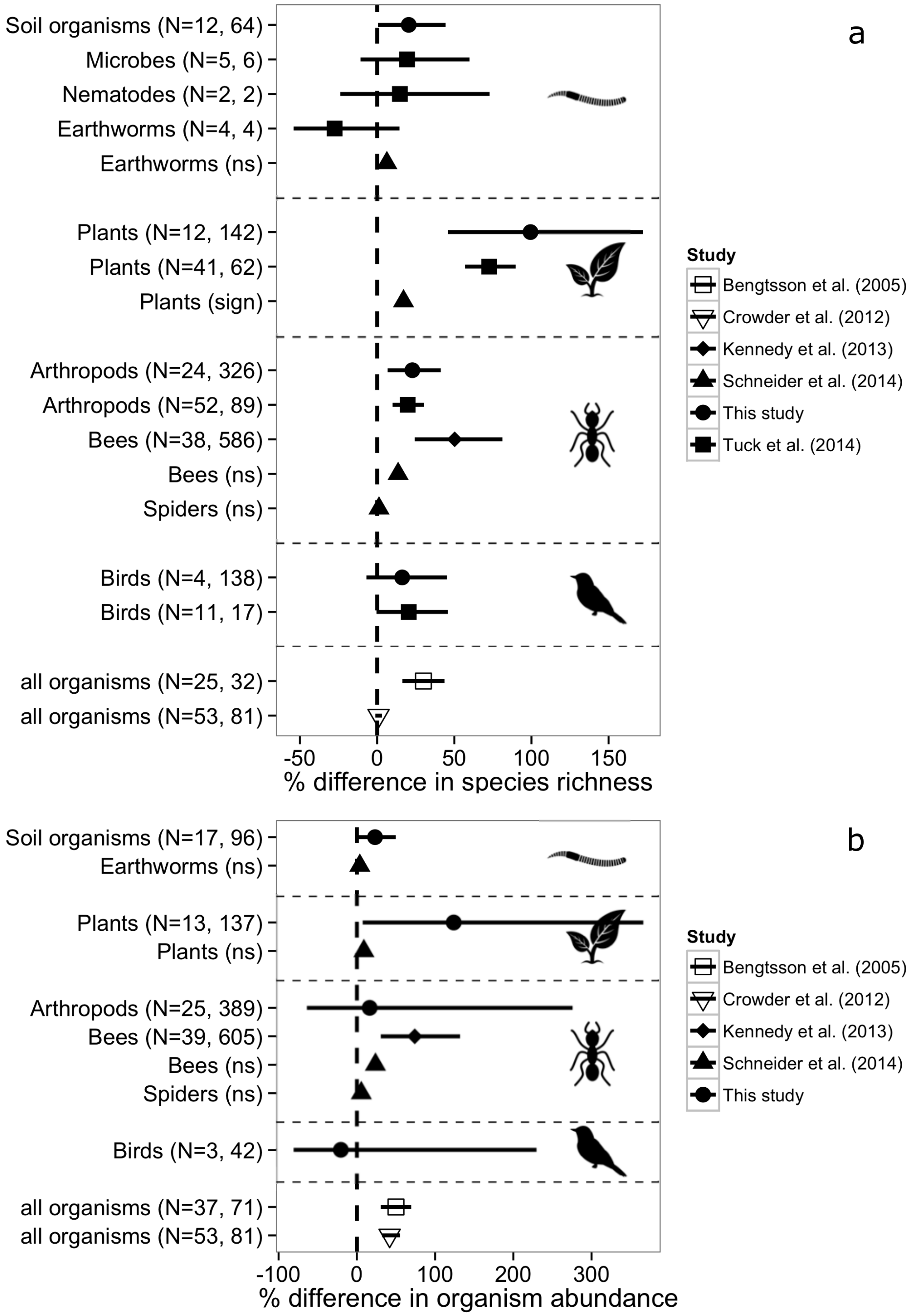


Figure S3.3. Comparison of results of effectiveness of organic management for organism abundance (a) and species richness (b) of different organism groups in different large-scale studies (i.e. Schneider *et al.* 2014) or meta-analyses (i.e. Bengtsson *et al.* 2005; Crowder *et al.* 2012; Kennedy *et al.* 2013; Tuck *et al.* 2014). The number of studies, and number of observations included in each meta-analysis are shown in parentheses. Note that mean estimates from different studies, as well as confidence intervals around the mean were calculated using different methods and thus represent different things (the Bengtsson *et al.* 2005 and Tuck *et al.* 2014 estimates represent, for example, the mean effect size from univariate models, while estimates from this study, as well as from Kennedy *et al.* 2013 represent model-averaged partial regression coefficients from multivariate models).

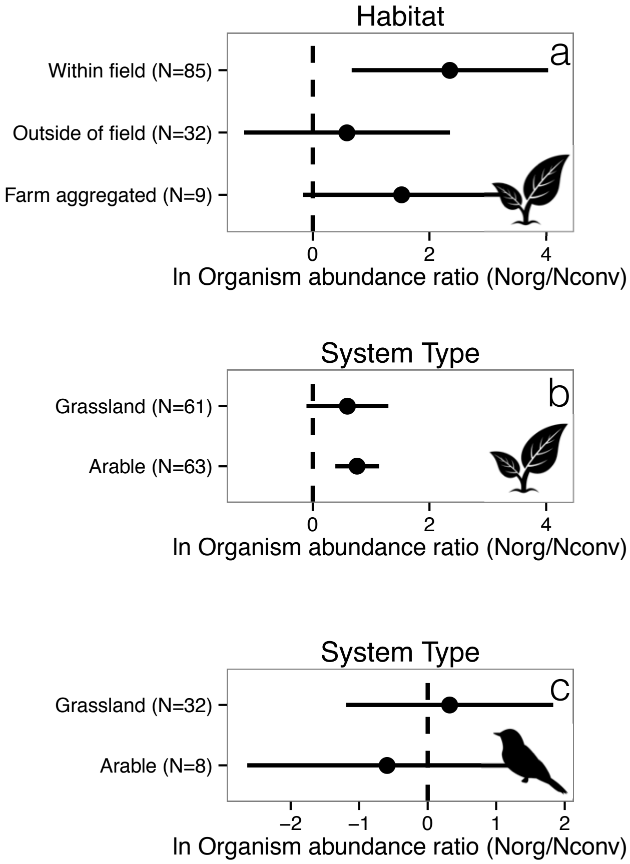


Figure S3.4. Effectiveness of organic management for organism abundance of different organism groups depending on Habitat (a), and System Type (b, c). Estimates show model-averaged fixed effects of each covariate, while holding the other covariates constant at their means, as well as 95% unconditional CIs. The number of observations for each category is shown in parentheses. Only relationships with covariates where the 95% CI of model-averaged partial regression coefficients does not overlap 0, and where Akaike weights > 0.4 (see Table 3.3, main text) are shown. The effect of organic management is considered to be significantly different from zero if CIs do not overlap zero. Note that biodiversity ratios are represented as natural logarithms and not back-transformed.

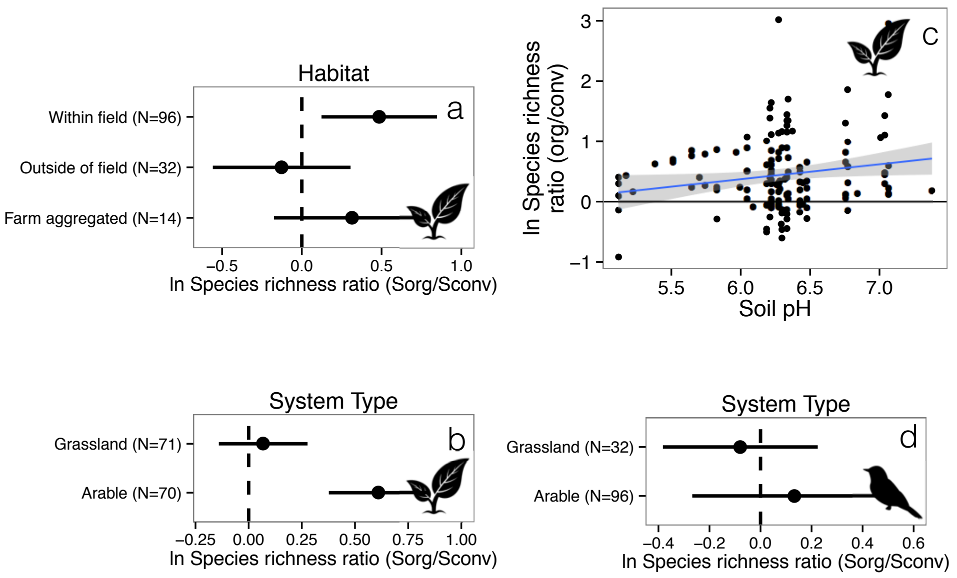


Figure S3.5. Effectiveness of organic management for species richness of different organism groups depending on Habitat (a), System Type (b, d), and soil pH (c). Estimates for panels a, b and d show model-averaged fixed effects of each covariate, while holding the other covariates constant at their means, as well as 95% unconditional CIs. The number of observations for each category is shown in parentheses. Panel c shows the regression line from the univariate mixed model (i.e. not accounting for covariates), as multivariate models are difficult to depict in two dimensions. Shaded area represents 95% CI. Only relationships with covariates where the 95% CI of model-averaged partial regression coefficients does not overlap 0, and where Akaike weights > 0.4 (see Table 3.4, main text) are shown. The effect of organic management is considered to be significantly different from zero if CIs do not overlap zero. Note that biodiversity ratios are represented as natural logarithms and not back-transformed.

Differences between habitats and farming systems

Although Akaike weights > 0.4 suggest that there is some effect of Habitat and System Type covariates, the confidence intervals of different categories often overlapped considerably (especially for System Type for bird abundance and bird richness, as well System Type and Habitat for plant abundance, Fig. S3.4, S3.5), which does not allow us to make strong conclusions about the influence of these covariates.

The influence of organic management appeared to be higher in arable systems than in grassland systems for plant species, and to a lesser degree for birds (Fig. S3.6). It has often been observed that organic management makes a stronger difference for biodiversity in intensive arable systems than in grassland systems, which are typically less intensively managed and generally host higher biodiversity than arable fields, especially for plant species (Batáry *et al.* 2010; Gabriel *et al.* 2010; Batáry *et al.* 2012; Schneider *et al.* 2014).

We also observed that organic management increased species richness and (to a lesser degree) abundance of plants more strongly within fields than outside of fields (e.g. in hedgerows or field boundaries, Fig. S3.4, S3.5). Although we cannot be very confident in this result (especially for plant abundance) due to overlapping confidence intervals, it confirms with the results of primary studies, which often have shown increased biodiversity of plants within fields (Gabriel *et al.* 2006; Gibson *et al.* 2007; José-María & Sans 2011; Power *et al.* 2012), while increases outside of fields are often lacking, or are smaller than in the field centre (Weibull *et al.* 2003; Gibson *et al.* 2007; Aavik & Liira 2010; José-María & Sans 2011; Power *et al.* 2012). A recent trans-regional study that sampled biodiversity in organic versus conventionally managed fields as well as non-productive farm habitats also observed that gains in species richness from organic management at the farm level were much lower than at the field level (Schneider *et al.* 2014). The same study also showed that organic farms did not have higher habitat diversity, or more semi-natural elements than conventional farms, while organic farms did differ from conventional farms in terms of on-field management practices like fertilization, pest management and tillage (Schneider *et al.* 2014). This lack of structural differences between organic and conventional farms has also been observed in other regions and other studies (Kragten & de Snoo 2008).

On the other hand, numerous primary studies also have shown benefits of organic management on plant diversity (Aude *et al.* 2003; Gabriel *et al.* 2006; Petersen *et al.* 2006; Clough *et al.* 2007a; Boutin *et al.* 2008; Batáry *et al.* 2012) or arthropod diversity (Cobb *et al.* 1999; Feber *et al.* 2007; Ekroos *et al.* 2008) also in habitats in field boundaries or outside of fields. For birds organic management has sometimes been found to be even more effective in hedgerow habitats than within fields (Chamberlain *et* *al.* 1999; Beecher *et al.* 2002). Studies have also often shown increases in the beta diversity between different habitats in organic farms, in addition to increases in local alpha diversity within habitats (Gabriel *et al.* 2006; Clough *et al.* 2007a; Rundlöf *et al.* 2008a). Furthermore, some studies have observed organic farms to sometimes be more structurally diverse, with higher amount of non-cropped habitat and more diversified local landscape structures like hedgerows (Chamberlain *et al.* 1999; Fuller *et al.* 2005; Gibson *et al.* 2007).

This contradicting evidence is likely related to the large variation in management practices between organic farms. Organic regulations mainly focus on the prohibition of synthetic inputs, but do typically not require any additional wildlife-friendly management practices (see Chapter 5). The clearest common denominator of organic farms is therefore a set of fertilization, pest and weed control practices that are different from conventional farms. It is thus not surprising if the highest impact of organic management across different studies and different regions is observed within arable fields. But in some countries other agro-environmental practices like cropping system diversification (e.g. through enhanced crop rotations, planting of cover crops), land set-aside from cultivation, non-conversion of important habitats and of extensive grassland systems, as well as the incorporation of larger areas of non-productive habitats on farms (like ditches, hedgerows, or woody patches) are encouraged and financially rewarded through other policies (e.g. Kleijn & Sutherland 2003), and organic farmers are often interested in adopting such diversification measures (Stobbelaar *et al.* 2009). The standards set by organic regulations are thus often considered minimum requirements, and many organic farmers voluntarily go beyond these minimum standards (Darnhofer *et al.* 2010).

Management practices and the degree of system diversification on organic farms thus vary considerably depending on the policy and economic context but also depending on farmer motives. This variation in management practices is a likely explanation for the large variation between studies in how organic management influences biodiversity (see e.g. the large confidence intervals for bird and arthropod abundance, Fig. 3.3b, main text, as well as the variation in results from different large-scale studies or meta-analyses, Fig. S3.6). Many of the measures adopted by organic farmers that are beneficial for wildlife are not unique to organic farms. While many management practices that are known to increase biodiversity - like higher crop diversity, reduced tillage, set-aside land, smaller field size, or increased wooded habitats - are not required by organic regulations. Organic agriculture can therefore not always be equated with more sustainable or more wildlife-friendly management practices (Williams & Hedlund 2013).

Another result that is probably related to organic management practices is the observation that the influence of organic agriculture on plant richness is dependent on regional soil pH (Akaike weight 0.49, see Table 3.4), with farms situated in regions with higher aka more alkaline soil pHs showing a higher influence of organic management on plant richness. Yields in organic farms are often nutrient-limited (Berry *et al.* 2002; Seufert *et al.* 2012), and non-arable plant richness and abundance could thus also be influenced by nutrient availability in organic fields. This pattern could thus potentially be explained by phosphorus availability, which is strongly dependent on soil pH status, especially in organic systems that are more dependent on microbial decomposition (Mäder *et al.* 2002).

S3.5 LANDSCAPE RELATIONSHIPS

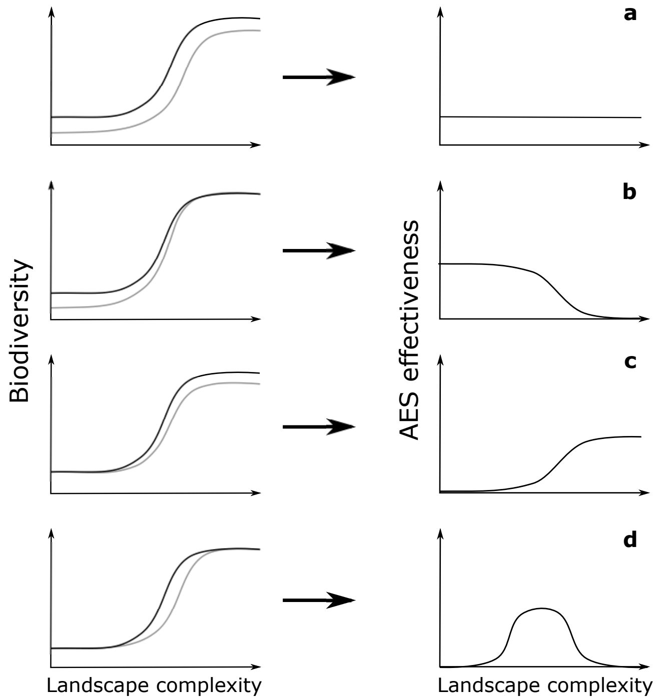
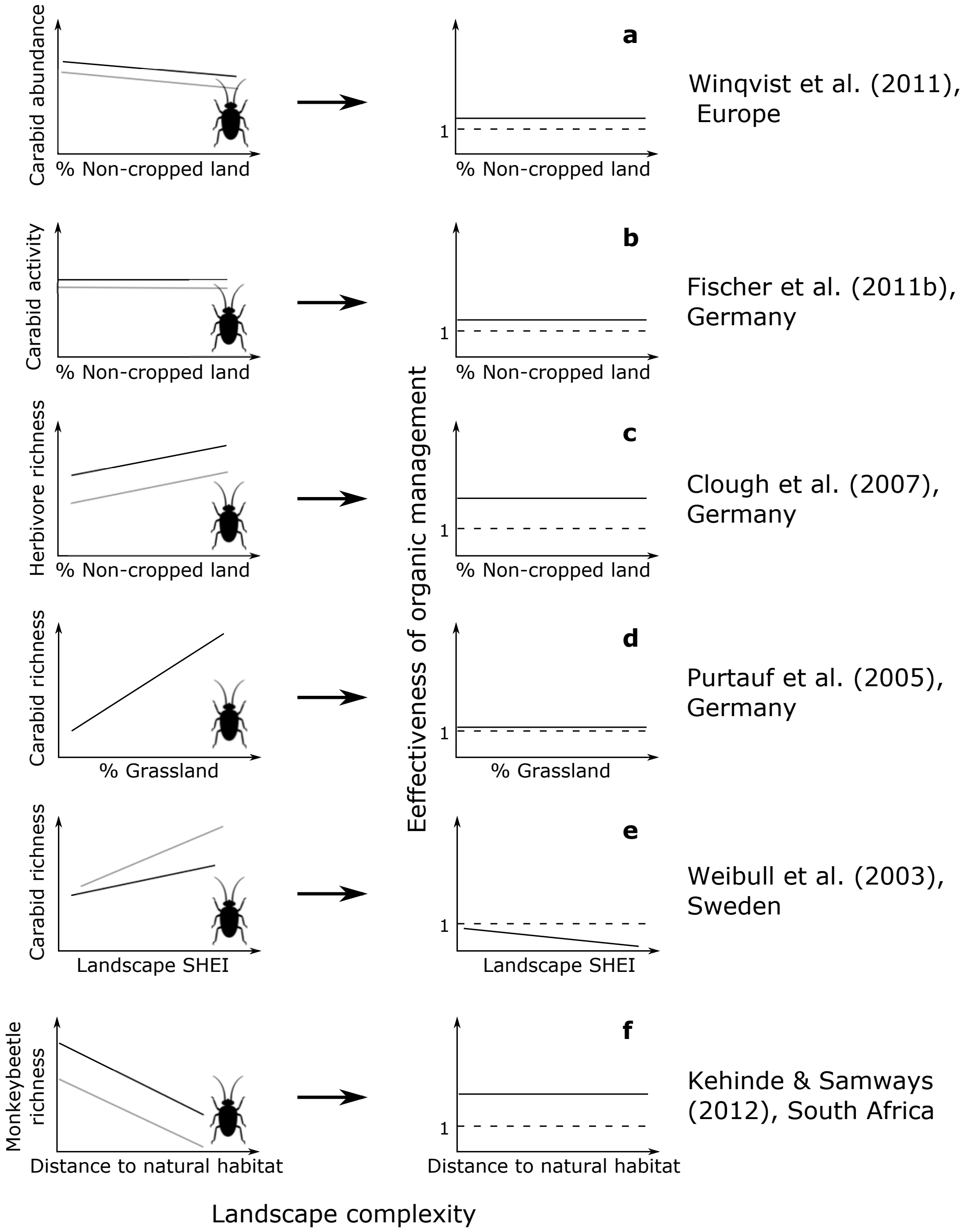
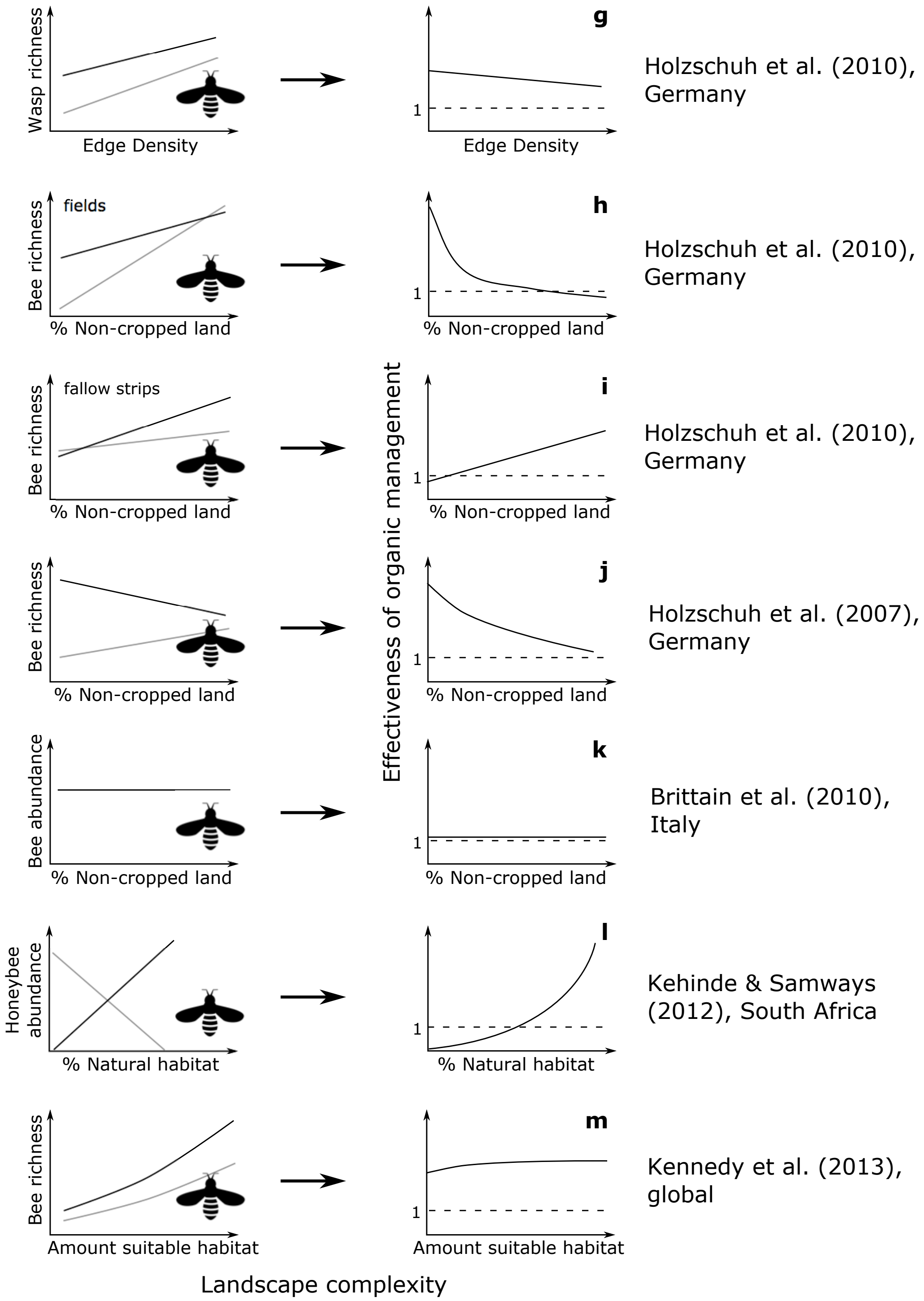
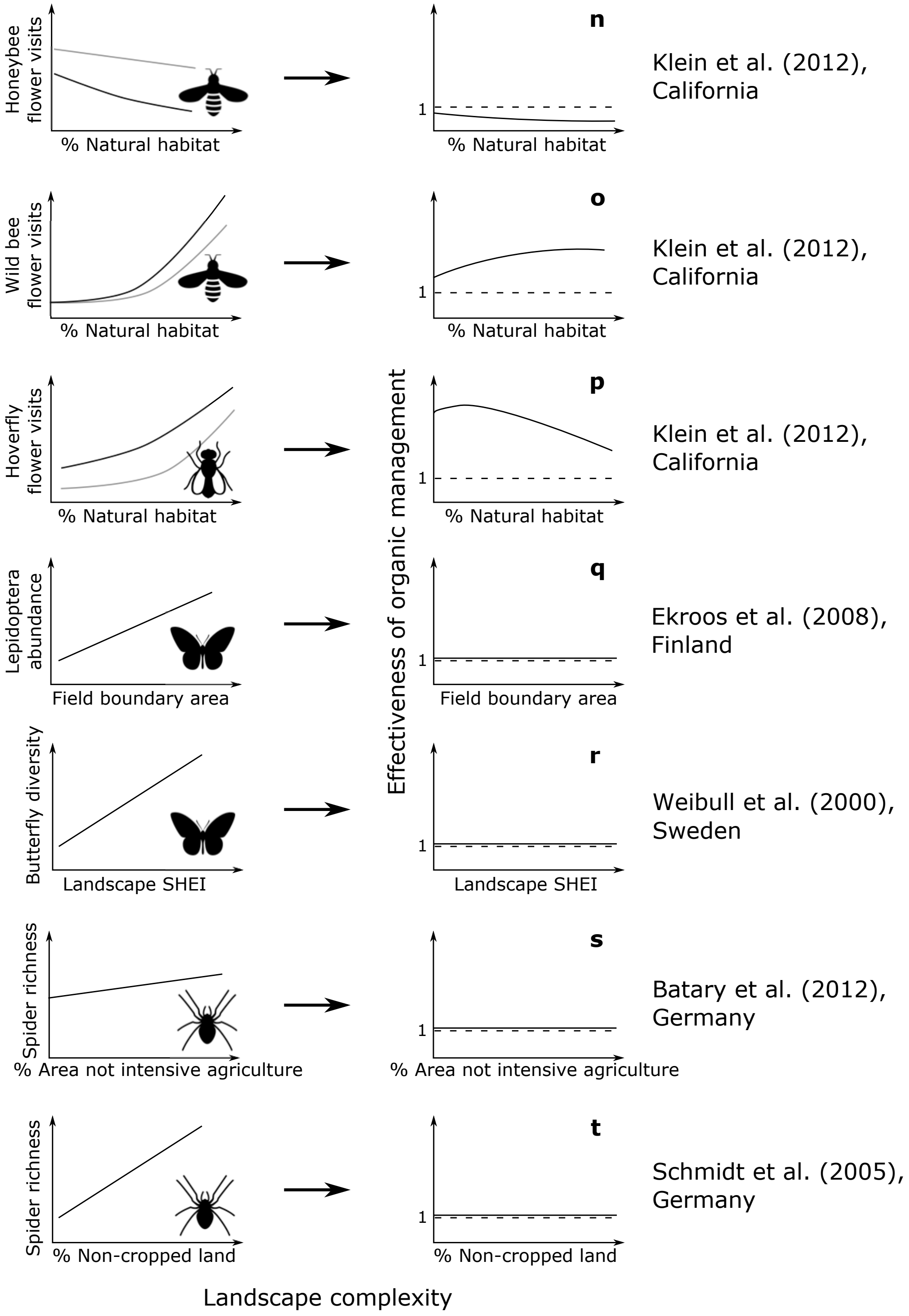
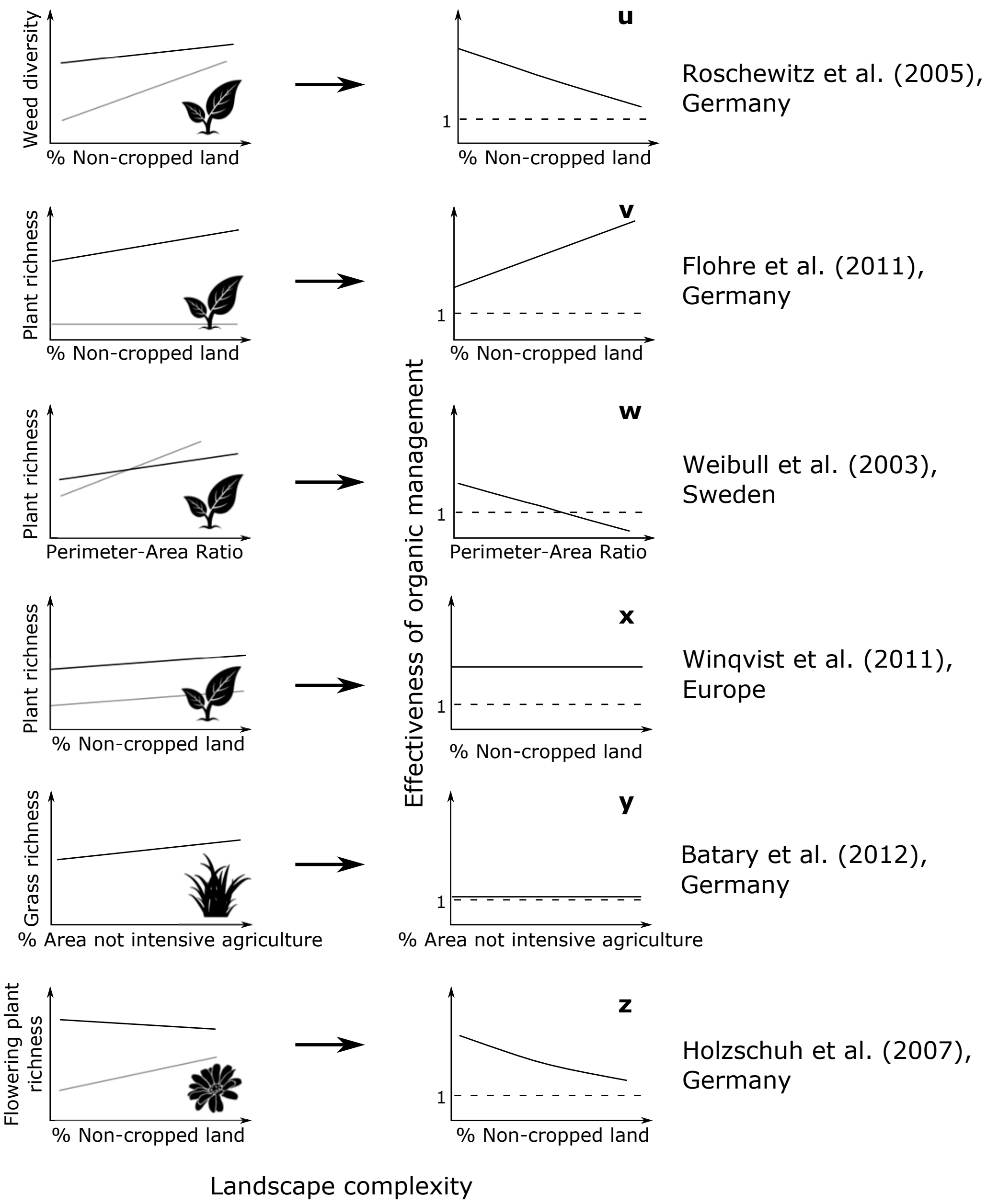


Figure S3.6. Response of biodiversity in organic versus conventional farms to landscape heterogeneity, as suggested by Tscharntke *et al.* (2005) and Concepción *et al.* (2008). Redrawn from Fig. 2 in Concepción *et al.* (2008). In the left panels the black line represents biodiversity in organic fields, and the grey line represents biodiversity in conventional fields.


Carabid abundance
% Non-cropped land
a
1
% Non-cropped land
Winqvist et al. (2011), Europe
Carabid activity
% Non-cropped land
b
1
% Non-cropped land
Fischer et al. (2011b), Germany
Herbivore richness
% Non-cropped land
c
1
% Non-cropped land
Clough et al. (2007), Germany
Carabid richness
% Grassland
d
1
% Grassland
Purtauf et al. (2005), Germany
Carabid richness
Landscape SHEI
e
1
Landscape SHEI
Weibull et al. (2003), Sweden
Monkeybeetle richness
Distance to natural habitat
f
1
Distance to natural habitat
Kehinde & Samways (2012), South Africa
Eeffectiveness of organic management
Landscape complexity


Wasp richness
Edge Density
g
1
Edge Density
Holzschuh et al. (2010), Germany
Bee richness
fields
% Non-cropped land
h
1
% Non-cropped land
Holzschuh et al. (2010), Germany
Bee richness
fallow strips
% Non-cropped land
i
1
% Non-cropped land
Holzschuh et al. (2010), Germany
Bee richness
% Non-cropped land
j
1
% Non-cropped land
Holzschuh et al. (2007), Germany
Bee abundance
% Non-cropped land
k
1
% Non-cropped land
Brittain et al. (2010), Italy
Honeybee abundance
% Natural habitat
l
1
% Natural habitat
Kehinde & Samways (2012), South Africa
Bee richness
Amount suitable habitat
m
1
Amount suitable habitat
Kennedy et al. (2013), global
Effectiveness of organic management
Landscape complexity


Honeybee flower visits
% Natural habitat
n
1
% Natural habitat
Klein et al. (2012), California
Wild bee flower visits
% Natural habitat
o
1
% Natural habitat
Klein et al. (2012), California
Hoverfly flower visits
% Natural habitat
p
1
% Natural habitat
Klein et al. (2012), California
Lepidoptera abundance
Field boundary area
q
1
Field boundary area
Ekroos et al. (2008), Finland
Butterfly diversity
Landscape SHEI
r
1
Landscape SHEI
Weibull et al. (2000), Sweden
Spider richness
% Area not intensive agriculture
s
1
% Area not intensive agriculture
Batary et al. (2012), Germany
Spider richness
% Non-cropped land
t
1
% Non-cropped land
Schmidt et al. (2005), Germany
Effectiveness of organic management
Landscape complexity


Weed diversity
% Non-cropped land
u
1
% Non-cropped land
Roschewitz et al. (2005), Germany
Plant richness
% Non-cropped land
v
1
% Non-cropped land
Flohre et al. (2011), Germany
Plant richness
Perimeter-Area Ratio
w
1
Perimeter-Area Ratio
Weibull et al. (2003), Sweden
Plant richness
% Non-cropped land
x
1
% Non-cropped land
Winqvist et al. (2011), Europe
Grass richness
% Area not intensive agriculture
y
1
% Area not intensive agriculture
Batary et al. (2012), Germany
Flowering plant richness
% Non-cropped land
z
1
% Non-cropped land
Holzschuh et al. (2007), Germany
Effectiveness of organic management
Landscape complexity

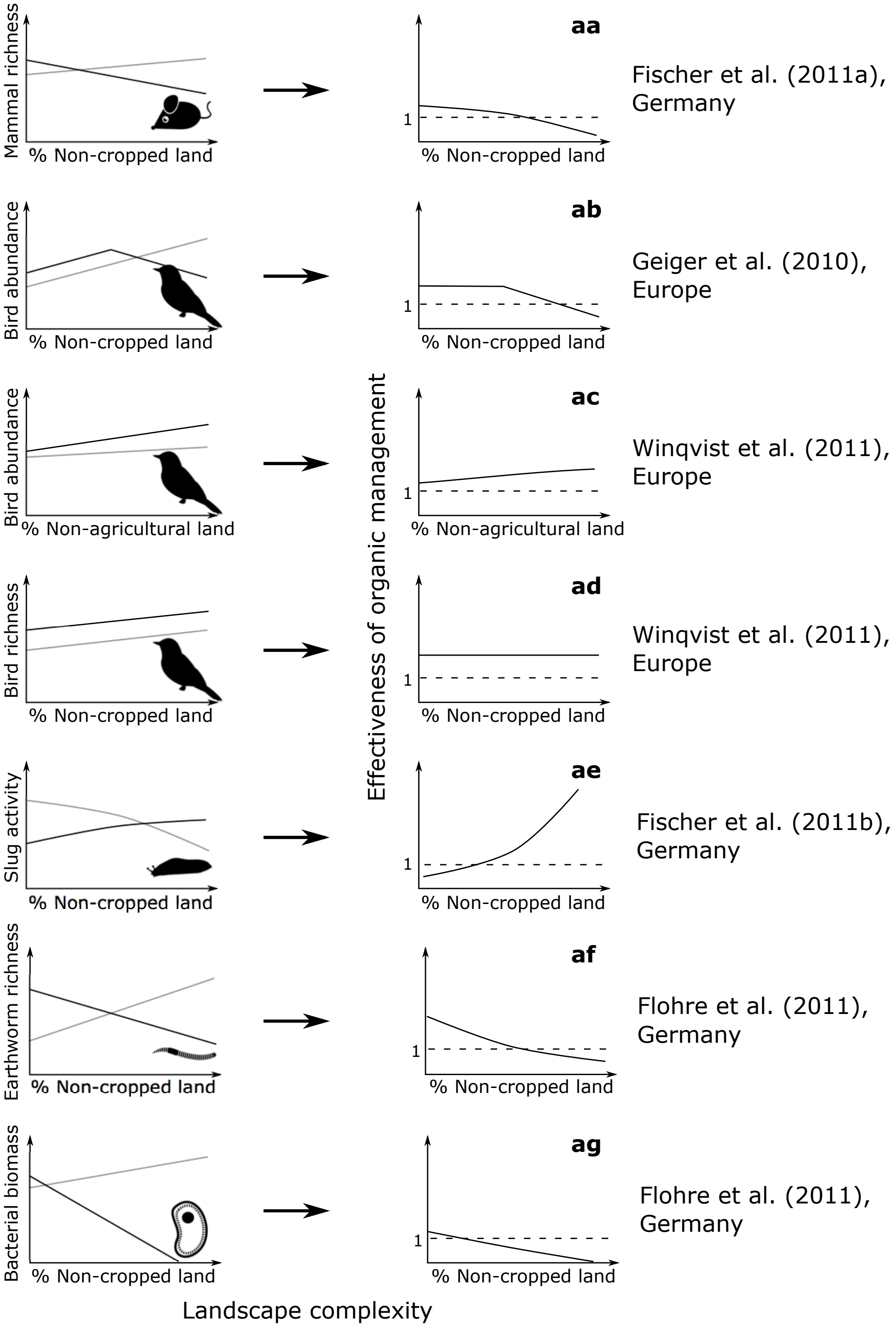

Mammal richness
% Non-cropped land
aa
1
% Non-cropped land
Fischer et al. (2011a), Germany
Bird abundance
% Non-cropped land
ab
1
% Non-cropped land
Geiger et al. (2010), Europe
Bird abundance
% Non-agricultural land
ac
1
% Non-agricultural land
Winqvist et al. (2011), Europe
Bird richness
% Non-cropped land
ad
1
% Non-cropped land
Winqvist et al. (2011), Europe
Slug activity
% Non-cropped land
ae
1
% Non-cropped land
Fischer et al. (2011b), Germany
Earthworm richness
% Non-cropped land
af
1
% Non-cropped land
Flohre et al. (2011), Germany
Bacterial biomass
% Non-cropped land
ag
1
% Non-cropped land
Flohre et al. (2011), Germany
Effectiveness of organic management
Landscape complexity

Figure S3.7. Response of biodiversity in organic versus conventional fields to landscape heterogeneity, as observed in primary studies. In the left panels the black line represents biodiversity in organic fields, and the grey line represents biodiversity in conventional fields. The right panels show the ratio of organic to conventional biodiversity, i.e. the effectiveness of organic management, along a gradient of landscape complexity. The curves in the right-side panels (i.e. effectiveness of organic management) were typically not represented by the studies themselves but calculated from data extracted from the figures of absolute biodiversity (left side panels) presented in the studies. Note that not all results from all studies are shown here. Some results that show very similar patterns as the ones presented here have been omitted. For Holzschuh *et al.* (2010), for example, wasp richness in fallow strips responds very similarly to wasp richness in fields (Fig. S3.7g). For Weibull *et al.* (2003) the butterfly data is not presented, as this is the same data as presented in Weibull *et al.* (2000). For Kennedy *et al.* (2013) we only show total wild bee richness (Fig. S3.7m), and do not present the separate relationships for solitary and social bees, and we only present data for richness (not abundance) and from diverse farms (not simplified farms). The shape of the curves not shown here differ slightly from the ones presented, but the main pattern does not (i.e. increasing biodiversity with increasing amount of suitable habitat, higher biodiversity in organic farms, and basically no response of effectiveness of organic management to landscape characteristics). For Winqvist *et al.* (2011) plant abundance is not shown (as it shows the same pattern as plant richness, Fig. S3.7x). Also note that the range of landscapes sampled differs between studies, and some studies do, for example, not include landscapes with less than 20% or more than 80% non-cropped habitat. For Schmidt *et al.* (2005) only the data for May is presented (Fig. S3.7t) and the data for July (which did not show any response to landscape context) is omitted. For Fischer *et al.* (2011) only the pattern for mammal richness (Fig. S3.7aa) and not for mammal abundance or mammal diversity (which show similar patterns) is presented.

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CONNECTING STATEMENT

In Chapter 2 I examined the agronomic, and in Chapter 3 the ecological consequences of organic agriculture. In the following chapter I will now analyse the social consequences of organic farming, examining my research question 3 - why do farmers adopt organic agriculture and what are the impacts of organic agriculture on farmer livelihoods? Unlike the previous chapters I will not conduct a global scale analysis but examine the question in a regional case study in Southern India. Also unlike the previous chapters I will not use quantitative methods, but combine quantitative data collection from surveys with qualitative data collection from interviews and focus group discussions. Chapter 4 is situated within and contributes to the body of literature on sustainable livelihoods and farmer decision-making.

4. SUCCESS OF ORGANIC FARMING DEPENDS ON WHO ADOPTS IT AND WHY

“To judge something, you have to be there.” - Bronislaw Malinowski

In preparation for *World Development*.

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4.1 ABSTRACT

Organic agriculture is often proposed as a means to improving farmer livelihoods and promoting more sustainable agriculture in developing countries. The evidence on the effect of organic management on farmer livelihoods is, however, mixed. Studies suggest that the benefits of organic agriculture depend strongly on context. Here we examine the reasons why farmers decided to adopt organic agriculture and the subsequent livelihood outcomes in two districts in the South Indian state of Kerala. We identified three different types of organic farmers in our case study: export farmers who produce coffee or pepper for certified organic export markets, committed farmers who produce non-certified organic produce for domestic markets, and hobby farmers who derive most of their income from non-agricultural sources. Our study shows that export-oriented organic management is not financially viable in the Keralan context due to lower yields, low premium prices, and high labour costs. Export farmers, who typically adopted organic management to access premium prices, are usually middle-class farmers employing a lot of labour and relying on high external inputs, and are therefore dissatisfied with organic agriculture. They often consider reverting back to conventional management. Committed farmers, instead, are typically poorer farmers who carry out most of the farm work themselves and cannot afford costly inputs. Committed farmers are also encountering yield declines and marketing problems, but are generally more successful with organic agriculture, as, on the one hand, they adopted organic agriculture mostly for ideological and not economic reasons, and on the other hand, organic management typically improves their income due to reduced input costs and premium prices received. For hobby farmers, the financial viability of organic farming does not matter much as the majority of their income comes from other sources and they adopted organic agriculture for ideological and personal reasons. The success of organic farming in Kerala thus depends on both *why* farmers adopt organic agriculture (i.e. ideological versus economic reasons) and on *who* adopts organic management (i.e. poorer versus wealthier farmers).

4.2 INTRODUCTION

Organic agriculture has been proposed as a more sustainable farming system than conventional agriculture that reduces the environmental impacts of farming but also provides stable and viable livelihoods to farmers. In developing countries, where three out of four poor people live in rural areas and where more than 80% of rural people live in households that are involved in agriculture, improving poor farmers livelihoods is central for addressing poverty reduction and food security (World Bank 2007). Proponents of organic agriculture say that it has the potential to contribute to these goals by providing an accessible means of intensifying production due to its lower input costs and by subsequently improving the incomes and livelihood security of poor farmers (Scialabba & Hattam 2002; IFAD 2005; UNCTAD & UNEP 2008).

Organic agriculture is growing rapidly in developing countries, mostly as an export-oriented farming system feeding the demand for organic products in developed nations (Willer & Kilcher 2011). One-third of organic agricultural land and more than three-quarters of organic producers are located in developing and transition countries, but 96% of the organic food produced is sold in European and North American markets (Willer & Kilcher 2011). Demand for organic produce by urban middle class consumers appears to be also growing in many developing and transition countries (Scott *et al.* 2009; Freidberg & Goldstein 2011; Shi *et al.* 2011).

Evidence from developed countries suggests that farmers adopt organic management for a multitude of different reasons, from strongly ideological to purely economic motivations (Padel 2001). In general, adopters of organic agriculture in developed countries are often better educated, have less farming experience, are more often female, have smaller farms and are more motivated by personal and idealistic reasons than by profit maximization compared to conventional farmers (Burton *et al.* 1999; Padel 2001; Läpple 2013). Studies often identify strong organic values, like health and environmental protection, amongst organic farmers (Padel 2008), and many organic farmers are motivated by a larger sense of responsibility and 'stewardship' towards their land (Padel

2001). If subsidies are available for organic agriculture, or if farmers can receive a substantial price premium for organic produce, some farmers, however, also enter organic production purely to gain a higher profit (Fairweather 1999; Darnhofer *et al.* 2005). In addition to such economic (e.g. costs, prices and marketing opportunities) and personal reasons (e.g. attitudes, beliefs and objectives), operational aspects (e.g. pest and weed control, daily work routine) of organic management are also important aspects farmers in developed countries consider in their decision to adopt organic management (Padel 2001; Best 2009).

Research on motives of organic farmers in developing countries is limited. Due to the different policy context and because organic agriculture is mostly an export-oriented farming systems, it seems that, despite some similarities, the pathway of adoption of organic agriculture might be quite different. In developed countries organic agriculture has often evolved bottom-up, i.e. through initiatives and networks between farmers (Padel 2001). In developing countries, instead, information about organic agriculture and access to organic markets appears to often be dependent on the presence of governmental or non-governmental institutions and farmer cooperatives (Bray *et al.* 2002; Giovannucci 2006; Goldberger 2008). Studies conducted in India, Thailand and the Philippines show that organic farmers are especially motivated by health concerns about the use of chemical pesticides, as well as the goal to improve soil fertility, and the reduced input costs of organic practices (Mendoza 2004; Panneerselvam *et al.* 2011; Thapa & Rattanasuteerakul 2011).

While the extent of research on farmer motives to adopt organic farming has been limited in developing countries, the influence of organic agriculture on livelihood outcomes has received considerably more attention. This literature suggests that the impact of organic agriculture on farmer livelihoods is strongly context-dependent. The profitability of organic agriculture for small farmers is dependent on organic yields, the costs of production and the size of the organic price premium. All of these factors can vary between systems and years. On the one hand, organic farmers often receive higher and more stable prices for their products (Bacon 2005; Bolwig *et al.* 2009; Valkila 2009) and organic inputs are often cheaper and total production costs thus lower (Mendoza 2004; Eyhorn *et al.* 2007; Valkila 2009; Forster *et al.* 2013). On the other hand, organic production comes along with high entry costs, including higher labour requirements that often cannot be met by household resources, the need for increased knowledge and training, substantial certification costs and sometimes the need to purchase expensive organic inputs (Bray *et al.* 2002; Calo & Wise 2005; Chongtham *et al.* 2010). This is aggravated by the required transition period, in which organic practices need to be applied but the products cannot be sold yet with an organic price premium. Organic yields can sometimes be comparable or higher than yields of local conventional farming systems (Eyhorn *et al.* 2007; Panneerselvam *et al.* 2011; Forster *et al.* 2013), but they typically do not reach the levels of high-input conventional systems (de Ponti *et al.* 2012; Seufert *et al.* 2012; Ponisio *et al.* 2015). Premium prices are often essential but not always sufficient to make up for the cost of conversion and certification (Bray *et al.* 2002; Calo & Wise 2005). Organic farmers in developing countries are typically dependent on an exporting company to access international organic markets and associated premium prices. The international organic trade has therefore been criticized for reproducing the inequalities of conventional North-South trade by concentrating market power in the hands of transnational organic buyers and certifiers and by imposing additional costs of certification on producers (Raynolds 2004; Scott *et al.* 2009).

Organic agriculture can also provide benefits independent from the profitability of the organic cash crop, for example allowing the integration of traditional knowledge, or providing training, and access to health and credit programs (Bray *et al.* 2002; Bakewell-Stone *et al.* 2008). In addition, organic cash crops are often part of a diverse mixed farming system including livestock and cultivation of other crops for subsistence or local markets (Bacon 2005). Such a diverse system can contribute to a wider spread of risk by reducing the economic dependence on a single crop. Last but not least, farming systems following agro-ecological principles have been shown to often provide more stable yields and to be more resilient against extreme weather events than conventional systems

(Holt-Gimenez 2002).

The success of organic agriculture as a livelihood strategy is context-dependent (see Table 4.1). For organic agriculture to expand and contribute to a more sustainable food system we need to better understand why farmers adopt organic practices, and how well organic agriculture works for them in different contexts. In this study we aim to examine the livelihoods and motives of organic farmers in the South Indian state of Kerala, addressing three main research questions:

Research question 1: What are the characteristics of organic farmers in Kerala?

Research question 2: What motivates different types of organic farmers in Kerala? Why do they do organic?

Research question 3: How does organic farming work for these farmers?

Table 4.1. Impact of organic agriculture on farmer's livelihoods. Positive impacts are shaded in green, negative impacts in red, and impacts that are ambiguous as they vary between studies or they have not yet been studied sufficiently in orange.

	Impact of organic
Yields	increased/decreased
Costs[1]	increased/decreased
Prices	increased
Resilience	increased
Dependence[2]	increased
Other benefits[3]	increased

[1] - inputs or + labour, + certification

[2] dependence on certifying & exporting companies

[3] + organization, access to knowledge, health & credit services

4.3 STUDY METHODS

4.3.1 CONCEPTUAL FRAMEWORK

There are multiple theories to explain farmer decision-making, ranging from purely economic approaches that assume farmers behaviour is mostly driven by profit goals, either as rational actors (rational choice theory, Lin *et al.* 1974; Herath *et al.* 1982), or bounded by their social and physical environment, and personal circumstances (bounded reality, Einhorn & Hogarth 1981; Simon 1982), to behavioural approaches, which consider an individual's attitudes in the explanation of decision-making (e.g. theory of planned behaviour, Willock *et al.* 1999; Burton 2004). Behavioural approaches, unlike purely economic ones, have been successfully applied to explain farmer decision-making (Beedell & Rehman 1999; Heong & Escalada 1999; Beedell & Rehman 2000; Austin *et al.* 2001).

To some degree behavioural approaches have, however, gone too far from purely economic models by neglecting the economic and political context in which farmer's decision-making is situated. Some studies have attempted to combine individual behavioural characteristics of farmers with household characteristics and external socio-economic and biogeographic drivers (e.g. Willock *et al.* 1999; Siebert *et al.* 2006; Valbuena *et al.* 2010). Here we adopt the well-established sustainable livelihood framework, which provides a strong conceptualizing of farmers diverse livelihoods within a structural context of vulnerability, and transforming structures and processes, to examine farmer-decision making as influenced by both internal and external factors.[19]

Livelihood approaches were developed as a critique to purely income-based and employment-focused poverty discussions (Chambers & Conway 1991). In the words of Ellis (2000, p. 10): "A livelihood comprises the assets (natural, physical, human,

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[19] It is important to note that internal factors here are not synonymous with intrinsic decision-making factors. We define internal factors as factors that pertain to the farm scale, and thus can be external to the farmer's person (e.g. farm size, financial assets). The term intrinsic factors (as used for example in self-determination theory) instead denote motivations that come from within oneself (e.g. for pleasure, satisfaction).

financial and social capital), the activities, and the access to these (mediated by institutions and social relations) that together determine the living gained by the individual or household".

The sustainable livelihood framework examines the individual or household activities within a broader geographical (i.e. politics, history, agro-ecology and socio-economics of the location) and individual (i.e. assets or livelihood resources) context, which determines the range of possible strategies a household can pursue (Scoones 1998). Livelihood outcomes are not only assessed in terms of household income or employment but as a multitude of factors based on the key goal of enhancing capabilities, equity and sustainability (Chambers & Conway 1991). Sustainability in the livelihood context has two dimensions – its effect on local and global resources (environmental sustainability), as well as its ability to cope with stress and shocks (social sustainability; Chambers & Conway 1991).

This definition of sustainability in the context of sustainable livelihoods is strongly related to the more recent concept of social resilience. Following the suggestions of Obrist *et al.* (2010) we therefore include resilience more explicitly, by changing the focus from vulnerability to the reactive and adaptive capacity of livelihoods. Desirable livelihood outcomes in our view therefore do not only include income generation, well-being, and food security, but also include the important aspect of resilience building, or the "human capacity to anticipate, resist, cope, adapt, or recover from the impact of a hazard" (Obrist *et al.* 2010, p. 285).

Figure 4.1 provides a visual representation of how we conceptualize farmer's decision-making and farmer's livelihoods based on behavioural approaches combined with the sustainable livelihood framework. Our analysis of organic farmers in Kerala has three key components: the examination of (1) farmer sustainable livelihood characteristics, (2) farmer decision-making, and (3) farmer livelihood outcomes. While we situate farmer's livelihoods and decision-making within a broader context of institutions, markets, and social networks, the focus of the study is at the farm scale.

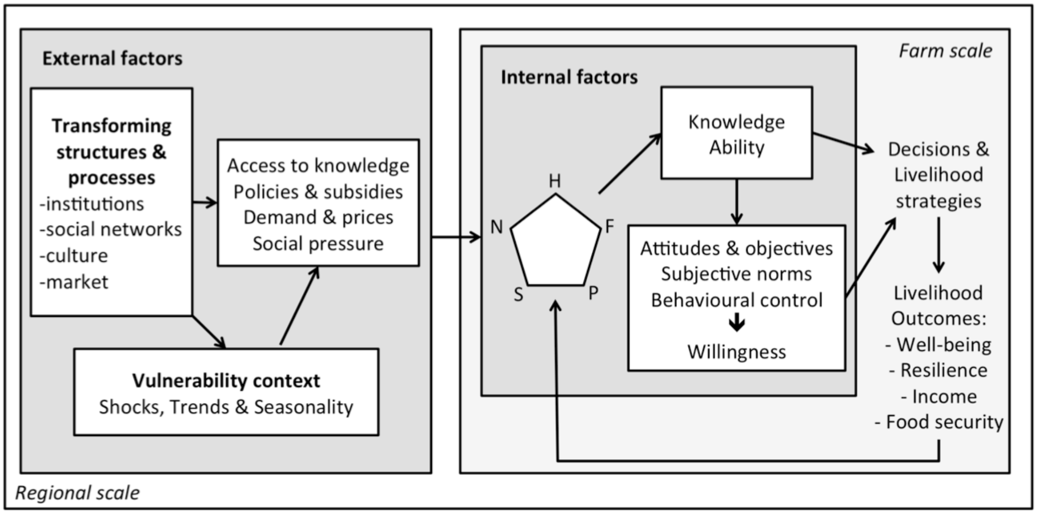

Figure 4.1. Conceptual framework of the study, combining sustainable livelihood framework (see e.g. Fig. 1 in DFID 1999), and farmer decision-making (see e.g. Fig. 2 in Valbuena *et al.* 2010). N, H, F, P and S denote the five capitals, i.e. natural, human, financial, physical and social capital.

4.3.2 STUDY AREA

Kerala – a small state in South-western India (Fig. 4.2) – has always intrigued development scholars, as it showcases consistently the highest human development of all Indian states (much higher than the national average and at par with many emerging and developed economies) while at the same time experiencing below average economic growth rates. Since independence Kerala has undergone extreme changes, not only increasing the literacy rate from 47% in 1951 to 94% in 2011 but also more than doubling population during the same period, and simultaneously experiencing a strong transition from a predominantly rural (85% rural population in 1951) to a highly urbanized state (48% urban population in 2011; Government of India 2011). Today Kerala's economy is dominated by the service sector, and its population density of 860 people per square kilometre is one of the highest in India (Government of Kerala 2013). The high human well-being paired with low economic development of Kerala has often been dubbed the 'Kerala model' and has typically been explained by progressive socialist politics, including far-reaching labour and land reforms (Franke & Chasin 1994; Heller 1999).

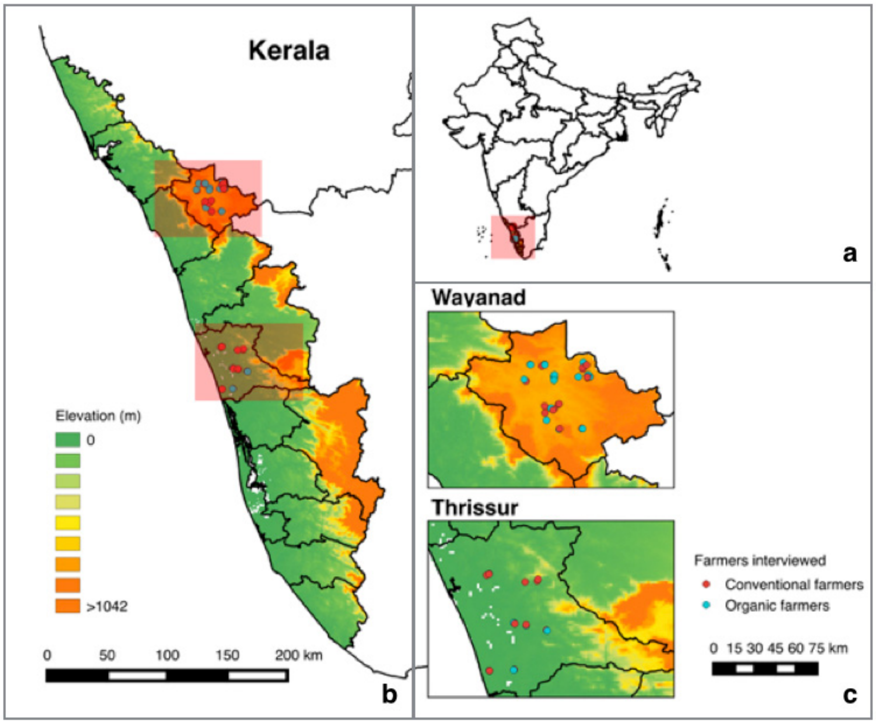

Figure 4.2. Map of study region, showing India (a), Kerala (b) and the two study districts with locations of interviewed farming households (c).

In addition to being a state dominated by strong left-wing politics, Kerala has also always been a stronghold for environmental movements (e.g., the 'Save Silent Valley' movement of the 1970s and 1980s (Karan 1994), or the more recent public debate on the preservation of the Western Ghats (Padma 2013)). Kerala has also been at the forefront of the development of organic agriculture in India. The Kerala Organic Farmer Association (KOFAI, or Jaiva Karshaka Samithy in Malayalam) emerged in 1998 to provide a platform for the local organic movement. Following the adoption of the national organic standard in the National Program for Organic Production (NPOP) in 2000, Kerala was the first state to have a national organic certification agency

(INDOCERT), and the first state to have an organic producer company (IOFPCL, Indian Organic Farmers' Producer Company) focused on direct involvement of organic farmers in marketing of their produce (Vakkayil 2010; Thottathil 2012; Venkattakumar & Sontakki 2012). In 2010 the state government further declared that Kerala would transform all its agriculture to organic management within the next ten years, again the first in the nation. The draft organic farming policy aims to gradually convert 20% of cultivable land to organic management every year (Government of Kerala 2010). The policy especially aims to increase the scope of domestic organic production as a means of addressing soil fertility and health issues, as well as to increase food security and food sovereignty (Government of Kerala 2010; Thottathil 2012). In addition to this government-led organic movement, numerous non-governmental organizations (NGOs) have also started promoting certified organic export agriculture in the agricultural districts of Wayanad, Idukki, and Kannur as a means of addressing farmer distress and economic hardship, and in response to strong price drops in prices of important cash crops in the conventional market in the early 2000s (Thottathil 2012).

In 2012-2013 the area under certified organic agriculture was estimated by the Kerala State Planning Board to be 10,169 ha, representing ca. 0.5% of Kerala's total cropland area in the same year (Government of Kerala 2013). This estimated share of area under certified organic production is not any higher than the national average of 0.6% in 2011 and 0.28% in 2012 and 2013 (FAO 2015). These numbers, however, only comprise *certified* organic agriculture, while area under uncertified organic management is unknown.

Considering that organic agriculture in developing countries is mostly an export-oriented activity, Kerala is of particular interest, and is particularly well suited for organic agriculture, as it already has a strong export-oriented agricultural sector focused on cash and plantation crops like rubber, coffee, pepper and tea (Nair & Menon 2004). Food crops like rice paddy fields, tubers, and vegetables only make up 10% of Kerala's cropped area (Government of Kerala 2013). In summary, Kerala is an appropriate place to examine the farmer motivations and livelihood outcomes related to organic farming.

We focused our study on two districts within Kerala – the highly urbanized and densely populated district of Thrissur as well the poorer and more agriculture-based district of Wayanad (see Fig. 4.2). Wayanad is located in the Western Ghats mountains and has only recently been more densely settled by immigrants from other parts of Kerala. Before independence in 1947 it was mostly populated by Adivasi[20] groups who practiced swidden agriculture in the forests (Muenster 2012). Thrissur, instead, is a highly urbanized lowland district with below average agriculture (Table 4.2).

Table 4.2. Characteristics of the two study districts Thrissur and Wayanad compared to state-averages. Data is for the year 2011 (where not otherwise specified). Data source: Government of Kerala (2013)

	Kerala		**Thrissur**		**Wayanad**	
	Rural	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**
Population	34,933,832,000		3,244,000		896,000	
(%)	52%	48%	33%	67%	96%	4%
Population density (people per km^2)	860		1031		384	
Pop decadal growth rate	-26%	+93%	-52%	+149%	+5%	+7%
GSDP per cap (in Rs)[1]	99,977 (14th/32)		103,501 (6th/15)		77,243 (14th/15)	
Literacy rate	94%		95%		89%	
Av. farm size (acre per holding)	0.59		0.44		1.43	
GSDP from agriculture[1]	12%		6%		24%	
Forest cover	44.52%		30.71%		83.29%	

[1] GSDP represents gross state domestic product for Kerala and district domestic product (DDP) for Thrissur and Wayanad for the years 2012-13.

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[20] *Adivasis* are Scheduled Tribes, i.e. a term used to describe a diverse set of aboriginal groups of India. 17.43% of Wayanad's population is Adivasi (much higher than the state average of 0.1%).

4.3.3 MIXED METHODS CASE STUDY

Organic agriculture in the context of this study is defined as agriculture that follows the rules of organic management practices as laid out in organic regulations and standards. Organic agriculture is thus a management system that is adopted by farmers and its food purchased by consumers as a conscious choice among several other alternatives. To be characterized as organic in this study, farmers did not necessarily have to be *certified* organic but they did need to (1) follow organic rules, (2) identify themselves as organic farmers and (3) purposefully manage their fields using organic practices. Farmers who practice 'organic-by-default', i.e. who do not apply chemical inputs as they have no need for them or cannot afford them, are not considered organic farmers in the context of this study.

Conventional agriculture, in this study, is defined as agriculture as dominantly practiced today. This can include both low-input and high-input farming systems. Low-input farming systems that do not use chemical inputs as a default rather than as a conscious choice are considered to be conventional agriculture.

We carried out fieldwork during the months of October through December 2013 in Kerala, India. We conducted a descriptive case study (Flyvbjerg 2006) using a mixed-methods approach, collecting quantitative data to describe the household, farm and management characteristics of the study population, and complementing this with qualitative data (from semi-structured interviews and focus group discussion) to provide a more in-depth assessment of the pathways that lead to organic adoption, personal experiences with organic management, opinions on problems and benefits of organic agriculture, as well as more nuanced assessment of household assets and livelihood experiences. The quantitative and qualitative parts of the field work were complimentary, providing information on different aspects of the research question, as well as corroborative, as they validated insights gained from the other method (e.g. statements on yields, assessment of social capital) (Greene *et al.* 1989). Overall, we interviewed 32 conventional and 36 organic farmers, as well as 22 key informants. We also conducted three focus groups with organic and conventional farmers. We created a multidimensional wealth indicator, a social capital indicator, as well as a commitment indicator (capturing commitment of organic farmers to organic agriculture). Value presented in this paper are always median ± median absolute deviation (MAD). Interviews and focus group discussions were transcribed and their content coded into themes. See Supplementary Material 4.1 for more details on the methods used.

4.4 THE EXPERIENCE OF ORGANIC FARMERS IN KERALA

The average farm size of our study population (3.05 ± 2.89 acres per holding) is considerably larger than average size of land holdings in the state (see Table 4.2). This is probably because we focused our study mostly on farmers who engage in farming as their main activity, while the state average includes the numerous households that have some land in 'homegardens' surrounding their houses, but derive most of their income from non-farming related activities. Almost every farmer interviewed had children, and in most households some children were still living at home. The farmers interviewed were well educated (on average they had 11 years of schooling, which corresponds to higher secondary level), and organic farmers were slightly more educated (12 ± 5.93) than conventional farmers (10 ± 2.97). Adult children of farmers were typically better educated than their parents. Nearly all households interviewed were managing agroforestry plots, and they were all cultivating food crops for own consumption, as well as cash crops. Typical crops grown included coconut, banana, nutmeg, arecanut, coffee, pepper, vegetables, tubers, and paddy (Fig. 4.3). Only few of the farmers interviewed - four organic farmers and five conventional farmers - said they were receiving remittances. The amount of remittances received varied from negligible amounts (relative to total household income) received only when needed (e.g. to pay for medicines) from family members living abroad, to 30 to 50% of total household income.

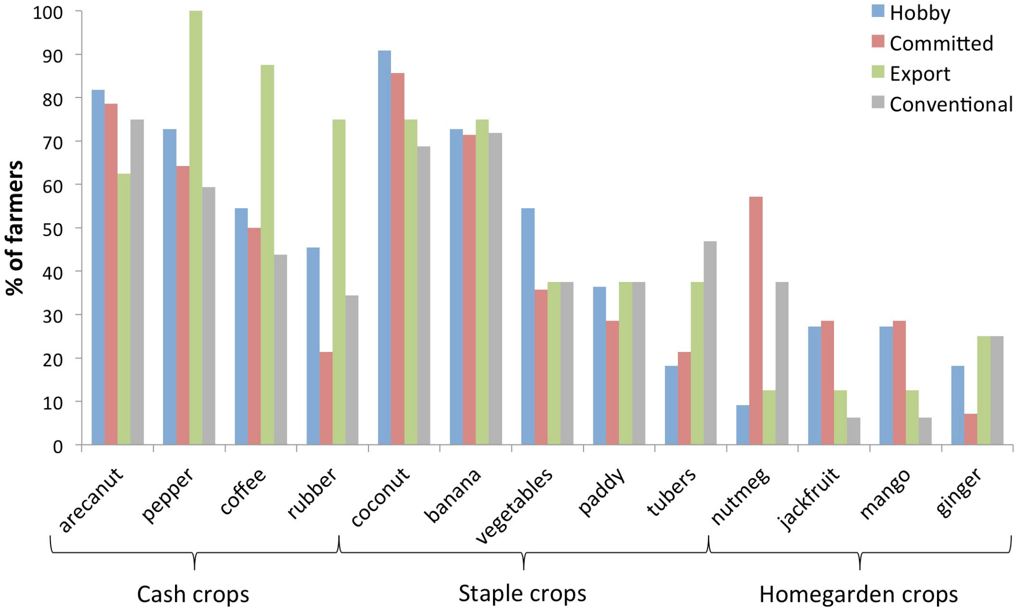

Figure 4.3. Crops grown by the three different organic farmer groups, as well as conventional farmers. We categorized crops as *cash crops* if they are grown primarily for commercial purposes, typically at a larger scale and typically for export markets; as *staple crops* if they are grown primarily for own consumption, or at smaller scale and for domestic markets and if they are a central part of people's diet; and as *homegarden crops* if they are grown either for own consumption or for commercial purposes but they are not a central part of the diet and are typically grown at a smaller scale.

Organic farmers are not a homogeneous group and we therefore categorized them into three distinct farmer types: **Hobby organic farmers** (n=12) are those who practice agriculture as a side-activity and derive the majority (>50%) of their income from non-agricultural sources. **Export organic farmers** (n=8) are those who are certified organic and produce certified organic spices and coffee for the export market. **Committed organic farmers** (n=15) are non-certified and derive the majority of their income from agriculture. We label this last group *committed* as they entered organic agriculture out of their own initiative (rather than through the influence of an export NGO), and not for economic reasons, and moreover farming was their major livelihood (unlike hobby farmers). This does not, however, preclude hobby or export farmers from also showing commitment to organic agriculture. Only one farmer could not be easily classified (as he derived only 50% of his income from farming, but did not carry out farming as a 'hobby' but out of necessity), so we excluded this farmer from this grouped analysis.

In the following we will, in turn, discuss the (1) livelihood characteristics, (2) livelihood outcomes, and (3) motivations of each of these three organic farmer types. Livelihood characteristics comprise assets of farmers at a single point in time, while livelihood outcomes represent changes in these assets over time through the adoption of organic agriculture.

4.4.1 HOBBY FARMERS

"I am basically a couch-man who is interested in growing my own food without any pesticides." (OF02)

Livelihood characteristics

Hobby farmers are those for whom agriculture is not the main source of income; their main income source is typically banking, teaching, pension, or business. Hobby farmers are highly educated (equivalent of more than a bachelor's degree, Table 4.3), and typically own large land areas (Table 4.3). They are generally financially well off – they have the highest wealth score of all farmers (14/20, Table 4.3), they live in large urban houses and own many consumer goods (Fig. 4.4). They live in slightly smaller households than other farmer types, but have 2 children on average like others. Their children are as well educated as they are (Table 4.3). Some hobby farmers do not sell their produce at all but only produce food for own consumption (e.g. vegetables, see Fig. 4.3). But typically hobby farmers sell their produce in the conventional market without any premium prices (Table 4.4, Fig. 4.5).

Table 4.3. Household and farm characteristics of the three different organic farmer groups, as well as conventional farmers. Characteristics used to define farmer groups are shown in italic.

	Hobby	Committed	Export	Conv
n	**12**	**15**	**8**	**32**
Household characteristics				
%income from agriculture	*19 ± 22*	*98 ± 4*	*100 ± 0*	*90 ± 15*
%farmers certified	*36*	*7*	*100*	*/*
%farmers in Wayanad	58	40	100	56
Farm size (acres per holding)	3.7 ± 2.0	2.3 ± 1.5	5.6 ± 2.5	3.02 ± 2.9
Age of interviewed farmer	60 ± 5	63 ± 18	51 ± 5	54 ± 15
Household size (number of people)[1]	3.5 ± 2.2	4.0 ± 1.5	4.5 ± 2.2	4.0 ± 1.5
Total number of children	2 ± 0.74	2 ± 1.48	2.5 ± 0.74	2 ± 0
Education farmers (years of schooling)	16 ± 1.5	10 ± 3.0	12 ± 1.5	10 ± 3.0
Education adult children (years of schooling)	17 ± 1.5	13 ± 1.0	16 ± 0.7	14 ± 1.7
Duration farming (years)	30 ± 23	41 ± 13	33 ± 10	33 ± 18
Wealth score (out of 20)	14 ± 0.0	10 ± 1.5	12 ± 0.7	11 ± 4.5
Farm characteristics				
Tree density (trees per acre)	220 ± 106	284 ± 198	396 ± 105	267 ± 127
Livestock (LSU)[2]	0.04 ± 0.06	2.08 ± 1.61	1.80 ± 1.63	0.61 ± 0.91
LSU change compared to 10 years ago	-4.11	-1.43	-2.08	-2.62
Part-time labour employed (number of labour-days)	50 ± 74	30 ± 44	251 ± 335	50 ± 74
Full time labour employed (% of farmers)	42	25	13	28
Use agricultural machinery (% of farmers)	67	73	75	84
Biomass production diversity (SHDI per acre)[3]	1.39 ± 0.08	1.09 ± 0.49	1.20 ± 0.22	0.92 ± 0.36
Caloric production diversity (SHDI per acre)[3]	1.09 ± 0.15	0.86 ± 0.43	1.01 ± 0.28	0.82 ± 0.39
Monetary production diversity (SHDI per acre)[3]	1.37 ± 0.23	1.50 ± 0.21	1.07 ± 0.52	1.24 ± 0.31

[1] Family members are considered household members if they are currently living in the household or absent for less than 1 month.

[2] LSU = livestock units (i.e. different livestock types aggregated using coefficients from (Eurostat 2015); reference unit (=1 LSU) is the grazing equivalent of one adult dairy cow)

[3] SHDI = Shannon Diversity Index

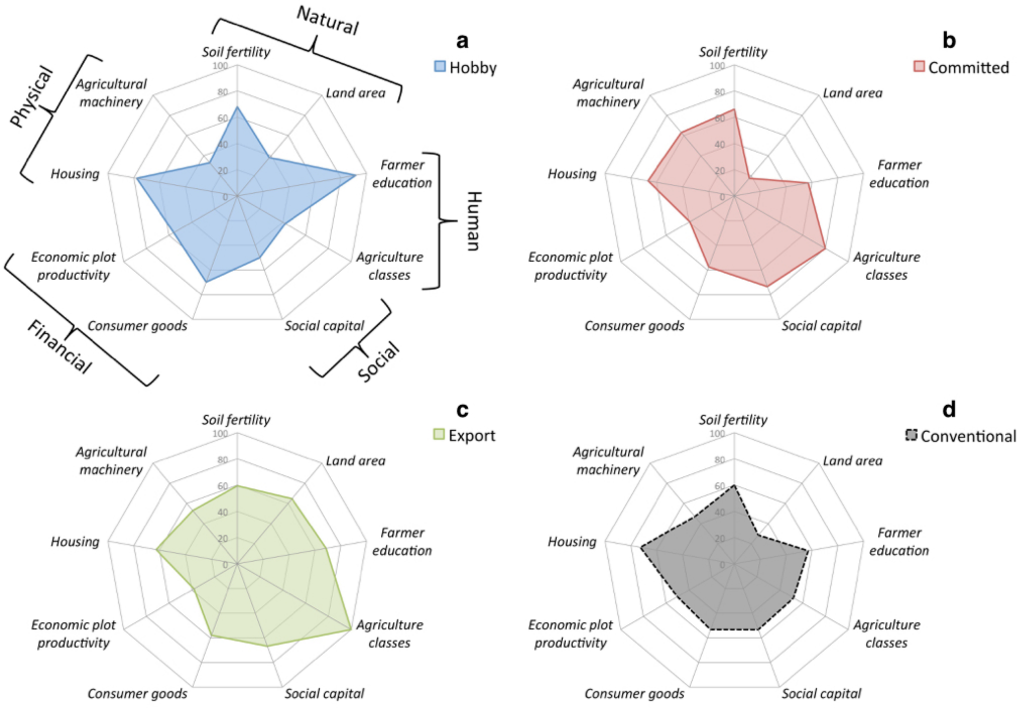

Figure 4.4. Sustainable livelihood characteristics of organic and conventional farmers, showing the five capitals (natural, physical, human, social and financial capital). Each capital is measured by different indicators. Spider diagrams are typically scaled by the maximum value of each indicator across farmer groups (except for farm size, farmer education, and economic plot productivity, where median + MAD (median absolute deviation) is used to scale due to existence of high outliers). Units are: farmer education (years of schooling), agriculture courses (% of farmers taken), social capital (aggregate indicator ranging from 0 to 20, see methods), consumer goods (number of consumer goods owned, out of 8 key consumer goods), economic plot productivity (Rs/acres, see methods), housing (house type on 4-point scale), agricultural machinery (% of farmers owning), soil fertility (average soil fertility of plots according to farmers own assessment, based on 3-point scale), land area (acres).

Hobby farmers typically employ some fulltime labour on their farms (Table 4.3). They use and own less agricultural machinery than other farmers (Table 4.3, Fig. 4.4). They do not own any livestock anymore, having reduced their stocks considerably compared to 10 years ago (Table 4.3). The typical reason given for this marked reduction in livestock is the lack of care-takers, as labour for the upkeep of livestock is expensive, and the farmers themselves are getting older and facing deteriorating health. Hobby farmers tend to use management practices requiring minimal labour input (Table 4.5; e.g., do not make compost or control pests and weeds), as they employ few part-time workers[21] and are also often unable to work on their farm themselves due to other employment or old age. They use animal manure as fertilizer but the majority of this is purchased (Table 4.5) as they have little livestock of their own.

Table 4.4. Organic management and marketing characteristics of organic farmer groups.

	Hobby	**Committed**	**Export**
% of farm area organic	100 ± 0	100 ± 0	88 ± 18
Duration farming organic (years)	12.0 ± 11.1	7.5 ± 5.2	6.5 ± 3.0
Previously farmed conventionally (%)	73	69	100
Receiving premium price (%)	22	73	100
Receiving premium on all produce (%)	0	33	13
Knows of organic farm subsidies (%)	60	17	57
Receives organic farm subsidies (%)	30	8	43
Taken agricultural courses (%)	42	80	100
from NGO (%)	80	33	100
from university/government (%)	20	25	25
from organic movement[1] (%)	0	42	0
Learned organic management			
from NGO (%)	29	23	88
from university/government (%)	0	23	13
from organic movement[1] (%)	0	38	0
from childhood (%)	29	8	13
from media (%)	29	15	0
from friends or family (%)	0	23	13
Member of NGO (%)	25	7	100
Member of organic movement[1] (%)	25	20	0
Commitment indicator (out of 1)	0.75 ± 0.37	0.67 ± 0.25	0.12 ± 0.19

[1] Organic movement here denotes talks, workshops organized by, or membership in the Kerala Organic Farming Association (KOFAI), or lectures or talks by key figures of the organic movement.

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[21] While hobby farmers do more often employ full-time workers than other farmer groups, this usually represents only a singe labourer who often also helps with household duties. But this one person cannot do as much work as dozens of temporary labourers employed throughout the season (as other farmers, especially the export farmers do).

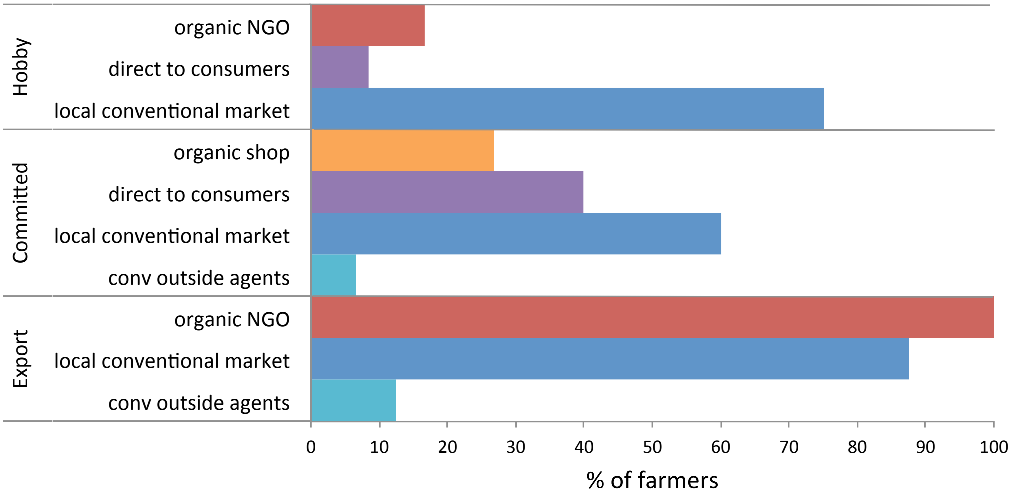

Figure 4.5. Marketing channels of organic farmer groups.

The yields (and economic productivity of plots) of hobby farmers are often higher (Fig. 4.4; especially in paddy and arecanut, data not shown), despite the apparent lack of high labour input, generally low tree density (Table 4.3), non-reliance on farming for livelihoods, and selling none or very little of their produce. This high productivity could be due to the high financial capital and education of hobby farmers. Paddy productivity in Kerala has, for example, been shown to often be limited by lack of knowledge and financial capital (Reddy *et al.* 2001).

Hobby farmers are typically not well integrated into their local communities and thus have a low social capital indicator (Fig. 4.4). They often have jobs outside the village, and sometimes even a second house in the city. Hobby farmers often complain that solidarity amongst people has suffered compared to the past, and that the sense of the community is disappearing. Some hobby farmers also have very negative opinions about their fellow farmers:

> At least in Kerala, farming is a last resort of the intellectually destitute. I know I should not be using such strong words, but you know somebody is going to say this. […] The majority [of farmers] are no good for this (OF02).

Instead, hobby farmers are typically well connected within the organic movement and have relationships with fellow organic farmers and key figures of the organic movement across different districts. When asked about other organic farmers they typically recommended people in other districts rather than in their own or neighbouring villages. For the wealthy and educated hobby farmers horizontal networks within communities appear to have been replaced by vertical networks to distant organisations and people.

Overall, hobby farmers have high financial, physical and human capital, low social capital, and intermediate natural capital (Fig. 4.4). While their general physical (housing) and human (education) capital is high, their agricultural physical (agricultural machinery) and human (agricultural course) capital is comparatively low, as livelihoods of hobby farmers are not centred around agriculture.

Table 4.5. Management practices of different organic farmer groups.

		Hobby	Committed	Export
Fertilizer	Chemical fertilizer (% of all farmers)	0	0	50
	Animal manure (% of all farmers)	100	73	75
	Compost (% of all farmers)	42	60	50
	Jeevamrutha (% of all farmers)	25	47	38
	Oilcakes (% of all farmers)	25	27	63
	Bacterial inoculants (% of all farmers)	8	7	25
	% of all fertilizer purchased	50 ± 8	20 ±30	47 ±31
	% farmers purchasing animal manure	67	27	38
Pest control	Chemical pesticides (% of all farmers)	8	7	13
	Organic pesticides (% of all farmers)	58	80	75
	Biological pesticides (% of all farmers)	17	0	50
	No pesticides (% of all farmers)	33	13	13
Weed control	Herbicides (% of all farmers)	0	0	0
	Manual weeding (% of all farmers)	75	93	100
	Mechanical weeding (% of all farmers)	42	20	38

Livelihood outcomes

Hobby farmers often increased their income in the last ten years, did not have to take a loan, and even sometimes increased their farm size (Fig. 4.6). The soil fertility of their land also generally improved during the last ten years due to organic management (Fig. 4.6b).

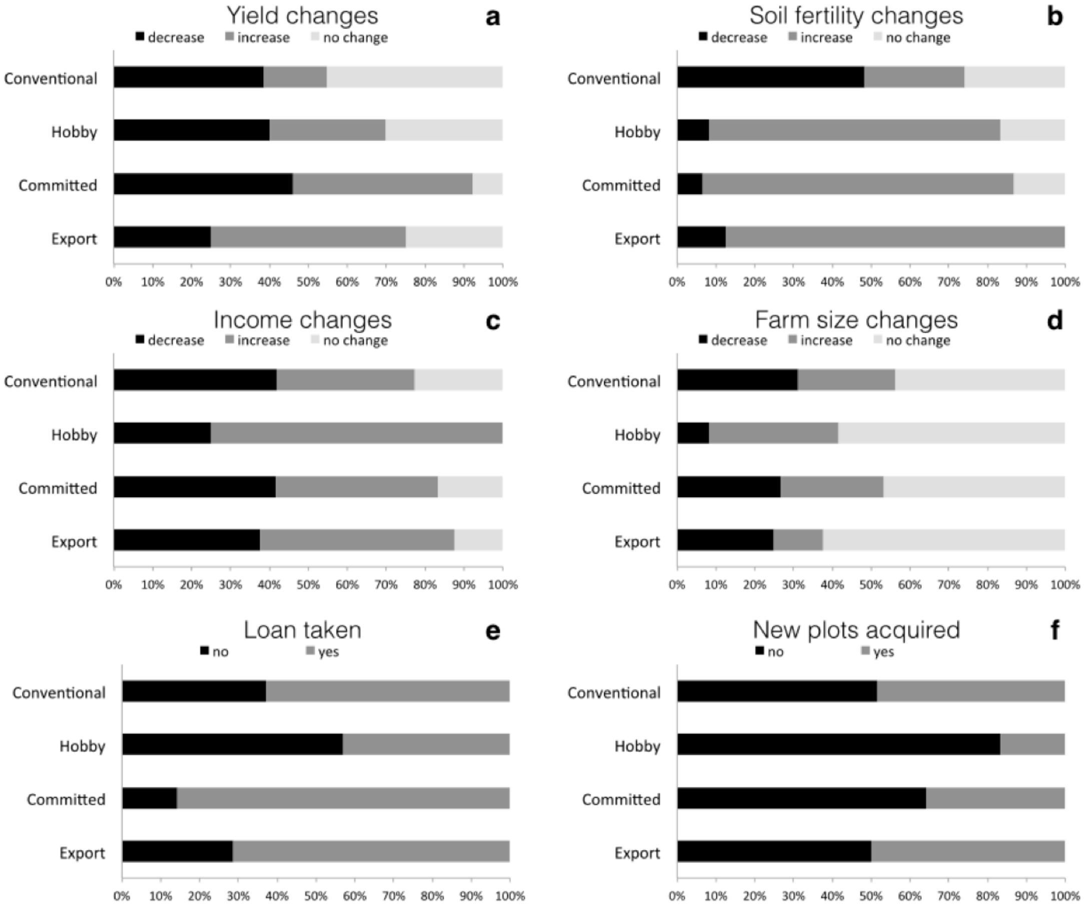

Figure 4.6. Livelihood changes experienced by the three organic farmer groups, as well as conventional farmers in the last ten years.

While the overall income of hobby farmers typically increased over the last ten years, their income from agriculture typically decreased after adoption of organic farming, often caused by reductions in yields (Fig. 4.7). Hobby farmers show an intermediate level of resilience - on the one hand they have low labour dependency, and high diversity in the economic value of their crops, but on the other hand they have low caloric plot productivity and are dependent on external nutrient sources (Fig. 4.8).

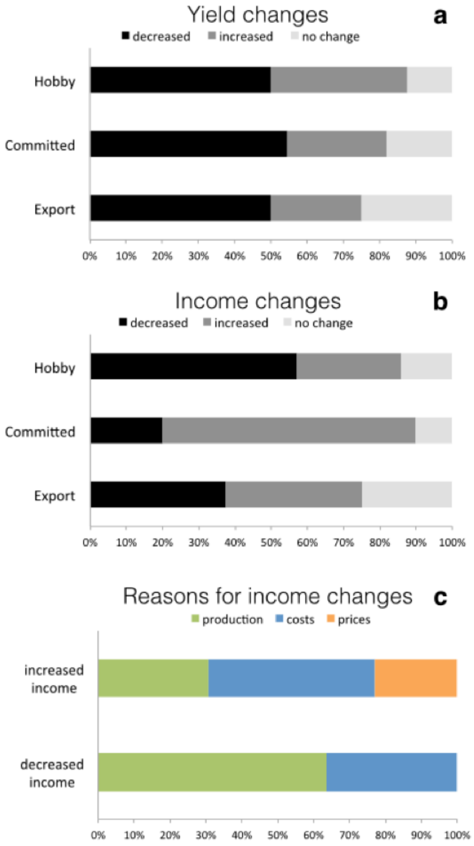

Figure 4.7. Livelihood changes experienced by the three organic farmer groups after adoption of organic agriculture.

Farmer motivation

Hobby farmers did not enter organic farming for economic reasons, but purely out of interest in farming, out of a wish for tasty, safe and healthy food: "I get a satisfaction from farming. I am working here and most of the time I am not satisfied in this work. This is an official procedure and full of laws. But in my farming I get much and much satisfaction" (OF13). Because farming is typically practiced out of personal interest and not with an economic goal, there is no need for organic farming to be financially viable.

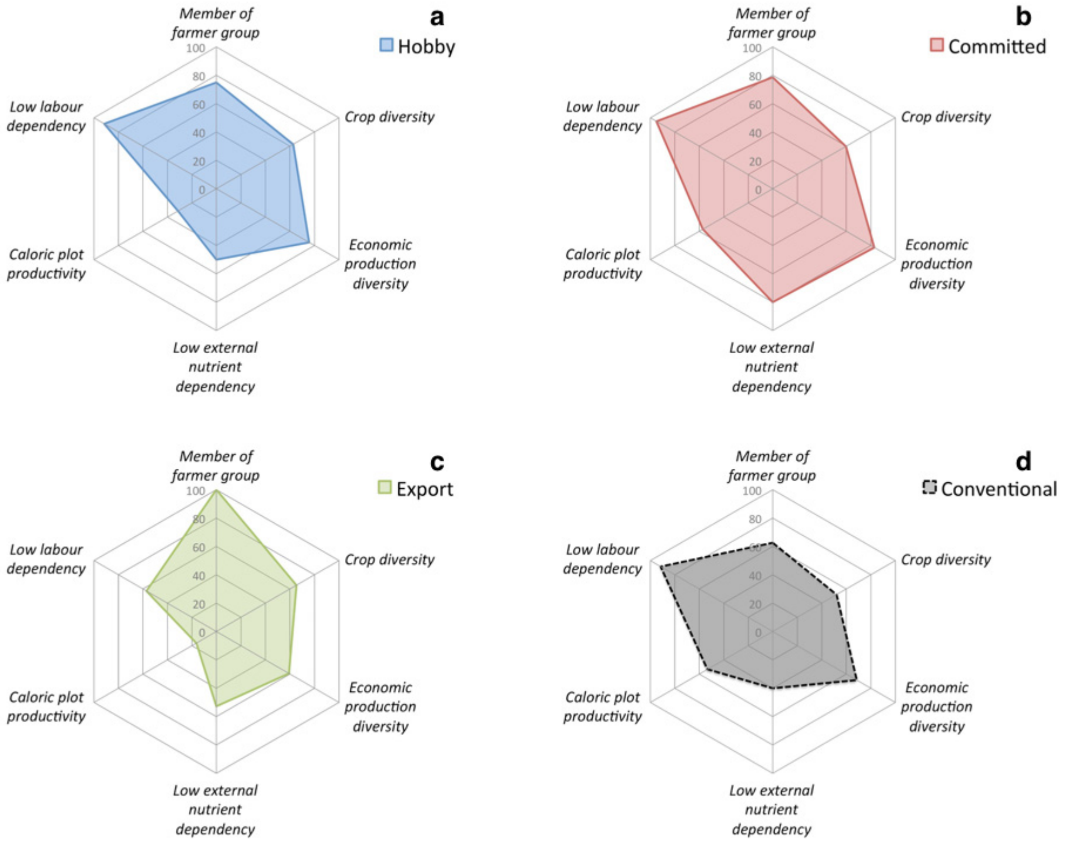

Figure 4.8. Livelihood outcomes in terms of resilience. Resilience indicators were chosen to represent several aspects of resilience, including social self-organization (member of farmer group), diversity and redundancy (crop diversity and economic production diversity), coupling with local natural resources (low external nutrient dependency), and global autonomy (low labour dependency), which have been identified as key indicators for agroecosystem resilience (Darnhofer *et al.* 2010a; Cabell & Oelofse 2012). Spider diagrams are scaled by the maximum value of each indicator across farmer groups (except for labour dependency and caloric plot productivity, where median + MAD (median absolute deviation) is used to scale due to existence of high outliers). Units are: member of farmer group (% of farmers); crop diversity (average number of crop species grown per plot); economic production diversity (Shannon diversity index of economic production in Rs/acre, see methods); low external nutrient dependency (proportion of nutrient inputs purchased); caloric plot productivity (cal/acre, see methods); low labour dependency (part-time labour employed, in labour-days).

Hobby farmers practice organic as they do not want chemical inputs on their land or on their food, believing that food grown with chemical inputs is poisonous and leads to serious health issues like cancer and deformities in children. But often there is more to the decision to go organic than just healthy food. Hobby farmers are often well versed in organic ideas, have read organic literature and personally met prominent figures from the organic movement. They are often involved in the organic farming movement (see Table 4.4), editing journals, organizing meetings, writing books, or teaching courses about organic farming. Hobby farmers have developed strong beliefs about organic farming, and their organic practices are founded on informed political opinions. Hobby farmers have holistic views on human and ecosystem health, and for example, believe that pest problems in plants are best addressed by proper soil management. Hobby farmers see themselves as stewards of the land and believe that farming has an important role in society.

Because of these strong beliefs hobby farmers are typically highly committed organic farmers who have been farming organically for longer than others, who are happy about organic agriculture, farm their entire property organically (Table 4.4), and would never consider going back to conventional farming. About one third of hobby farmers had actually never farmed conventionally before, but came into farming only through organic agriculture (Table 4.4).

4.4.2 COMMITTED FARMERS

"Never. I will never go back to the chemical one." (OF16)

Livelihood characteristics

Committed farmers are those who are not certified but entered organic agriculture out of their own initiative, and who are deriving the majority of their income from agriculture. This group of farmers is the most diverse as it basically represents the 'other farmers' category (i.e., they are not certified unlike export farmers and agriculture is their main livelihood unlike hobby farmers). However, despite being, by definition, a diverse group, we still find substantial commonalities between these farmers.

Committed farmers are typically less wealthy, farm a smaller plot of land and are less educated than other farmers (Table 4.3). They own more livestock and use the animal manure to prepare complex organic composts and pesticide solutions – often based on concepts developed in Zero Budget Spiritual Farming[22]. Despite using labour-intensive management practices, committed farmers do not employ much labour (Table 4.3). Although committed farmers are not certified, they often receive premium prices on some (40% of committed farmers) or all (33%) of their produce, especially for paddy and vegetables. This non-certified organic produce is sold in organic stores in nearby towns or directly to organic consumers (Fig. 4.5).

As committed farmers are not certified organic, their access to organic markets depends on social networks and trust. Committed farmers are typically not associated with an organic NGO, and they do not typically know of or receive any organic subsidies (Table 4.4). Committed farmers have, however, high social capital (Fig. 4.4) and are often part of the organic farming movement and members of KOFAI (see Table 4.4). They rely on the network provided by KOFAI to exchange knowledge, contribute to the promotion of organic farming, as well as for accessing organic markets and urban middle class consumers interested in organic food. Committed farmers typically have received training in organic agriculture from KOFAI, an organic NGO, or an agricultural university or agricultural extension office (Table 4.4).

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[22] The Indian agriculturalist Subhash Palekar developed the concept of Zero Budget Spiritual Farming, influenced by Marxist ideas, Hindu spiritualism, and principles of organic farming. Zero Budget Spiritual Farming is composed both of a concrete set of suggested management practices (including composting techniques to prepare Jeevamrutha), as well as an elaborate philosophy about humans and nature.

Committed farmers are, however, also the group amongst whom social capital varies the most. Some committed farmers are not well integrated into their communities and complain about isolation and animosities with neighbours due to their organic practices:

> Nobody is ready to accept me as I am doing this. And this is a big problem for me because I would like to get the support from the people (OF09).
>
> There was a lot of animosity [from neighbours] because my products are getting more profit, and getting more demand. […] And many people became enemies (OF06).

Other committed farmers are, instead, highly integrated in their communities. One organic farmer told us how in each season he organized a big harvest festival, inviting neighbours, friends and family to help him harvest the paddy in return for some of the produce.

Livelihood outcomes

Overall, committed farmers are often struggling to make a living. More than 40% of committed farmers say that their income, as well as the yields of their land, have declined in the last 10 years (Fig. 4.6). Several committed farmers have had to sell some of their land for their daughter's marriage, and are now struggling to make a living out of the remaining land. The majority of committed farmers have taken a loan in the last 10 years (Fig. 4.6).

Within this rather challenging setting, organic agriculture is often a means of improved income for committed farmers (Fig. 4.7):

> There is no question about that - organic is more profitable. If we compare one acre land of organic farming to one acre of land with conventional farming, it's without any doubt that the organic farming is much, much, much [more] profitable than conventional farming (OF09).

Because committed farmers are typically rather poor, organic management presents a way of minimizing input costs, and sometimes also labour costs:

> We don't have to employ many labourers here because we don't do weed control or something like that. And the fertilisers and all can be prepared by ourselves. More emphasis is given on the soil. If the health of the soil is good, automatically the crop will be healthy, no pest attack (OF09).

The large majority of committed farmers (86%) say that they do not encounter any problems selling their produce, that there is a high demand for their organic produce in the market, and more than one third of committed farmers even say they are receiving premium prices on all of their produce. Those farmers who do encounter marketing problems typically complain about low prices, and that they have to sell their organic produce in the conventional market.

While committed farmers are often struggling, less wealthy and have fewer assets than other farmers (Fig. 4.4), they show the highest resilience indicators (Fig. 4.8). Committed farmers are 'globally autonomous and locally interdependent' (Cabell & Oelofse 2012) by employing little external labour, applying few external inputs, producing a lot of food on their plots (Fig. 4.8), and by selling in local rather than global markets (Fig. 4.5). Committed farmers produce few crops and these are of high caloric value (lowest caloric production diversity, Table 4.3, combined with highest total caloric production, Fig. 4.8) in combination with a wide array of different crops of different monetary values (highest monetary production diversity; Table 4.3), thus spreading economic risk more widely:

> Usually I do mixed cropping. It's done in such a way that even if some crop fails, another one can give some yield (OF22).

For committed farmers organic agriculture appears to be a means of reducing risks by providing more pest-resistant crops, improved soil fertility, reducing input costs, providing higher self-reliance in marketing, and the potential of accessing premium markets through social networks.

Farmer motivation

Committed farmers started organic management of their own initiative. They are typically not associated with an NGO promoting organic agriculture, but often say they first learned about organic agriculture and decided to adopt organic farming inspired by talks, media, friends, neighbours or other members of the organic farming movement (Table 4.4). Like hobby farmers, they are often influenced by ideas of Subhash Palekar and Zero Budget Spiritual Farming (see footnote 22). They often read his books, attended his talks, use his composting techniques, and explain processes in their land based on his concepts.

Committed farmers are practicing organic agriculture mostly for ideological, not for economic reasons. They typically do not know about organic farming subsidies and do not receive any financial support for their farming (Table 4.4). They typically say they converted to organic farming because they experienced or heard about the negative effects of conventional farming (e.g. on health, soil fertility, quality of food). The most commonly stated reasons for going organic included – in this sequence - (1) better food quality, (2) better for one's health (both due to reduced exposure to chemicals, and due to chemical-free and more nutritious food), (3) better for soil fertility, (4) more resistant crops, (5) better long-term yields.

For some committed farmers organic management provided a type of lifeline in a life marked by financial and personal hardship. One farmer had, for example, lost his wife to cancer, and after this event decided to entirely change his lifestyle, adopting a vegetarian diet consisting mostly of fruits, as well as adopting organic agriculture. Another committed farmer had experienced financial troubles, having to give up first paddy and then banana cultivation and work in a bar for several years. At the same time he was afflicted by serious personal health issues. Natural medicine, introduced to him by a neighbour, proved the only method able to alleviate some of his suffering. His discovery of naturopathy then provided an entrance for him to organic farming. He read a book and then attended a talk by Subhash Palekar and decided to adopt organic practices on his own land as well as to manage the land of several absentee landlords with organic practices in return for part of the produce. For this farmer organic agriculture was part of a larger fundamental shift in his life in response to health as well as financial problems that included naturopathy, meditation, religious practices, and organic farming.

As committed farmers chose organic agriculture out of their own initiative, they firmly believe in the superiority of organic farming:

> Where the people are practicing organic agriculture, the agriculture production will be higher, and it will be a solution for the food security and the food scarcity we are now facing (OF10).

Committed farmers often have a wider political belief in organic farming as a way forward for society, and they perceive themselves as taking on an important role trying to change society through their farming:

> I am trying to create a model of this one here, so I can introduce more people to this world and to bring the people to the farming (OF16).

Committed farmers take up organic farming based on a long-term perspective:

> That is if you are using the chemicals at first, there will be more yield, but then it gradually decreases. But if you are using organic first it will be bit less, but gradually it will be increasing (OF14).

Many committed farmers believe that organic management will provide higher yields in the long-term, even though only very few have experienced such yield increases to date (Fig. 4.7a).

While committed farmers are experiencing some problems with organic agriculture (e.g. lower yields, having to sell some of their produce in the conventional market), these problems do not discourage them and induce them to revert to conventional methods.

> Researcher: And have you ever considered converting back to conventional farming?
>
> OF16: Never. I will never go back to the chemical one.

4.4.3 EXPORT FARMERS

"As an organic farmer I am saying that organic farming is not a sufficient way for farmers to maintain their family livelihood." (OF6, Focus Group 2)

Livelihoods characteristics

Export farmers are those who are associated with an NGO that specializes in selling certified organic coffee and spices in the export market (thus producing more coffee and pepper than other farmers, Fig. 4.3). These farmers are certified organic and are receiving a premium price on at least part of their organic produce (Table 4.4). In our study all export farmers were located in Wayanad (and none in Thrissur), as Wayanad is one of the districts that organic NGOs focused their work on (see section 2.1).

Export farmers are typically younger and have a larger household size than other farmers (Table 4.3). They are farming more land (which is at least partly a function of being situated in Wayanad, where farm sizes are generally larger, see Table 4.2), and are well-educated (having attended on average 12 years of schooling, i.e. finished higher secondary schooling). With a median wealth score of 12/20 export farmers could be considered middle class farmers, lying in between the richer hobby farmers and the poorer committed farmers (Table 4.3).

Export farmers are typically closely tied to an organic export NGO, receiving training on organic practices, being organized in farmer groups, attending meetings and receiving subsidies through the NGO (Table 4.4). They are typically highly integrated in their local communities, attend many farmer and village meetings, and have strong relationships with their neighbours, and overall high social capital (Fig. 4.4).

Export farmers purchase a large portion (median of 47%) of their nutrient inputs in the form of animal manure, oilcakes and bacterial inoculants (like Trichoderma or Pseudomonas). Some of these inputs (like oilcakes, Pseudomonas, or lime) are sold at a subsidised price by the organic NGO. Asked about the difference between traditional farming and organic farming, one export farmer said:

> In organic farming we are giving everything from the outside, that is even the organic manures and all things we are buying from outside and we are using. But in the traditional one everything is obtained from the field itself, that is the main difference (OF23).

Plots of export farmers have a very high tree density indicating intensive management of agroforestry plots, but their productivity is rather low (Fig. 4.4) – potentially due to their focus on high-value low-yielding cash crops like coffee, pepper, and nutmeg. Export farmers employ a very high number of temporary labour but not a lot of permanent labour (Table 4.3).

Export farmers are the only organic farmers who apply chemical fertilizers on some of their plots (Table 4.5). They have typically adopted organic farming more recently than other farmers but have always been farming conventionally before (Table 4.4).

Even though only 13% of export farmers have increased their farm size in the last ten years, 50% of export farmers have acquired new plots recently (Fig. 4.6). This suggests that export farmers are carrying out more land transactions, selling, and buying or renting new plots. Several export farmers also are currently, or have been farming land in the neighbouring state of Karnataka or Tamil Nadu (typically with ginger production). This land outside the province is used as an additional important income source, and managed with intensive conventional methods to maximize output and profit. Export farmers can thus be described more as entrepreneurial farmers who are trying out new things, do not necessarily shy away from risky ventures, and aim at profit maximization. This is also reflected in their more frequent cultivation of rubber compared to other farmer groups (Fig. 4.3).

Livelihood outcomes

Of the three major organic farmer groups, export farmers are typically the ones loudly voicing their discontent with organic agriculture. They complain that from an economic perspective organic farming is not very beneficial:

> I am saying that it [organic agriculture] is not successful because I am doing it for 4 years and I am finding that there is a reduction in the yield, especially in the coffee. […] It is also very difficult to maintain the agriculture, and also for the livelihood, if the yield is not produced (OF25).

There are several problems associated with organic agriculture for the export farmer, including (1) substantial yield losses, (2) higher labour demand of organic methods resulting in higher costs, (3) too low premium prices that do not make up for higher costs and reductions in yield, (4) other marketing problems regarding the quantities purchased by organic NGOs, as well as the timing of procurement.

The first problem mentioned by almost every export farmer is reduced crop yields under organic management. This is apparently more of a problem for certain crops. According to farmers, coffee yield, for example, is reduced substantially through organic practices (up to half of conventional yields), while pepper – which was strongly affected by a large outbreak of quickwilt in the early 2000s in Wayanad - performs as well (or better) with organic methods.

Export farmers more often complain about the high labour costs of organic farming, as they need to hire more labour to produce and apply organic fertilizers and pesticides. Agricultural labour is not only costly but also scarce in both Thrissur (due to the high development of the province) and Wayanad (partly due to the Rural Employment Guarantee Scheme[23] introduced by the Indian government in 2006).

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[23] In 2006 the national government introduced the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS), which guarantees public work for part of the year to eligible households. This scheme has been criticized for removing labour from the agricultural labour market. But MGNREGS can also, under some conditions, provide farmers with cheap labour under the scheme (Thadathil & Mohandas 2012).

Another common complaint amongst export farmers is that the organic premium is insufficient for making up for yield losses. Even the head of a large organic export NGO in Wayanad acknowledged this:

> Even though these two kinds of certificates are there [organic and fair trade] and they will get a premium price, famers are saying that is not much in their cost of production. Because yield is very less, and it is getting lower every year. […] It's not sufficient for them, to meet the needs and necessities (KI6).

Even though organic agriculture was introduced by NGOs as a measure to address the hardships caused by the dramatic price drops in key cash crops in the early 2000s, under current economic conditions organic agriculture does not appear to provide any financial benefit anymore. In the 2000s regular market prices were very low (as low as 60 Rs per kg for pepper in 2004 and 2005, and 28 Rs per kg for coffee in 2002; (Government of Kerala 2008), while organic farmers were able to get a premium of 50-100%. Now, as the prices in the conventional market have increased considerably (increasing by more than 200% for coffee, up to 66 Rs per kg, and by 580% for pepper, up to 347 Rs per kg in 2013; (Government of Kerala 2013)), the premium for organic coffee is typically only around 15-20% higher than conventional market prices. Export farmers thus often complain that they have to follow organic guidelines (which typically require more work), and pay extra collection charges, but without actually getting much financial benefit from organic management.

On the other hand, being associated with an organic NGO provides other benefits to export farmers. The NGO provides farmers with access to knowledge (all export farmers had taken agricultural courses provided by an NGO, and most had learned about organic management from NGOs, Table 4.4), as well as access to subsidies (export farmers had the highest rate of access to organic subsidies of all farmers, Table 4.4). In addition, the NGO often is an important part of social lives, providing farmers with a good social network and a sense of belonging, particularly in those villages that have been entirely converted to organic agriculture through the NGO (see discussion below).

Despite this strong social network, export farmers have low resilience (Fig. 4.8) due to their dependence on high labour inputs, high external nutrient inputs, their focus on the production of a few cash crops, and dependency on an external agency for marketing. Export farmers also often voice their concerns about the future of their livelihoods as farmers, which they feel is threatened by the economic and political context. This sense of being exposed to external (and detrimental) economic and ecological forces while being neglected by politics results in often strong negative opinions about the government. Export farmers say that the government's commitment to organic agriculture is only lip service, but that it does not actually provide useful support to organic farmers (for example providing poor quality organic inputs).

Farmer motivation

Export farmers recognize wider benefits of organic management (mostly related to healthier food and healthier agroecosystems) but their main reason to go organic is to access a premium market.

> In simple words - we decided to try organic expecting more price for the organic products and thus we can make more money. Only for that we adopted organic farming. Or else what is the advantage for us by cultivating coffee and pepper organically? Because we are not eating that (OF5, Focus Group 2).

Despite many export farmers being motivated by better prices, several also say they carry out organic management for non-economic reasons:

> First thing is that I can prepare my own food in my land, organic food and it will be good without any poisons, and no chemicals and all. The second one is to conserve and preserve the soil for the coming generations and there is not any other way of doing that (OF23).

But when export farmers talk about the health and soil benefits of organic farming, they often refer to information they learned in the agricultural courses taken, repeating what they were told by organic NGOs about the benefits of organic agriculture.

Export farmers entered organic agriculture as part of a larger group, and through the support of an organic NGO. Organizations like WSSS, Organic Wayanad or the Fair Trade Association Kerala (FTAK) promote the widespread adoption of organic agriculture by providing seminars and courses in target villages, teaching about methods and benefits of organic farming. These organizations often aim to create clusters of organic farmers, trying to convert entire villages to organic agriculture. Doing this, NGOs often rely on the model function of a smaller group of initial adopters. Export farmers joined organic farming thus first and foremost because of the support provided by the different NGOs: “We came to the organic farming because of WSSS” (OF29).

Export farmers often emphasize long-term family values, and the wish to provide their children with a decent standard of living and a good education:

> We told you already - we need money, we want to educate our children, we want to live prestigiously in the society. We don’t wish to live for long but would like to live prestigiously as long as we live. For that we need money. We are not thinking of adopting organic to improve our health. We don’t have time to think all about that. How can a person without money think in such a way? (OF5, Focus Group 2)

They also voice concerns about the future of their children in a difficult economic context. Export farmers are thus often willing to take risks in order to maximize their income (see earlier discussion) to provide financial security to their families.

If the problems experienced with organic agriculture continue, export farmers are often considering reverting to conventional methods:

> I won’t continue for a long period. If it is heavy loss then I will turn from that, for sure. If it is not profitable within 3 years, then almost all of the organic farmers will be turning back (OF6, Focus Group 2).

There are no official statistics about the dropout rates of organic farmers. However, several of the organic farmers themselves talked about high rates of drop-out. One farmer, for example, said that in his unit only 16 of the original 48 farmers who converted to organic farming with him four years ago were still managing their land organically today. While another export farmer said that of initial 98 farmers only 5 were still managing their land organically.

While some export farmers are seriously considering reverting back to conventional methods, others say they will stick to organic practices a little longer as they are hoping for an improvement of yields after the initial transition period, and believing that in the long-term organic practices will lead to more fertile land and healthier crops. Several export farmers are also putting hopes into the new processing plant being installed by WSSS[24]. They expect to be able to sell more of their produce at a premium once the processing plant starts operating.

A small fraction of export farmers are, however, committed to organic management. These farmers say they carry out organic management because they get satisfaction out of it and because they believe in organic principles. Several export farmers for example say that while organic farming is less profitable for them, it is still good in the end, as it will reduce the health costs by eliminating exposure to chemicals. These ‘committed export farmers’ (different from other export farmers) do not use any chemical fertilizers on their land:

> Other people use inorganic fertilisers also. But the organic fertiliser is what we should use. Only organic fertilisers and organic pesticides, so it is decently. Decent living and through that I am happy (OF34).

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[24] WSSS just inaugurated the new Biowin organic processing facility in Fall 2014, which will be processing pepper, coffee, and freeze-dried fruits and vegetables at large scales.

4.5 DISCUSSION

We have identified three types of organic farmers in the Thrissur and Wayanad districts of Kerala: hobby farmers, committed farmers and export farmers. Grouping farmers into these categories reveals not only clear differences in farmer characteristics but also differences in farmers' attitudes and livelihood outcomes. Wealthy hobby farmers carry out organic farming out of personal interest and to produce chemical-free food for their own consumption. They are satisfied with the outcomes of organic agriculture, even if organic management decreases the income they receive from farm activities, as their main income is from other sources. Poorer committed farmers adopt organic agriculture because they perceive it to be a superior farming system. Committed farmers often experience an increase in their income after adoption of organic management due to lower labour and input costs, as well as by being able to access domestic organic premium markets. Middle class export farmers, instead, are members of an organic export organization and adopted organic management to access premium prices for certified organic coffee and spices for export markets. Due to reduced yields, high expenses for labour and external inputs, as well as low premium prices, organic agriculture does not provide an economic benefit for export farmers, and many export farmers are considering going back to conventional management.

Several studies of organic farmers in developed countries have developed a classification of organic farmers according to their motivations into 'pragmatic' and 'committed' organic farmers (Fairweather 1999; Darnhofer *et al.* 2005). Similar farmer typologies have also been identified for the adoption of other agro-environmental management decisions (Fish *et al.* 2003). Our study is the first, to our knowledge, to identify such a typology for organic farmers in a developing country.

4.5.1 LIVELIHOOD OUTCOMES OF ORGANIC FARMERS

Our typology of organic farmers was also useful in explaining the success of organic agriculture as a livelihood strategy for farmers, and how satisfied farmers were with organic agriculture. Committed farmers did not experience as much of an economic loss compared to export farmers, as they were generally poorer and farming less land and thus relying mostly on their own labour and local inputs. While organic agriculture led to yield reductions for most farmers, the impact on costs and income varied between farmers and often between farmer groups. Across all farmers, organic agriculture does, however, appear to be able to address biophysical problems, as it restores soil fertility, might provide increased pest resistance, and – as many farmers believe – can potentially improve yields in the long-term.

Table 4.6 summarizes the impact of organic farming on different livelihood aspects for the three farmer groups, based upon the problems and benefits of organic agriculture as identified earlier through a literature review (see Table 4.1). This table summarizes the most common tendencies for each group identified in our study. But as our results show (see section 4.4), there were important nuances within each group, and not all farmers in each group had the same experiences.

Table 4.6. Impact of organic agriculture on livelihood aspects of different organic farmer groups. Positive impacts are shaded in green, negative impacts in red, and neutral impacts in blue.

	Hobby	Committed	Export
Yields	decreased	decreased	decreased
Costs	increased	decreased	increased
Prices	no change	increased	increased
Resilience	no change	increased	decreased
Dependence[1]	no change	no change	increased
Other benefits[2]	no change	no change	increased

[1] dependence on single certifying & exporting company with limited purchasing capacity and non-negotiatable prices

[2] organization in farmer groups, access to subsidies & knowledge

Overall, hobby farmers had the most negative livelihood outcomes. But because hobby farmers relied on income from non-agricultural sources and are generally financially well off, this does not affect them much. Committed farmers generally had positive livelihood outcomes from organic agriculture due to reduced costs, increased prices and increased resilience. Export farmers had negative livelihood outcomes due to higher costs, lower yields, lower resilience, and increased dependence, despite receiving higher prices, and other benefits from being associated with an organic farmer association.

The form of organic agriculture practiced by committed farmers shows more characteristics of traditional farming systems, where stability and a safety net are given priority over maximization of production and maximization of income, and where farmers are dependent on social capital for marketing. While the type of organic agriculture practiced by export farmers resembles a modern farming system connected to fluctuating and distant markets, and aimed at profit maximization (Scott 1977).

4.5.2 MOTIVATIONS OF ORGANIC FARMERS

Even though economic factors are often emphasized in farmer-decision making, several studies have also shown that farmer behaviour is strongly influenced by personality traits that result in different attitudes and objectives (Austin *et al.* 2001). The importance of non-economic, and particularly ecological factors appears to be especially important amongst organic farmers (Duram 2000). In our study the decision of organic farmers to adopt organic management was influenced both by external structural factors (e.g. support by organic export NGO, contact with the organic farming movement), internal structural factors (e.g. soil fertility and pest problems farmers wanted to address with organic management), as well as personal factors ranging from knowledge, and ability to carry out organic management to personal objectives and attitudes (e.g. wish for chemical-free food for own personal health and/or for societal health, responsibility towards the next generation, long-term sustainability, harmony with nature).

Duram (1997) observed that organic farmers often were more proactive than conventional farmers about things they perceived as wrong in the current agricultural systems, and that they had a stronger sense of being able to control their lives and their management decisions. Reactive farmers, instead, tend to accept the current agricultural system, but at the same time feel manipulated by policies and regulations. In our study hobby farmers and committed farmers more often criticised the current system and conventional agriculture for its ill effects on society. Hobby farmers and committed farmers sought out organic agriculture out of their own initiative in response to issues in their personal lives, on their farms, or in society that they wanted to address through organic management. Hobby and committed farmers thus show characteristics typical of proactive farmers. Export farmers, instead, were typically not as adamant in their criticism of conventional agriculture, while they often voiced a feeling of being neglected by the government, and sometimes by the export NGO as well. Export farmers, like conventional farmers, thus show more reactive characteristics.

All groups of organic farmers in our study shared a concern for the future economic viability of farming, but committed organic farmers appeared to be more willing to forego current short-term profit for long-term sustainability and viability of their system than export farmers. Mccann *et al.* (1997) observed that conventional farmers in Michigan put more emphasis on values of long-term profitability of the farm, as well as family values, while organic farmers emphasized environmental sustainability, as well as personal satisfaction more highly. In our study export farmers valued family well-being, and a good standard of living very highly - showing characteristics more typical of conventional farmers – while committed and hobby farmers highly valued personal satisfaction, health, and long-term soil fertility - showing characteristics typical of organic farmers.

It has been emphasized that discourse and the construction of a shared story and of a collective model can be a useful means to explain human decision-processes in the context of complex socio-ecological systems (Beratan 2007). The shared story conveyed to us by almost every single organic farmer pertained, firstly, to the ill effects of chemical fertilizers on soil fertility through its negative influence on microorganisms, whereas organic practices were perceived to improve soil fertility resulting in better pest-resistance of crops and a healthier agroecosystem. The second part of the story shared by organic farmers pertained to the ill effects of chemical fertilizers and pesticides on human health, whereas organic management allowed the production of healthy, nutritious and tasty food. But even though all organic farmers broadly shared this collective model, the importance they gave to it, and the degree to which this story had been internalized varied between farmers. Committed and hobby farmers, who had first learned about organic agriculture from books, other media, and by attending events organized by the organic farming movement, were typically highly convinced of these ideas and prioritized this organic concept of health over financial goals. Export farmers, on the other hand, who were first exposed to these ideas in seminars provided by organic export NGOs, simply repeated these messages, but in conversations often placed higher priority on financial goals than these organic ideas.

In this respect, social interaction – which is an important component of individual decision making (Beratan 2007) – in some instances was able to provide meaning and a collective model of organic agriculture to farmers (i.e. in the case of hobby farmers and committed farmers who were involved with the organic farming movement). But in other instances (i.e. in the case of export farmers) the association to a social network (i.e. export organic NGOs) failed to provide meaning or a strong shared story that could guide farmer behaviour, as “the vision has turned to a business” (OF6, Focus Group 2).

The fact that entire villages adopted organic farming at the urging of NGOs suggests that considerable social pressure may have been involved in the conversion to organic farming. Export farmers were motivated mostly by external financial and social factors in their decision to adopt organic, while committed and hobby farmers adopted organic management out of their own initiative following internalized beliefs about the superiority of organic farming. Research about environmentally responsible behaviour has shown that when behaviour is self-initiated and self-maintained and resulting from intrinsic motivations it is more likely to be sustained than when it is driven by extrinsic motivations like monetary incentives or social norms (De Young 1996; Brown & Kasser 2005; Zepeda *et al.* 2013).

Although the importance of attitudes and values for the adoption of environmentally-friendly farm management practices have already been emphasized (Siebert *et al.* 2006), the importance of intrinsic motivations for commitment to environmentally-friendly behaviour of farmers have rarely been studied (see Stobbelaar *et al.* (2009) for a discussion of intrinsic motives for adoption of agro-environmental schemes by farmers). Intrinsic motivations are especially important for activities – like organic farming in Kerala - that lack a clear financial incentive.

4.5.3 THE PROSPECTS FOR ORGANIC FARMING IN KERALA

The main problems voiced by organic farmers were higher labour costs, yield decreases (especially during the first years after adoption of organic) and lack of sufficient premium prices. Many farmers said that the government should be supporting organic farmers to deal with these problems, especially during the transition period when soil fertility is being restored and crop yields are lower. Organic farmers across the board said that the government did not provide any support for organic agriculture, and that the organic farming policy was only a lip-service that was not backed by concrete actions.

In the context of Kerala, export organic agriculture does not currently provide much economic benefit due to the unreliability of premium prices and higher labour costs. Organic farmers who were able to access premiums in domestic organic markets were experiencing more economic benefits. But this domestic organic market is very limited to date. The city of Thrissur – the fourth largest city in Kerala - has, for example, only two stores selling organic produce to consumers, while Kozhikode – the third largest city – has only one organic store. Given these challenging economic circumstances it is questionable whether a large number of new farmers will enter organic agriculture in the coming years. In addition, it is very possible that more farmers will exit export organic agriculture as prices in the conventional market continue to rise along with labour costs.

The economic viability of organic agriculture critically depends on access to the organic market and labour availability.

Typically, organic agriculture is portrayed as a success story with a continuously growing market and covering an increasingly expanding land area. It has also been argued, however, that this growth trend might be hiding more complex dynamics of entrance and exit from organic agriculture (Harris *et al.* 2008). In recent years India and Kerala have seen considerable fluctuations in the area of certified organic agriculture, and the growth trend has not been very clear or consistent (Fig. 4.9). These numbers indicate substantial year-to-year variation in the numbers of organic farmers and the area under organic agriculture, suggesting considerable numbers of farmers leaving organic agriculture. The total number of farmers certified organic appears to be increasing in Wayanad, according to data provided by the NGOs (see Figure 4.9). According to WSSS the total sales of organic produce they are handling increased by almost 200 times between 2005 and 2014, and the number of farmers certified under their program increased almost threefold between 2010 and 2014. But this data does not provide information about the number of farmers entering or exiting organic agriculture.

The degree of exit from organic agriculture, and the reasons for it, are generally not well studied (Harris *et al.* 2008; Flaten *et al.* 2010). We did not interview any farmers who exited organic farming. But the experience of Organic Wayanad - one of the NGOs that provided us an entry point to organic farmers in Wayanad - shows the potential for a mass exodus out of organic farming if economic conditions are not favourable (Fig. 4.9). In the beginning of its program in 2004 the organization approached farmers and tried to recruit as many members as possible. At that time they were the biggest organic marketing agency in the state and had 2,000 farmers joining their program in Wayanad alone. But today only 350 farmers are left. The majority of members left the organisation, as they did not receive the financial benefit they had expected and their yield losses were not being compensated by the organic premium. Now Organic Wayanad only takes on new farmers as members if farmers approach them, as they learned that only farmers who are convinced of the principles of organic farming will stay in organic farming.

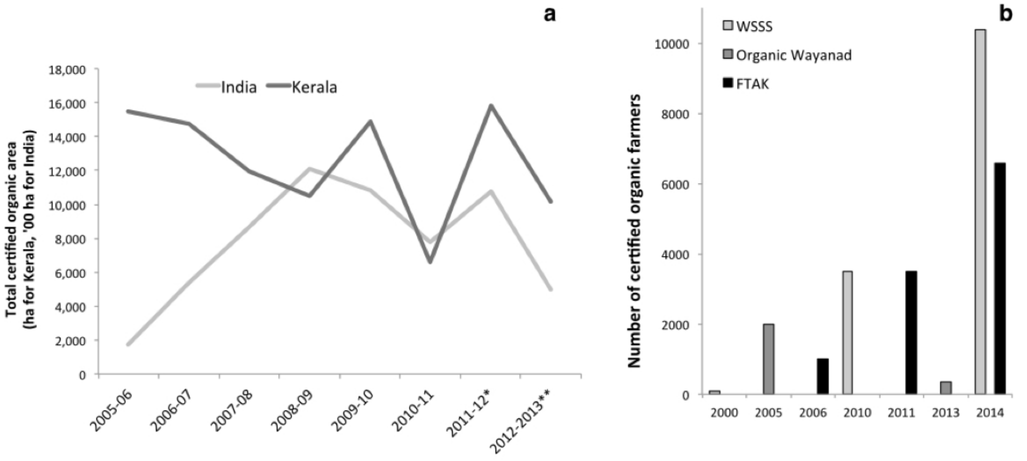

Figure 4.9. Change in area of organic agriculture in India and Kerala from 2005 to 2012 (a) and change in number of certified farmers who are members of three of the key local organic NGOs active in Wayanad, Kerala (b). Acronyms: Wayanad Social Services Society (WSSS), Fair Trade Association Kerala (FTAK).

Even in places like Cuba or the European Union, where concrete policy measures and institutional support for agro-ecological management practices exist, it is often suggested that the success of agro-ecological programs is hindered by a lack of internalization of environmental values by farmers (Nelson *et al.* 2009; Stobbelaar *et al.* 2009). In Kerala, where such concrete policy support for organic farming is lacking, internalization of organic values appears to be especially important for the adoption and success of organic agriculture. In addition to more favourable economic and policy context, a stronger ideological commitment to alternative management practices might be essential for a true transition to more sustainable agriculture in the state.

4.6 CONCLUSIONS

Organic agriculture in Kerala appears to be successful (despite certain cross-cutting problems) when it is practiced for ideological rather than economic reasons; while it only appears to be economically profitable for small farmers who can use their own labour and local inputs, and access domestic organic premium markets. For farmers who produce for the certified organic export market, organic management tends to, instead, not be financially viable due to yield reductions, low premium prices, and higher labour and input costs.

Siebert *et al.* (2006, p. 318) wrote that “financial compensation and incentives [are] a necessary, though clearly not sufficient condition” for the adoption of conservation measures by farmers. Here we instead conclude that financial incentives are not necessary for the adoption of organic agriculture by some individuals. Instead, we identified strong pro-organic attitudes to be a necessary condition for the adoption and satisfaction with organic farming under the economic context in Kerala.

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SUPPLEMENTARY MATERIAL

S4.1 DETAILED METHODS

We conducted quantitative surveys and semi-structured interviews with 32 conventional and 36 organic farmers. Conversations with farmers lasted on average 90 minutes, and were typically held in Malayalam with a translator present. Typically the male farmer was the main person answering questions, but often the farmer's wife was also present and occasionally participated in the conversation. On numerous occasions other relatives or neighbours were also present and sometimes participated in the interview. The qualitative part of the interview included open-ended questions covering certain pre-defined topics, but also allowing interviewees to discuss unsolicited topics and letting the conversation move in un-directed ways (Arksey & Knight 1999).

Sampling design

Organic farmers were chosen using a purposeful snowball sampling. We aimed to cover as many different types of organic farmers – in terms of farm size, wealth, marketing channels, and crops grown - as possible. We identified organic farmers based on contact information for organic farmers that we found online, that we received from key informants, or from other farmers. We thus managed to cover a wide breadth of different types of organic farmers, while sacrificing any representativeness for the organic farming population in Kerala. In other words, we aimed for an 'illustrative sample' rather than a 'representative' one (Valentine 2005). Conventional farmers were also chosen with a type of purposeful snowball sampling - combining criterion-led and convenience sampling. For each organic farmer interviewed we tried to interview a conventional farmer that was similar in size, similar in wealth and living in the vicinity of the organic farmer.

It is important to note that our sampling strategy was developed following a qualitative approach to data collection. The quantitative part of our study is thus sub-ordinate to the qualitative one (Bryman 2006), and due to the non-representative sampling design our quantitative data cannot be used for any generalizations about the larger population. We therefore purposefully refrain from any inferential statistical analysis of our quantitative data and their use is purely descriptive in nature.

Indicators

The quantitative data was summarized and some variables combined into indicators. We report median and median absolute deviation (MAD) values (if not otherwise noted), as the distribution of some variables was strongly skewed due to a few outliers and the median represents the central tendency of the data more accurately than the mean. We constructed three different types of indicators: a wealth indicator, a social capital indicator, as well as a commitment indicator for organic farmers.

Multidimensional **wealth indicators** are useful proxies for household economic status, as they are less time-consuming, less intrusive to interviewees, and less prone to over-reporting than collecting household income or expenditure data (Filmer & Pritchett 2001). We created a wealth indicator as a combination of (1) size of land holding, (2) ownership of six key consumer goods, (3) highest education in household, (4) type of housing, (5) number of rooms in house. These different variables were identified based on a potential list of variables used in the scientific literature, or by the state and national governments to identify BPL (below poverty line) households (e.g. Filmer & Pritchett 2001; Thomas *et al.* 2009; Usami *et al.* 2010). From a wide array of possible choices we selected these five variables as they captured key aspects of wealth relevant in the local context (e.g. access to sanitation would not have been relevant as all households had running water and toilets), and involved questions that would not discomfort interviewees (e.g. questions about indebtedness or alcoholism). Farmers are typically not amongst the poorest members of society in Kerala (Thomas *et al.* 2009) and thus we did not encounter extreme poverty in our study population[25]. The continuous data on each variable were converted to scores by binning them by quantiles, and the scores on each variable summed for each farmer. All variables were weighted equally.

Social capital is the degree of social networks, bonds and norms holding a community together (Pretty 2003). Typically social capital is separated into *bonding* (links established between people of the same group), *bridging* (links between different groups), and *linking* (links with external agencies) social capital. Here we construct a simple **social capital indicator** composed of information about (1) the frequency farmers attend farmer meetings, (2) the frequency farmers attend village meetings, (3) the degree of help shared with relatives within the village, (4) the degree of help shared with relatives outside of the village but within the district, and (5) the degree of help shared with neighbours. As with the wealth indicator, continuous variables were partitioned into bins using quantile distribution, and the scores on each variable summed for each farmer. By capturing aspects of participation in the local community, as well as neighbourhood, and family connections, these variables provide a useful albeit simplistic proxy for bonding and bridging social capital, while not capturing linking social capital. To complement and contextualize this quantitative assessment we also examined qualitative interviews for information about social capital.

For organic farmers we developed a **'commitment indicator'** to capture the degree of commitment for organic farming. We considered farmers to be committed if they were (1) farming 100% of their land with organic practices, (2) did not receive premium prices on organic produce, (3) had adopted organic

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[25] Many of the poverty indicators used in the literature were not relevant in our case (e.g. availability of clothing, man unable to work, or food security), as we tried to identify differences in wealth amongst the non-poor rather than trying to identify the very poor and poor.

agriculture more than 10 years ago, and (4) were not associated with an NGO promoting organic farming.

Plot productivity and diversity

To assess the productivity of organic and conventional agriculture we collected information about annual crop production from farmers. The productivity of crops is difficult to assess in a context like Kerala, as crops are typically grown in diverse multi-cropping systems, and the yield of a single crop species thus depends strongly on the crop association it is grown in, as well as the planting density of that particular crop species. In order to allow for a better assessment of farmer's productivity we therefore assessed the total productivity of plots rather than yields of individual crop species. To be able to compare the total productivity of plots we first had to fill some data gaps, as for multi-cropping plots a data gap for only one crop species would otherwise exclude an entire plot from the analysis. We did this by calculating average crop yields for crops grown in organically and conventionally managed multi-cropping plots (after removal of outliers) and used these values to fill missing values for mango, arecanut, vegetables, banana, and nutmeg in a total of 10 (out of 205 total yield values) instances for conventional farmers and 7 (out of 217) instances for organic farmers. We only used this gap-filling procedure for multi-cropping plots that had only one missing value (multi-cropping plots with more than one missing values or mono-cropping plots with missing values were excluded from the analysis).

We also converted crop production into caloric (kcal per ha) as well as monetary values (Rs per ha), which provide more holistic measures of productivity in comparisons of organic and conventional systems (Seufert *et al.* 2012). We used country-specific values of crop caloric content (cal/kg) from (Cassidy *et al.* 2013) and (Tilman *et al.* 2011), which is mostly based on data provided by FAO. Caloric values are typically specific for India, but where no values for India were available we used averages from other countries in developing Asia. Values for crop prices (Rs/kg) were more difficult to get than values of caloric content and were collected from multiple different sources (see Table S4.1). For most crops we compiled prices from a market in Kerala (e.g. crop prices in the Chelai market, as stated on the website of the agricultural department of the state government, or state-level prices as given in the yearly economic reviews of the Kerala government), but in some cases (e.g. for mangosteen, annona fruit, watermelon and cocoa) we had to use prices from other places in India. We were mostly interested in the general magnitude of crop value (e.g. pepper receiving approximately 300 Rs/kg, while coconut receives approximately 4 Rs/kg), not in the exact values actually received by farmers, so such temporal and spatial inconsistencies were considered to be acceptable.

Focus groups

In addition to farmer interviews we also conducted 22 conversational interviews with key informants from academia, policy, and key figures of the organic movement in Kerala. Finally, we conducted three focus groups - one with male organic farmers who were part of an NGO-network and produced certified organic crops for export in Wayanad, one with male conventional farmers who were attending a course on organic vegetable production in Thrissur, as well as one with female conventional farmers who were attending a village meeting about organic vegetable cultivation in Wayanad. Focus groups were intended to provide triangulation of the results from farmer interviews, allowing participants to freely express and develop their opinions on organic agriculture in a potentially more comfortable setting and more uninhibited manner than in one-on-one interviews.

Qualitative data analysis

The qualitative sections of the farmer interviews, key informant interviews, as well as focus groups were transcribed. Starting with themes based on the list of questions that guided the semi-structured interviews, transcripts were initially coded into different topics like ‘reasons to go organic’, ‘adoption pathway’, ‘problems of organic’, ‘benefits of organic’, ‘barriers to organic’, and ‘profitability of organic’. As new topics emerged during this coding process new themes and sub-categories to these initial themes were added, e.g. ‘societal changes’, ‘labour issues’, ‘livestock changes’, ‘transition period’, or ‘soil fertility’ and earlier transcripts were re-coded including these new themes. To assess which themes were relevant across farmers and which themes varied between different individuals we separated themes into ‘cross-cutting themes’ and ‘variable themes’. Finally we searched for commonalities, as well as variability of opinions within different farmer groups, identifying statements that were representative of an often-shared opinion, as well as statements that were unique to certain individuals. Verbatim quotes used in the article were minimally edited to remove grammatical errors (note that quotes were usually translations by research assistants, and not direct representations of the interviewee’s words).

Table S4.1. Overview of sources used for prices of different crops grown by farmers.

Crop	Rs/kg	Variable	Source	Year	Location
annona fruit	100	Retail price	The Times of India (2012)	2011-12	India
arecanut	44	Monthly average farm price	Government of Kerala (2013b)	2012-13	Kerala
ash gourd	17	Wholesale and retail price	Government of Kerala (2014)	2014	Chalai, Kerala
banana	29	Monthly average farm price	Government of Kerala (2013b)	2012-13	Kerala
beans	36	Wholesale and retail price	Government of Kerala (2014)	2014	Chalai, Kerala
bittergourd	45	Wholesale and retail price	Government of Kerala (2014)	2014	Chalai, Kerala
cabbage	16	Wholesale and retail price	Government of Kerala (2014)	2014	Chalai, Kerala
cardamon	674	Monthly average farm price	Government of Kerala (2013b)	2012-13	Kerala
clove	797	Monthly average farm price	Government of Kerala (2013a)	2011-12	Kerala
cashew	55	Monthly average farm price	Government of Kerala (2013b)	2012-13	Kerala
cauliflower	37	Wholesale and retail price	Government of Kerala (2014)	2014	Chalai, Kerala
chili	60	Wholesale and retail price	Government of Kerala (2014)	2014	Chalai, Kerala
cocoa	40	Farm price	Deccan Herald (2009)	2009	India
coconut	4	Monthly average farm price	Government of Kerala (2013b)	2012-13	Kerala
coffee	71	Monthly average farm price	Government of Kerala (2013b)	2012-13	Kerala
colocasia	36	Wholesale and retail price	Government of Kerala (2014)	2014	Chalai, Kerala
cucumber	18	Wholesale and retail price	Government of Kerala (2014)	2014	Chalai, Kerala
elephant yam	26	Wholesale and retail price	Government of Kerala (2014)	2014	Chalai, Kerala
ginger	20	Monthly average farm price	Government of Kerala (2013a)	2011-12	Kerala
jackfruit	40	NA	The Times of India (2013a)	2013	Kerala
ladies finger	24	Wholesale and retail price	Government of Kerala (2014)	2014	Chalai, Kerala
mango	84	Retail price	The Times of India (2013b)	2013	India
mangosteen	110	Farm price	The Hindu (2014)	2014	Kerala
medicinal	40	Average price provided by medicine manufacturing unit	Sasidharan and Muraleedharan (2009)	2006	Kerala
nutmeg	346	Monthly average farm price	Government of Kerala (2013a)	2011-12	Kerala

paddy	15	Monthly average farm price	Government of Kerala (2013b)	2012-13	Kerala
peas	75	Wholesale and retail price	Government of Kerala (2014)	2014	Chalai, Kerala
pepper	365	Monthly average farm price	Government of Kerala (2013b)	2012-13	Kerala
pineapple	23	Wholesale and retail price	Government of Kerala (2014)	2014	Chalai, Kerala
rubber	158	Monthly average farm price	Government of Kerala (2013b)	2012-13	Kerala
tapioca	9	Monthly average farm price	Government of Kerala (2013b)	2012-13	Kerala
tomato	16	Wholesale and retail price	Government of Kerala (2014)	2014	Chalai, Kerala
tubers	24	Wholesale and retail price	Government of Kerala (2014)	2014	Chalai, Kerala
tumeric	70	Monthly average farm price	Government of Kerala (2013a)	2011-12	Kerala
vegetables	31	Wholesale and retail price	Government of Kerala (2014)	2014	Chalai, Kerala
watermelon	20	Farm price	Dawn (2014)	2014	Karachi, Pakistan

S4.2 POSITIONALITY

Social interactions are defined by power relationships, and research is based on the situated knowledge of both interviewer and interviewee. It is therefore important to reflect on ones own positionality, the values and background one brings to the field, as well as the way these values and background are perceived by interviewees, when conducting research that relies on such social interactions (England 1994; Rose 1997; Sultana 2007; Heller *et al.* 2011). This research project was led by me, the first author of the study and author of this thesis, but was carried out with the support of Stephanie Austin (the third author of this study), who accompanied me to the field as a research assistant (and who conducted part of the interviews), as well as two local interpreters. In the following I will reflect on the positionality of both myself, as well as my research team (which is important given that field assistants can shape research considerably, Twyman *et al.* 1999; Scott *et al.* 2006), trying to reflect how our combined roles might have influenced our interactions in the field, and our research.

Organic agriculture is part of an alternative agricultural paradigm that is in opposition to the currently dominant conventional agricultural paradigm, and the topic of organic agriculture is therefore often controversial, polarized, and ideologically charged. We were aware that the way interviewees perceived our position on organic agriculture could potentially strongly influence their responses. Just the fact that we were interested in organic agriculture, for example, already positioned us in a certain way with several people, who assumed we were in support of organic ideas. On the other hand, our affiliation with the Kerala Agricultural University (KAU), which is generally seen as an advocate of chemical fertilizer and pesticide use, also sometimes positioned us on the organic-critical spectrum. For many of the interviews we relied on export organic NGOs for putting us in touch with interviewees, and we were often accompanied during interviews by a representative of the NGO. We tried to avoid this as much as possible, to be able to also capture critical opinions from farmers. The heads of the different NGOs we interacted with were, however, typically very supportive of our research, and did not attempt to keep critical opinions from us.

Given the importance of our personal stance on organic agriculture for the way we conducted interviews, and the way interviewees would respond to us, I want to briefly reflect on our personal preconceptions on the topic. I personally try to be as impartial as possible, and I try to avoid a clear opinion in favour or against organic agriculture but instead try to view the topic in terms of problems and benefits that have to be identified (see Chapter 1 of this thesis). But I still rather tend to have a bias in favour of organic agriculture as an alternative mode of production due to my identification as a left-wing social democrat who is critical of the current neoliberal capitalist system. During fieldwork I therefore tried to address my bias by taking a rather organic critical stance. If I am (secretly) in favour of organic, I need to examine it even more critically, and thoroughly identify and examine every criticism raised against it. Stephanie had conducted research on organic farmer decision-making and livelihoods in the neighbouring state of Tamil Nadu for her honours thesis one year prior to our fieldwork in Kerala. Her role as an interviewer was therefore influenced by this previous experience. In the end she discovered that the context in Tamil Nadu was very different from the one we encountered in Kerala. In general, Stephanie also had a positive attitude towards organic agriculture, but because she was not as involved in the topic as me, her opinions were less strongly developed and I perceived her way of formulating questions during interviews as quite balanced.

My primary role in the field, as well as that of Stephanie, was as a white educated woman of Western origin. On the one hand, our identity as Western researchers automatically established an asymmetrical power relationship (Katz 1994; Scott *et al.* 2006; Heller *et al.* 2011). But I want to qualify this notion of asymmetry by noting that Kerala is different from many other contexts in the Global South, as Keralites are typically highly educated, largely middle class, and many have been abroad themselves, or have relatives who live and work abroad. While our race was associated with privilege (we were for example automatically treated with respect by authorities), our class or education provided little additional privilege. As many people have noted before, power and privilege in relationships between researchers and the researched are often not binary but continuously negotiated and influenced by many different, sometimes opposing roles between researcher and research participant (Scheyvens & Leslie 2000; Thapar-Björkert & Henry 2004). Our role as young women in a highly patriarchal society, for example, appeared to counterbalance some of our white privilege. Gender and age play defining roles in the Keralan society (Mitra & Singh 2007), and being two young women in our early to late twenties who were travelling without a male companion we were often treated with fatherly care by the typically older male interviewees. Many interviewees opened up quite quickly after starting to talk with us, and I believe that our role as young women helped this process, as we were typically not perceived as a threat but rather as in need of support.

During my fieldwork I tried to find a careful balance between these two roles as a foreigner and as a young women. On the one hand, I tried to develop a more equitable relationship by emphasizing my role as someone young, and inexperienced, who had come to Kerala to learn, and who had a strong respect for the experiences and opinions of the interviewees. On the other hand, I also sometimes needed to establish my authority as the leader of this field study, especially in interactions with key informants and gatekeepers who provided us contacts to interviewees and sometimes tried to influence our study.

We were highly aware during our fieldwork of our role as outsiders to the communities we were researching. The areas where we conducted research do not receive a lot of Western visitors. We were thus often seen as an interesting novelty and welcomed with curiosity and hospitality. In many households we visited neighbours and other household members joined the conversation out of curiosity for us and for what we were doing. Typically conversations started or ended with us being questioned by interviewees about where we came from, our families and backgrounds.

We were assisted during our research by Haseena Kadiri and Vishnu Satheesan, two young forestry students from the Kerala Agricultural University (KAU), who were local to the study region (Haseena's family is from Wayanad, her father is a farmer, and some interviewees knew her family). Haseena's family is Muslim and Vishnu's family is Hindu, while 62% of the farmers we interviewed were Christian, 32% Hindu, and only 6% Muslim. Both Haseena and Vishnu had very little previous experience working as translators, and having just completed a BSc degree in forestry they did not have a strong background in agriculture. They were nonetheless much more familiar with local farming systems than either Stephanie or I were. But their lack of an academic background in agriculture was, in hindsight, probably an advantage, as they both did not have strong predetermined opinions about the research questions we were asking. Their proficiency of English was high, but given their limited experience working as translators, they often had difficulties providing a verbatim translation of the farmers' words. Often farmers would talk for several minutes, and Haseena or Vishnu would provide a two-sentence summary of what the farmers had said. My interpretation of the farmers' voices is thus strongly influenced by the involvement of both interpreters. Generally, all three of my research assistants had very amicable and deferent personalities and were typically received positively and able to build up trusting relationships with interviewees. This is probably also due to their young age (all three of them were in their early twenties).

Given the many discussions in the literature about the dangers of asymmetrical power dynamics in fieldwork, especially in the Global South, as well as the dangers of exploiting the knowledge and time of the researched without being able to compensate adequately for their contributions (Scheyvens & Leslie 2000; Scott *et al.* 2006; Heller *et al.* 2011), I had expected to feel stronger ethical dilemmas about my role as researcher during my fieldwork. But on the one hand, I was surprised at how much my role as a young woman offset my role as a white foreigner in terms of power dynamics. On the other hand, people often expressed gratitude that we were taking an interest in their views and problems. We always took care to give interviewees a lot of room to express their ideas. One interviewee, for example, started the recital of a poem about agriculture's role in societal change. While another interviewee performed a song that he often uses in lectures about organic agriculture for us. Many interviewees gave us tours of their farms, showing us all the innovative management practices they were using. Because of the space we left for interviewees to express their ideas, even if they were not directly related to our research questions, our interviews sometimes took up to three hours.

One focus group participant said at the end of a focus group discussion that in his more than ten years of being involved with farmer groups this was the first time that someone had actually asked him about his opinions. The focus group ended with us expressing our thanks for the farmers' participation, for their time and for exchanging their ideas with us, and the participants expressing thanks for our time, and interest in their problems. This was a very powerful experience.

Despite this generally positive experience, we still were also treated with suspicions and reservation by several interviewees, and in several interviews we did not manage to overcome the initial reservation and to build a trusting relationship. Farmers were especially reluctant to answer questions about yields and detailed management practices, as well as details (including age and education) of household members. This process was often tiresome (because it often required a lot of repeated questions) for both the interviewees and us, and on several occasions the interviewees asked us for what we needed this information.

I conducted a mixed-method case study, which meant that I relied both on qualitative data from in-depth interviews, as well as quantitative data from surveys. For survey purposes we tried to interview as many farmers as possible. This meant that all four members of our research team experienced substantial research fatigue at some point during our fieldwork. My personal struggle with this fatigue and the difficulty of balancing a high sample size needed for quantitative purposes with the need to do justice to the opinions of every interviewee in the qualitative part of the research, is captured in this excerpt from my research diary, which I wrote down after a challenging interview with a conventional farmer towards the end of our fieldwork:

> I was not very present, felt tired and over-interviewed. But when he told me that he had lost 4 lakh Rs in 1 year and 3.5 lakh Rs the next year after a failed ginger cultivation, I realized that I was not giving him

> justice. Even after 60 interviews and with many answers repeating, I should really try to get involved and engaged with every single farmer, as every farmer has his own story and individual background and interesting history. Was touching to hear him talk about his financial problems and his biggest concern for the future, which is to have enough money to pay for his daughters wedding. The conversation with him brought me back down again to the ground, realizing I need to concentrate more and be more present at all times during interviews.

This balancing act between generalizations drawn from the quantitative data collected and nuanced context provided by farmers' individual voices from semi-structured interviews also continued during the data analysis process. This was particularly difficult as amongst every farmer group identified there were individuals who differed in their views and experiences from other farmers. I tried to avoid using the quantitative data to tell a story and then handpicking farmer voices that supported this story by doing the qualitative data analysis first - I started examining quantitative data for patterns between farmer groups only *after* having analysed about half of the organic farmer interviews.

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CONNECTING STATEMENT

After having examined agronomic (Chapter 2), ecological (Chapter 3) and social (Chapter 4) consequences of organic farming, I will now address the policy context of organic agriculture and examine my fourth research question - What does organic agriculture mean today and how are organic principles codified in organic regulations? On the one hand, I will go back to the drawing board and ask what organic agriculture actually means today, by examining how organic agriculture has been codified in regulations. On the other hand, I will look ahead and provide suggestions as to how organic regulations could contribute to improving the sustainability of organic systems. The following chapter will again (like Chapters 2 and 3) be global in scale, but (like Chapter 4) will use qualitative tools of analysis.

5. WHAT IS THIS THING CALLED ORGANIC? – HOW ORGANIC FARMING IS CODIFIED IN REGULATIONS

“Für uns Wissenschaftsmenschen ist nichts wichtig als das Feststellen von Verschiedenheiten, Wissenschaft heißt Unterscheidungskunst.”[26] – Hermann Hesse, Narziss und Goldmund

In preparation for *Food Policy*.

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[26] *“For us science people nothing is as important as the establishment of differences; science is the art of differentiation.”*

5.1 ABSTRACT

Organic farming is one of the fastest growing sectors of world agriculture. Although organic farming represents only 1% of world agricultural area, organic is one of the most recognized food labels and most people in developed countries consume some amount of organic food today. While organic farming is clearly on the rise, there is a wide range of definitions and interpretations by different actors in the organic sector. Here we examine 8 different organic regulations from across the world to understand how they have codified the large diversity of ideas inherent in organic agriculture. Our analysis shows that organic practices and regulations do not differ substantially between countries – across the board organic regulations understand and define organic mainly in terms of 'natural' vs. 'artificial' substances that are allowed (or not) as inputs. This interpretation of organic, as “chemical-free” farming, largely void of broader environmental principles, does not fully incorporate the original ideas of organic theoreticians, who conceived organic agriculture as a holistic farming system aimed primarily at improving soil health, thereby leading to improved animal, human, and societal health. This narrow focus of organic regulations can be explained by the interest of organic consumers, who predominantly buy organic because they believe it is healthier and more nutritious due to the absence of certain harmful substances. Organic regulations need to place more emphasis on environmental best practices in order to ensure that organic agriculture can contribute to sustainability objectives.

5.2 INTRODUCTION

Organic agriculture is often proposed as a solution for producing food with reduced environmental impact (Tilman 1998; Scialabba & Hattam 2002). Even though organic agriculture constitutes less than 1% of global agricultural land and less than 5% of retail sales in most developed countries (Willer & Lernoud 2015), it represents one of the fastest growing food sectors. In many developed countries organic food is consumed at least occasionally by a majority of people[27]. Organic is the most recognized food label, whose basic meaning is understood by most consumers today, and organic agriculture represents the only farming system whose management practices are codified by law in most countries (Rigby & Cáceres 2001). Organic food thus represents one of the few means through which consumers can have some control and knowledge about how their food is produced (Allen & Kovach 2000).

But what does organic agriculture actually mean? The meaning of organic is shaped by the different actors involved – consumers, producers, theoreticians, and regulations (see Figure 5.1). Accordingly, there have been many discussions and debates about the definition of organic agriculture (Rigby & Cáceres 2001), as well as the different forms in which organic agriculture manifests itself today (Guthman 2004). Many of the most commonly cited definitions are ambiguous (e.g. IFOAM 2006) and different people associate different things with it and buy organic products for different reasons (Hughner *et al.* 2007). This wealth of meanings and associations is also rooted in the history of organic agriculture and in the manifold ideas expressed by the original organic movement (Conford 2001; Heckman 2006). But the lack of a clear vocabulary and conceptualization of organic makes a discussion about the problems and benefits of organic agriculture challenging. Indeed, debates about whether organic farming could contribute to more sustainable agriculture are often highly polarized (Trewavas 2001; Goklany 2002; Mäder *et al.* 2002a).

What distinguishes organic from 'sustainable' or 'agroecological' management is that organic practices are well defined and in many countries regulated by laws. Regulation and certification is central to the current concept of organic agriculture in most countries. Organic regulations are therefore a useful place to start understanding how the views of the different organic actors have been codified and what organic agriculture means today (Rigby & Cáceres 2001).

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[27] Seventy three % of Americans, for example, consume organic food at least occasionally (Hartman Group 2006), while 58% of Canadians say they consume organic food every week (COTA 2013).

In this study we examine how organic agriculture is defined and codified in organic regulations today, and how organic practices and principles differ between regulations across the world. To this end we first provide a brief review of the history of organic agriculture, tracing the original ideas of organic pioneers and the history of organic regulations. We then compare **organic practices** between different regulations and standards for countries representing the largest organic producers and consumers across the world. Finally, we examine the **organic principles** used in the discussion and codification of organic agriculture in these regulatory texts. We conclude our study with some thoughts on the major influences on organic regulations, as well as a discussion of environmental best practices in organic regulations.

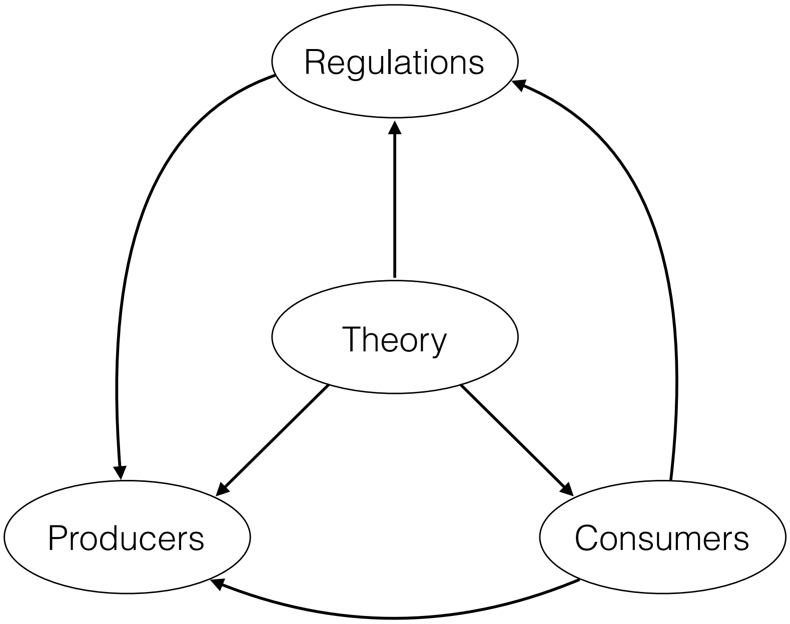

Figure 5.1. Different poles of influence defining organic agriculture today. Consumer demand for organic is often considered one of the main drivers of organic agriculture (Fromartz 2007). Producers shape how organic agriculture manifests itself in practice. Organic theoreticians influence the concepts and ideas about organic farming, and have an important role in the history of organic agriculture; and finally, regulations legally define organic practices and rules.

5.3 A BRIEF HISTORY OF ORGANIC AGRICULTURE

The original concept of organic agriculture developed as a fundamental critique of the emerging industrial food system in the 1920s to 1940s (Conford 2001; Fromartz 2007). Organic pioneers like the British Sir Albert Howard and Lady Eve Balfour, Germans Rudolph Steiner and Ehrenfried Pfeiffer and Americans Jerome I. Rodale and Louis Bromfield sought to develop alternatives to the fertilizer-reliant, reductionist and technology-centred industrial agricultural system. Inspired by peasant farming methods from South Asia (particularly India and Pakistan) they argued for the need to include processes from 'Nature' into human agricultural systems and preached about the vital connection between soil, food and health (Howard 1943; Balfour 1950; Steiner 1993). Walter Northbourne, who coined the term organic agriculture in 1940, used it to refer to a system 'having a complex but necessary interrelationship of parts, similar to that in living things' (Heckman 2006). In addition to its farming practices, the organic movement also criticised the centralized big-business model of industrial agriculture and emphasized the importance of artisanal farms and rural village life, being as much a social as an environmental movement (Berry 1977).

These ideas of the organic pioneers from the 1920s to 1950s were adopted in a slightly modified manner by the generation of the seventies, developing from a very rural movement led by rather more conservative and often religious or spiritually-motivated intellectuals into a more left-wing and secular 'counter-urbanite' movement (Conford 2008). In the 1980s, driven by an emerging environmentalism and health-concerns about exposure to pesticides, antibiotics and hormones, organic agriculture, which promised a more 'natural' and healthier agriculture, experienced a surge in popularity (Fromartz 2007). As organic sales began to skyrocket, organic groups started lobbying for a legal regulation of the organic label and of organic practices, which resulted in the development of national organic standards beginning in the 1990s (Conford 2001; Scott *et al.* 2009).

The codification of organic practices in legal standards and rules have led to a lively and often-controversial debate about what organic practices should entail. In the US the first state-level organic regulations emerged in the 1970s (Guthman 2004; Fromartz 2007). But it took almost another 30 years, including many years of extensive stakeholder consultation, until a national organic program was developed and the National Organic Program (NOP) Final Rules were implemented in 2000 (Vos 2000; Friedland 2005; Fromartz 2007). In Europe the first European wide organic regulation was established by the European Union (EU) in 1991 and it replaced national organic regulations, which had been established in most countries since the 1980s (Lampkin *et al.* 1999; Padel *et al.* 2009). National legal standards in Europe were often preceded by private and voluntary standards set mostly by organic producer organisations. Even after the implementation of the EU regulation many non-legal national standards that are often stricter than the EU standard are widely used and accepted by producers and consumers (Lampkin *et al.* 1999). Most European countries provide financial support for organic agriculture through agri-environmental programmes (Lampkin *et al.* 1999; Janssen & Hamm 2012). Some other countries, like Australia, do not yet have a legally binding national organic regulation but still use widely accepted national voluntary standards defined by government bodies (AUS 2009) or the organic industry (ACO 2010).

In recent years more and more developing countries have started implementing organic regulations in order to regulate the use of the organic label and to ease trade with developed country markets. Uganda, for example, adopted a national organic standard in 2004, followed by the definition of a regional East African organic standard in 2007, which was developed with the assistance of a UNEP-UNCTAD[28] initiative (UNCSD 2012). Similarly, after considerable growth of the organic sector, Mexico introduced a national organic program in 2006 (Nelson *et al.* 2010), which was translated into a national organic standard containing production guidelines in 2013. Today the majority of countries have some form of organic regulation – according to the Organic Trade

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[28] United Nations Environment Programme (UNEP), United Nations Conference on Trade and Development (UNCTAD).

Association (OTA) 99 countries worldwide have implemented or are developing organic standards (OTA 2014).

At the international level, several organizations are attempting to harmonize organic standards globally. The goal of the International Federation of Organic Agriculture Movement (IFOAM) (an international umbrella organization founded in 1972) and the *Codex Alimentarius* (set up by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) in 2001) is to establish a consensus definition of organic practices across different countries that facilitates free trade in nationally regulated organic food (Lampkin *et al.* 1999; Vos 2000). Both the IFOAM and *Codex Alimentarius* standards have been very influential in the definition of many national organic standards (Lampkin *et al.* 1999).

This codification of organic agriculture across the world has allowed the entrance of larger producers and agribusinesses into the organic market and led to organic food consumption becoming more mainstream, thus resulting in continuous growth of the organic sector (Fromartz 2007). This development has been dubbed the 'conventionalization' of organic agriculture, i.e. the incorporation of more and more elements of industrial agriculture into organic agriculture (Buck *et al.* 1997; Darnhofer *et al.* 2010b). This 'conventionalization' has resulted in considerable debate on the meaning of organic (Rigby & Cáceres 2001; Guthman 2004) and the political economy of organic agriculture in different countries (Campbell & Liepins 2001; Hall & Mogyorody 2001). Many authors have pointed out the apparent contradictions between organic agriculture as a movement representing an alternative to the globalized industrial food system rooted in social and environmental ideals and organic agriculture as a market sector that tries to pursue broad change through growth, adopting many elements of the food system that it initially set out to replace (Allen & Kovach 2000; Raynolds 2004; Fromartz 2007; Scott *et al.* 2009).

5.4 THE CODIFICATION OF ORGANIC IN REGULATORY TEXTS

In order to identify differences in the meaning and aim of organic agriculture in organic regulations we analysed the regulatory documents from a set of representative countries from across the world. We first chose 10 countries in which organic agriculture plays an important role. The most recent global organic data collected by IFOAM and the Research Institute of Organic Agriculture (FiBL) (Willer & Lernoud 2015) was used to identify (1) the three countries with the most organic producers, (2) the three countries with the largest organic agricultural area, (3) the three countries with the largest organic agricultural area and that have more than 5% of their total agricultural land under organic production[29], (4) the three countries with the largest organic domestic markets. The following 10 countries were selected by this process: India, Uganda, Mexico, USA, Germany, France, Spain, Italy, Australia and Argentina (see Table 5.1).

For European countries (Germany, France, Spain, Italy) the new harmonized EU regulation was analysed. Australia does not have a legally binding organic regulation. Instead, we used the National Standard for Organic and Biodynamic Produce, which is a voluntary standard for the organic industry defined by the Australian government (AUS 2009). We deemed this voluntary government standard more appropriate than other Australian voluntary industry standards (e.g. ACO 2010). Argentina does not have a single organic standard but organic agriculture is regulated in numerous separate laws. Because of the high number of legislative texts dealing with organic regulations in Argentina (i.e. Ley 25.127, Res. 423/92, Res. 82/93, Res. 331/94, Res. 1286/93, Res. 68/94, Res. 270/00, Res. 451/01 & Res. 503/05), we could not include Argentina in the analysis. Overall, we thus examined 8 different organic regulations representing 33

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[29] The countries with the highest share of organic agricultural land were not included, as these represent very small countries with small total agricultural area (e.g. Falkland Islands, Liechtenstein). To identify countries, where organic agriculture represents a significant share of total agricultural area but that at the same time are relevant at the global scale, we therefore chose those countries with the highest total organic area that have >5% of their agricultural land under organic production.

different countries (28 countries part of the EU + 5 other countries), as well as 2 international framework texts (Table 5.2).

Table 5.1. Countries included in the analysis. Values represent number of organic producers; total area certified organic and in conversion to organic agriculture (in ha); % of total agricultural area that is organic; organic sales (in Mio. €). Values are for the year 2013 if not otherwise indicated. Source: (Willer & Lernoud 2015).

	Country	**2013 value**
Countries with most organic producers	India	650,000
	Uganda	189,610 (2012)
	Mexico	169,703
Countries with highest total organic agricultural area	Australia	17,150,000 ha
	Argentina	3,191,255 ha
	USA	2,178,471 ha
Countries with highest total organic agricultural area that represents >5% of their total agricultural land[1]	Spain	6.5%; 1,610,129 ha
	Italy	10.3%; 1,317,177 ha
	Germany	6.4%; 1,060,669 ha
Countries with the largest domestic organic markets	USA	24,347 Mio. €
	Germany	7,550 Mio. €
	France	4,380 Mio. €

Table 5.2. Organic regulations included in the analysis.

Country	Regulation name	References
International	Joint FAO/WHO Food Standards Programme, Codex Alimentarius, Organically Produced Food (2001)	FAO and WHO (2001)
International	The IFOAM Norms for Organic Production and Processing, Version 2005	IFOAM (2006)
Australia	National Standard for Organic and Biodynamic Produce – Edition 3.4 (2009)	AUS (2009)
European Union	Council Regulation (EC) No 834/2007 on organic production and labelling of organic products &	EU (2007)
	Commission Regulation (EC) No 889/2008 laying down the rules for the implementation of EC No 834/2007	EU (2008)
India	National Programme for Organic Production (NPOP), sixth edition (2005)	NPOP (2005)
Mexico	Ley de Productos Organicos (LPO), Nueva Ley DOF 07-02-2006	LPO (2006)
	Lineamientos para la Operación Orgánica de las actividades agropecuarias, October 2013	LPO (2013)
Uganda	UgoCert (2005), Uganda Organic Standard (UOS) for organic production and processing	UOS (2005)
United States	National Organic Programme, e-CRF Data as of November 1, 2013	USDA (2013)

To compare the way organic agriculture is discussed in the selected organic regulations, we used several different approaches:

First, we conducted a detailed comparison of *management practices* regulated in different organic regulations. We coded rules on general land management (conversion, parallel production), crop production (species choice, pest control, fertilization), livestock production (species choice, breeding, feed, veterinary treatments, housing, transport and slaughter) and processing (food additives, processing aids) according to required, recommended, authorized, discouraged and prohibited inputs and management practices. This helped identify where regulations differed in the types of practices discussed, as well as in the extent to which these practices were regulated.

Second, in order to assess how the discussion of management practices might reflect differences in the conceptualization of organic agriculture, we conducted a content analysis using a qualitative weighting and scoring approach (see Hsieh & Shannon 2005; Krippendorff 2012)[30] to assess the importance of different organic *principles* in organic regulations. For this purpose we first identified management practices that are typically regulated in organic regulations. We focused our analysis on land-based crop and livestock systems, as well as on practices related to food production, thus excluding sections dealing with bee keeping, aquaculture, mushroom production, harvest of wild plants and animals, labelling, inspection & certification process, accreditation of certification bodies and packaging. We then inductively compiled a list of key organic principles, based on principles and objectives laid out in preambles of organic regulations. Instead of defining organic principles *a priori* based on theory and external sources (e.g. like Padel *et al.* 2009; Darnhofer *et al.* 2010b), we inferred organic principles from the legal texts themselves. We identified seven key organic principles discussed in organic regulations: (1) natural, (2) local, (3) soil, (4) biodiversity, (5) water, (6) animal well-being, and (7) human health. We excluded the principle of 'social' from our analysis, even though it was mentioned in definitions of organic principles in pre-ambles of several organic regulatory texts (e.g. Mexico, IFOAM), because social aspects are barely mentioned in most organic regulations.[31]

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[30] Krippendorff (2012, p. 24) defines content analysis as a "research technique for making replicable and valid inferences from texts (or other meaningful matter) to the context of their use".

[31] The IFOAM standard dedicates two pages to social standards, recommending some basic rights, social security systems and labour protection for organic farm workers and asking operators to have a policy for social justice, prohibiting the use of child or forced labour and declaring that production that is based on the violation of basic human rights shall not be declared as organic. The Mexican regulation does mention social standards in one sentence, while the Ugandan UOS dedicates an entire page to social justice, prescribing and recommending similar things as the IFOAM regulation.

Table 5.3. Matrix of organic management practices versus organic principles that could be used to discuss each practice.

	Organic principles						
Management practices	**Natural**	**Local**	**Soil**	**Water**	**Biodiv**	**Animal**	**Human**
Conservation areas			X	X	X		
Irrigation			X	X	X		X
Crop rotation			X	X	X		
Tillage			X		X		
Pest control	X				X		X
Fertilization	X	X	X	X			X
Species choice	X	X			X		
Livestock housing						X	
Livestock feed	X	X				X	
Veterinary treatments	X					X	X
Livestock breeding	X				X	X	
Livestock transport & slaughter						X	
Additives & processing aids	X						X

Based on the identified principles we constructed a matrix of organic principles versus organic management practices (see Table 5.3), identifying the organic principles management practices were based on. A regulation could, for example, discuss fertilizer use in the context of 'natural' by allowing only inputs from natural (i.e. plant, animal or mineral) origins while prohibiting substances from synthetic (i.e. chemical) origins; in the context of 'local' by emphasizing the need for nutrient sources to come from the farm or from the region; in the context of 'soil', if the regulation emphasized concepts like soil fertility, addition of soil organic matter or soil biological activity for nutrient management; in the context of 'water', if the need for responsible fertilizer use to minimize negative impacts on water quality was discussed; and in the context of 'human', if safe fertilizer and manure handling practices to ensure food and worker safety were discussed. We then assigned scores to each regulation based on how strongly the relevant principle was represented in the discussion of each management practice, giving a full point if the regulation of a specific practice was strongly oriented at achieving the envisioned purpose, half a point if the principle was a clear influence but considerable concessions were made, and zero points if it appeared to have no role in shaping the regulation of a specific practice. This scoring exercise was necessarily based on expert judgement. To minimize subjectivity two independent researchers (the first two authors of this paper) carried out the scoring exercise separately, and we used the average score assigned by the two researchers as our final score.

We then ranked (1) the importance of organic principles within each country/regulation, and we ranked (2) the countries/regulations regarding their emphasis on each organic principle. For the comparison, i.e. ranking of organic principles within each regulation the scores for each management practice across each organic principle were weighted according to the number of words used to discuss this management practice. We chose this approach, as the different management practices were not equally important in regulations (discussion of conservation areas was, for example, typically confined to a couple of sentences, while fertilization practices were usually discussed at length). The weight was based on the number of words used for each management practice in each regulation, relative to the total length of the text discussing all the management practices we included in our analysis. The weight thus reflects the relative importance each regulation gave to a certain management practice. We decided to use a squared weighting factor, as this put stronger emphasis on the more objective word count, compared to the subjective scoring.

For the comparison, i.e. ranking of organic principles between regulations we decided, instead, to use the un-weighted scores. The weighting factor based on word count is a relative measure that describes the relative importance given to different management practices *within* a regulation. But due to the very different organization of different regulations it is not appropriate for a comparison *between* regulations. Weighting by word count would have mostly benefitted regulations that dedicated a large proportion of their words to fertilizer use (as this is the management practice that is discussed in the context of the highest number of different organic principles, see Table 5.3), but would not provide an accurate comparison of the overall representation of organic principles between different regulations.

Finally, we conducted a sensitivity analysis for all three steps of our methods, to examine (1) whether the identity of the researcher, (2) the scoring system[32], or (3) the weighting method used influenced the results.

5.4.1 ORGANIC PRACTICES IN ORGANIC REGULATIONS

Broadly speaking, the organic regulations examined are quite similar, covering mostly the same aspects and offering similar solutions to the same problems. The influence of the IFOAM text on some of the national regulations, especially India and Uganda, is noticeable. This similarity in how management practices are regulated is not surprising given the large amount of trade in organic produce between countries (FiBL & IFOAM 2013). As mentioned earlier, the aim of international organic standards is to achieve some harmonization between countries in order to facilitate free trade in organic produce. IFOAM and *Codex Alimentarius* try to establish international reference standards that can act as minimum guidelines and that can be complemented by additional, stricter national or private labels. Several countries have also developed bilateral agreements in order to establish equivalency in organic standards[33]. The EU has, for example, established equivalency agreements with Argentina, Australia, Canada, Costa Rica, India, Israel, Japan, New Zealand, Switzerland, Tunisia and United States.

Generally, organic regulations define certain prohibited activities or substances (e.g. the use of genetically engineered products, synthetic pest or weed control substances, or the use of ionising irradiation for the treatment of food), and they formulate positive requirements (e.g. outdoor access for livestock or crop rotations). Compliance with the regulation is enforced by accredited government or private certifying agents. Some

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[32] A three-point scoring system of 0, 0.5 or 1 points, or a two-point scoring system only assigning either 0 (principle not discussed) or 1 point (principle discussed).

[33] Equivalency of organic standards means that although there are minor differences between organic regulations of countries (and regulations are therefore not harmonized), the guiding principles for organic production are acknowledged to be similar and the products certified under the other countries regulation is therefore allowed to be marketed as organic without needing to undergo a second certification (Giovannucci 2006; OTA 2009).

regulations (e.g. the Indian NPOP) also delegate the formulation of additional standards and management requirements (e.g. stocking rates or the minimum percentage of farm set aside as conservation area) to the certifying agents. The certifying agents are paid by producers, which, critics argue can create a conflict of interest as certifiers do not want to loose their customers through overly strict controls (Friedland 2005). Many regulations require the producers to formulate a management plan that details the production system and management practices used, the inputs applied and sometimes a prediction of the quantities produced. The control agency typically has to be informed of any changes to the management plan. In addition, inspections of the farm are carried out, typically a minimum of once a year. At such inspections producers need to be able to show documentation for all products used and currently stored on the farm, as well as for all products sold. Product testing is typically not required, except when there is reason to suspect non-compliance with the organic standards or contamination of products.

Despite the large similarities between regulations, some differences in organic practices between regulations are still worth noting. Some of these can be easily explained by considering country-specific context. For example, the EU standard has some unusual exceptions to the prohibition of genetically modified organisms (GMO) in organic agriculture compared to other regulations, allowing veterinary medicines produced from GMOs, as well as food and feed additives derived from GMOs if there are no alternative GMO-free substances on the market. But in the EU, GMO use in agriculture generally and its presence in food products is much more strictly regulated than, for example, in the US. Conventional produce in the EU is generally GMO-free or has to be labelled if it contains products derived from GMOs. Avoidance of GMOs is therefore not an important consideration for organic consumers in the EU (McEachern & Mcclean 2002).

Other notable differences include the US regulation, unlike all others, having blacklists of prohibited natural substances, thereby authorizing all natural substances that are not on this list, whereas other standards use positive lists of authorized substances. Furthermore, the US and the Australian regulation are especially strict about antibiotics compared to other regulations, in that slaughter stock that has been given antibiotics at any point cannot be sold as organic. In contrast, other regulations authorize the sale of organic animals treated with therapeutic use of antibiotics after certain withdrawal periods.

Even though the general principles according to which animal management is regulated are very similar in all regulations – e.g. animal housing that allows for natural behaviour & movement patterns, company with other individuals of the same species, natural light & ventilation – the degree to which these principles are translated into specific requirements differs substantially between regulations. The EU and Australian regulations are, for example, the only ones that prescribe the minimum amount of indoor (and in the case of EU also outdoor) area required per head of livestock. Also, while all regulations require access to the outdoors for livestock, only the US regulation requires a minimum proportion of livestock feed for ruminants to come directly from grazing. All other regulations recommend access to pasture whenever conditions allow, but do not require it. There are also some differences in how practices like crop rotations are regulated: In some cases (e.g. Mexico), they are strictly required; mostly, however, crop rotations are only recommended & typically discussed as part of a larger set of practices that can be chosen from.

Overall, there are more similarities than differences in how management practices are regulated in different organic regulations. Differences between regulations are often in the emphasis given to certain management practices rather than in concrete management requirements.

5.4.2 ORGANIC PRINCIPLES IN ORGANIC REGULATIONS

Comparison between regulations

Our first comparison of organic principles examines whether regulations differ in the degree to which they emphasise a certain organic principle in their discussion of organic management practices. Higher ranked countries/regulations put a stronger emphasis on a particular organic principle than others (Table 5.4). The first thing to note is that the range of scores between the highest and lowest ranked regulation is small (i.e. the score of rank 1 is not even double the score of rank 8). This does not differ if a weighted score is used (result not shown).

Due to these small differences between regulations, the ranking of regulations is strongly dependent on the scoring criteria (i.e. the identity of the researcher), as well as on the weighting and scoring method used (Supplementary Table S5.1). This suggests, on the one hand, that differences between regulations are not substantial, and, on the other hand, that they are rather subjective and dependent on judgement criteria.

Table 5.4. Comparison of organic principles in regulatory texts between countries/international bodies. See Table 5.2 for an overview of the different regulatory texts examined.

	Mexico	**IFOAM**	**Aus**	**Uganda**	**India**	**EU**	**US**	**FAO**
Natural	4	4	4	8	1	2	7	2
Animal	1	6	7	4	3	2	8	4
Human	1	1	4	8	5	6	1	6
Soil	3	1	2	3	6	7	5	8
Local	2	3	6	3	3	1	6	6
Biodiversity	1	5	3	1	4	6	8	7
Water	2	3	1	4	5	5	5	8
Rank	1	2	3	4	5	6	7	8
Score	24.3	21.8	21.0	20.5	19.5	18.3	16.0	14.5

This latter fact is very evident in the differing assessment of the EU and IFOAM regulations between the two researchers who carried out the scoring. Researcher 1 assigned scores mostly based on the specificity of regulations on a certain topic, while researcher 2 assigned scores mostly depending on whether a management practice was discussed in the context of a certain organic principle or not. The IFOAM standard thus receives high scores from researcher 2 as it dedicates a large portion of its text to the discussion of organic concepts behind different management practices. But the IFOAM standard receives low scores from researcher 1 as it lacks specifics about management recommendations or requirements. The EU regulation, instead, receives high scores from researcher 1 as it is very specific about the prescribed management practices, while it receives low scores from researcher 2 as it lacks a discussion of the principles and concepts behind these management requirements.

We did not attempt to harmonize the scoring method and criteria between the two researchers as the difference in assessment simply represents different conceptual understandings of what constitutes adherence to an organic principle. Researcher 1 put more emphasis on concrete requirements of regulations, thus favouring specific but sometimes reductionist regulations that do not allow room for interpretation; while researcher 2 emphasized more holistic regulations that sometimes lacked concrete rules. The average across the two scores therefore probably paints a more accurate picture than taking either score alone, as both approaches are legitimate.

Due to the strong influence of method on the results of this comparison, we cannot draw strong conclusions on how regulations differ in the degree to which they are representing and discussing organic principles. The sensitivity analysis does show some agreement, however – Mexico appears to be a country with a relatively strong discussion of organic principles, while the US has a weak discussion of organic principles, no matter the method used (Supplementary Table S5.1).

Comparison between organic principles

The comparison of organic principles within each regulation, instead, yielded remarkably similar results independent of researcher, scoring or weighting method used, despite the differences in assessment criteria by different researchers (Supplementary Table S5.2). Absence of synthetic inputs is the single most important principle in almost every one of the regulations examined (Table 5.5), ranked first by a wide margin in aggregate, receiving almost double the score as the second ranked principle. Animal welfare and human health receive similar scores, and their scores are again more than double that of the next principle (soil). The organic principles associated most with environmental sustainability, i.e. soil, water and biodiversity, are not very prominent in organic regulations. This picture does not differ much between different regulations (Table 5.5) or when different methods are used (Supplementary Table S5.2).

Table 5.5. Comparison of importance of organic principles within each regulation. See Table 5.2 for an overview of the different regulatory texts examined.

	Natural	**Animal**	**Human**	**Soil**	**Local**	**Biodiv**	**Water**
Mexico	2	1	4	5	3	7	6
IFOAM	1	7	2	3	6	5	4
Aus	1	6	3	4	7	5	2
Uganda	1	2	5	4	3	6	7
India	1	6	2	4	5	3	7
EU	1	2	3	5	4	7	6
US	1	2	3	4	7	6	5
FAO	2	1	3	4	7	6	5
Rank	1	2	3	4	5	6	7
Score	77	46	42	21	17	16	13

There are, however, some notable exceptions to this general picture. The Indian regulation stands apart in strongly emphasizing biodiversity, while the Australian regulation emphasizes water issues much more than other regulations (not surprising given the dry climate of Australia). Mexico and Uganda emphasize local issues more than other regulations, while the IFOAM, Indian and Australian regulations emphasize animal issues far less than other regulations. IFOAM, the most holistic but also least specific of the regulations, shows the highest rank for soil issues – a core idea of the original organic pioneers.

5.5 THE DEFINITION OF ORGANIC ACCORDING TO REGULATIONS

5.5.1 ORGANIC REGULATIONS ARE ABOUT ‘NATURAL’ VERSUS ‘SYNTHETIC’ INPUTS

Our examination of organic regulations highlights two major points:

1. There are no strong differences in the regulation of organic practices, or in the discussion of organic principles between different national and international organic regulatory texts.
2. The main principle underlying the regulation of organic management practices is the concept of ‘natural’ processes and inputs.

International trade in organic food has contributed significantly to a harmonization of organic regulations between different countries. Although there are still some differences between organic standards, these are minor compared to the similarities in the type of discourse about organic as well as in the specific practices prescribed in different organic regulations. As global trade in organic produce continues to increase, the need for equivalency or harmonization of organic regulations becomes more important. This is reflected in the on-going negotiations of equivalency agreements[34] as well as in the on-going work of the International Task Force on Harmonization and Equivalency in Organic Agriculture convened by IFOAM, FAO and UNCTAD (Giovannucci 2006). It is thus likely that the differences between organic regulations will continue to decrease in the future.

Despite the broader definitions used in preambles of organic regulatory texts (Padel *et al.* 2009), organic regulations are, in practice, regarding organic agriculture as a chemical-free management system, based on the avoidance of synthetic inputs, and reliance on natural substances instead. In all regulations the majority of management practices regulated and the majority of the texts are devoted to a discussion of allowed and prohibited inputs and these are typically discussed in the context of ‘natural’ versus ‘synthetic’ substances. ‘Natural’ substances are typically defined as those of animal or plant origin, as well as mined substances of low solubility, while ‘synthetic’ substances

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[34] The EU for example just signed an equivalency agreement with the US in 2012.

are “manufactured by chemical and industrial processes” and may “include products not found in nature, or simulation of products from natural sources” (IFOAM 2006, p. 13).

The organic principle of ‘natural’ does not, however, only relate to non-synthetic inputs. The idea of using natural *processes* to manage an organic system is also prominent in regulations; for example, the recommendation to use crop and animal species with high resistance to pests and diseases, or to use crop rotations and cover crops for crop nutrient management. Many regulations emphasize that the use of allowed substances should only be considered a last resort, when other measures have failed to achieve the intended management goal. The Australian standard, for example, states: “Inputs must not be used as a permanent measure to support a poorly designed or badly managed system. Non-essential use of inputs is counter to organic and bio-dynamic farming principles” (AUS 2009, p. 50).

In general, however, regulations tend to put a stronger emphasis on natural *substances* than natural *processes*. Typically regulations spend a couple of sentences stating that pest or soil fertility management or management of livestock health should be based on natural processes, after which they extensively discuss criteria and requirements for the use of allowed substances. In addition, the use of different natural processes is typically listed as recommended, and not as a required practice. For example, the European commission regulation (EU 2008) spends 40 words on the use of natural processes (e.g. high quality feed and exercise) for disease prevention in livestock, and then continues using more than 300 words to discuss requirements for the use of natural and synthetic veterinary treatments. The US NOP spends 65 words discussing the need to manage soil fertility and crop nutrient requirements using “rotations, cover crops, and the application of plant and animal materials” in order to “maintain or improve soil organic matter content in a manner that does not contribute to contamination of crops, soil, or water by plant nutrients, pathogenic organisms, heavy metals, or residues of prohibited substances”, and then discussing at length (using 450 words) requirements for what constitutes allowed inputs (USDA 2013).

5.5.2 ORGANIC REGULATIONS ARE NOT SETTING GOOD STANDARDS FOR ENVIRONMENTAL SUSTAINABILITY

Our analysis supports the frequent criticism that the codification of organic practices has led to a reductionist perspective of organic agriculture in regulations, focused on avoidance of synthetic inputs (Allen & Kovach 2000; Goodman 2000). The prohibition of synthetic inputs does not, by itself, constitute more environmental friendly management practices (Kirchmann & Bergström 2001; Bahlai *et al.* 2010). The avoidance of inorganic chemicals is not a sufficient condition for sustainability, and may not even be a necessary one (paraphrasing Hodges 1993, as cited in Rigby & Caceres 2001, p. 26). Management practices that have been identified as important components of sustainable agriculture - like permanent soil cover through cover and catch crops (Altieri & Rosset 1996; Tonitto *et al.* 2006), or the use of crop associations, and a mixture of crop varieties (Altieri & Rosset 1996; Zhu *et al.* 2000) - are, instead, typically not clearly regulated in organic regulations (see Table 5.6).

Some other concerns of sustainable agriculture are also mostly, or entirely, absent from organic regulations. Few of the regulations, for example, discuss water conservation, and none require specific irrigation practices, even though agriculture is the largest user of freshwater worldwide (Rosegrant *et al.* 2009), and increasing water use efficiency is a major concern for sustainable agriculture (Tilman *et al.* 2002). Only the Australian and Mexican regulations have detailed discussions of water management. The Australian regulation states that "where appropriate operators shall design, measure and monitor irrigation water application to minimise water loss" (AUS 2009, p. 16). It also requires farmers to ensure sufficient environmental flows if water is withdrawn directly from rivers. The Mexican regulation requires the farmer to specify, in the organic management plan, the type of measures to be implemented to conserve water and prevent pollution. It requires the producer to ensure water management in balance with regional water systems, and without influencing the flora or fauna dependent on this water (LPO 2013, Artículo 33). The IFOAM standard also mentions water management, stating that "operators shall not deplete nor excessively exploit water resources, and shall seek to preserve water quality" (IFOAM 2006, p. 15). The Indian and Ugandan regulations use these same IFOAM formulations, but without going into any further detail. All the other regulations examined – i.e. EU, US and the *Codex Alimentarus* - do not even mention irrigation or water management. In the scoring of organic principles water therefore received the lowest score of all organic principles (Table 5.5).

Table 5.6. Comparison of how different sustainable management practices identified by Altieri & Rosset (1996) are regulated in organic regulations. Red - the management practice is not discussed; orange - practice is discussed but not regulated, or its use is suggested but not required; green – its use is required. See Supplementary Table S5.4 for more details about how these practices are regulated.

	IFOAM	**FAO**	**Austr.**	**EU**	**US**	**India**	**Mex.**	**Ugan.**
Living mulch*	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Dead soil cover**	🟧	🟧	🟧	🟥	🟧	🟧	🟧	🟧
Cover Crops	🟧	🟥	🟥	🟥	🟩	🟧	🟩	🟧
Conservation tillage	🟧	🟥	🟧	🟧	🟧	🟥	🟧	🟧
Alley cropping	🟥	🟥	🟥	🟥	🟧	🟥	🟩	🟥
Agroforestry	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟥
Living Barriers***	🟥	🟥	🟧	🟥	🟥	🟥	🟧	🟥
Rotations	🟩	🟧	🟩	🟩	🟩	🟧	🟩	🟩
Crop Associations	🟧	🟥	🟧	🟥	🟧	🟧	🟩	🟩
Cultivar Mixtures	🟧	🟥	🟥	🟥	🟥	🟥	🟥	🟧
Animal integration	🟥	🟧	🟧	🟧	🟥	🟧	🟩	🟥

*a cover crop interplanted or undersown with the main crop
** mulching with dead biological or synthetic material
***a windbreak usually involving trees and/or shrubs

Another sustainability concern that is essentially absent from organic regulations is nutrient use efficiency. Regulations discuss organic agriculture as a farming system aimed at reduced nutrient losses, but they do not translate this goal into any concrete management requirements. Even though most organic regulations emphasize that the use of any nutrient inputs should only be considered as a last resort, and that the focus of nutrient management on organic farms *should* be on nutrient recycling rather than applying external inputs, organic regulations do not actually limit the *amount* of nutrient inputs. The European and the Mexican regulations limit the amount of animal manure applied to fields (to 170 and 500 kg of nitrogen per ha respectively), but they do not limit total nutrient inputs. The use of organic instead of synthetic nutrient inputs does not, however, by itself result in reduced loss of nitrogen or phosphorus from the system (Kirchmann & Bergström 2001; Rosen & Allan 2007). Nutrient efficiency in agriculture requires targeted nutrient management to reduce excess nutrient application by meeting crop nutrient demand as closely as possible (Berry *et al.* 2002; Chen *et al.* 2011).

This lack of concrete management requirements that relate to environmental sustainability appears rather paradoxical as the regulations often state that organic agriculture entails best environmental practices and is aimed at enhancing the environmental performance of agriculture. The US National Organic Standards Board (NOSB) writes for example (NOSB 2011, p. 30):

> An organic production system is designed to: Optimize soil biological activity; maintain long-term fertility; minimize soil erosion; maintain or enhance the genetic and biological diversity of the production system and its surroundings; utilize production methods and breeds or varieties that are well adapted to the region; recycle materials of plant and animal origin in order to return nutrients to the land, thus minimizing the use of non-renewable resources; minimize pollution of soil, water, and air.

In this definition, environmental outcomes are defined quite specifically and listed as the key goals of organic production. In the actual US regulation these concepts are, instead, almost entirely absent – soil principles are ranked as number 4 out of 8 principles in the US regulation, and biodiversity principles come almost last (Table 5.5).

It could be argued that some of the management methods associated with best environmental practices – like diversified crop rotations, integration of leguminous crops, or application of compost and crop residues – by default *have* to be part of an organic management system, as the prohibition of chemical nutrient inputs and pesticides - as regulated in organic standards – *requires* reverting to such practices to achieve good crop and animal production. In practice, however, it is perfectly possible to manage a farming system without chemical inputs but also without using sustainable management practices. Many examples show that organic farms, especially large-scale organic production, can rely on 'natural' but external inputs like animal manure and allowed organic fertilizers and pesticides, without adopting other sustainable management practices (Guthman 2000; Guthman 2004).

5.5.3 ORGANIC REGULATIONS ARE NOT WHAT ORGANIC PIONEERS WOULD HAVE ENVISIONED

Sir Albert Howard was arguably one of the most important figures of the original organic movement. Joseph Heckman, in a review of the history of organic agriculture, writes that "Sir Albert Howard would likely be dissatisfied with the current status of the organic movement" (Heckman 2006, p. 148). The ideas of Howard and other organic pioneers can be summarized as three key concepts:

1. A prosperous human society depends on respecting the rules that govern 'Nature'.
2. The concept of health is dependent on a healthy soil, which leads to healthy plants and animals, and in turn to healthy humans and a healthy society. Soil fertility therefore lies at the center of good agriculture.
3. Soil fertility is dependent on the 'Law of Return', i.e. the principle of returning to the soil what is taken from it, and on the preservation of 'humus'.

The conceptualization of organic agriculture in today's regulations differs in substantial ways from all three of these key concepts.

'Nature' was the idol of the organic philosophy – she represented the standard that human activities needed to mirror as closely as possible. The ideas of 'natural' versus 'artificial' developed by organic pioneers can be traced back to a religious philosophy of life that proclaimed the need to follow the rules of ‘Nature’ as given by God (Conford 2001) - an “obedience to the laws by which the world is governed” (Conford 2001, a writer to Sir Albert Howard’s journal ‘Soil and Health’, p. 92). Howard would have agreed with the prohibition of synthetic inputs in today’s organic regulations, as “artificial manures lead inevitably to artificial nutrition, artificial food, artificial animals, and finally to artificial men and women” (Howard 1943, chapter 3, para. 16).

Howard and other organic pioneers had, however, a more holistic understanding of health and of ‘natural’ than current organic regulations. The concept of ‘natural’ went beyond the avoidance of ‘artificial manures’ to understand and follow the rules of ‘Nature’ (Howard 2006, p. 194):

> The first duty of the agriculturist must always be to understand that he is part of Nature and cannot escape from his environment. He must therefore obey Nature’s rules.

Avoiding ‘artificial manures’ would therefore by itself not lead to healthy food, but human health was based on the fertility of the soil, as only a fertile soil would produce healthy and nutritious food. For organic pioneers like Albert Howard and Eve Balfour soil was at the centre of the organic philosophy (Howard 1943; Balfour 1950). Even many of the social and political ideas encapsulated in the organic movement were centred around soil - “wealth, welfare, prosperity and even the future freedom of this nation are based upon the soil” (Louis Bromfield, 1945, as cited in Conford 2001, p. 105).

Howard starts his ‘*An Agricultural Testament*’ with the sentence “The maintenance of the fertility of the soil is the first condition of any permanent system of agriculture” (Howard 1943, chapter 1, para. 1). Howard included other ideas in his writings – like social justice, animal nutrition, and crop diseases - but the soil was what connected them all, and humus lay at the center of it. Howard’s version of today’s organic regulation would probably have dedicated most of its rules and standards to good soil management practices and nutrient recycling. In today’s organic regulations soil is, instead, a concept that ranks far lower than other principles (Table 5.5), and key soil terminology used by organic pioneers like humus, composting, organic matter, and soil fertility is almost entirely absent.

The final point where Howard would probably have disagreed with current organic regulations concerns his ‘Law of Return’. One of the core rules that Howard observed in the ancient traditional farming systems of South Asia that he admired – most prominently the farming system of the Hunzas in Pakistan – was that “the very greatest care is taken to return to the soil all human, animal, and vegetable wastes after being first composted together” (Howard 1943, chapter 12, para. 10). He therefore proclaimed that a sound agriculture was not possible without returning to the soil what was removed from it through harvest. Howard is often referred to as the ‘father of modern composting’, as the study of different composting methods was a central element of his work. Composting was not only the best way to increase soil fertility and foster soil biological activity, but also allowed the recycling of urban wastes for use in rural agriculture – one of “Howard’s favourite projects” (Conford 2001, p. 86).

Organic regulations today are, instead, rather ambiguous about the use of human excrements or sewage sludge due to food safety concerns. Some regulations (e.g. US, EU, Uganda) do not allow any use of human wastes. Other regulations prohibit the use of sewage sludge but allow the use of human excrements on non-edible crops (e.g. Mexico), while some countries prohibit the use of human excrements but allow the use of treated sewage sludge (e.g. India, Australia). Supplementary Table S5.3 provides an overview of how sewage sludge, human excrements and municipal solid wastes are regulated in different organic standards.

Many current debates about what constitutes sustainable agricultural management are consistent with Howard’s idea that soil health lies at the core of sustainable agriculture (Parr *et al.* 1992; Doran 2002), and that closing nutrient cycles in agriculture - especially regarding the P cycle, where we know we are hitting limits in availability – is an important environmental goal (Tilman *et al.* 2002; Cordell *et al.* 2009).

Critics of organic agriculture have argued that there are not sufficient organic nutrient sources available for organic agriculture to be scaled up (Connor 2008). Such criticism is based on estimates of nutrient availability through leguminous crops, it does not account for potential nutrients available from recycling of plant residues, animal and human wastes. Leguminous crops, however, never featured especially prominently in Howard's work. Howard's ideas about organic nutrient management were centered around the 'Law of Return' and nutrient recycling. If organic agriculture is scaled up further, it might *have* to rely on human wastes, not only to improve nutrient recycling, but also to access sufficient nutrients.

5.5.4 THE DEFINITION OF ORGANIC AGRICULTURE IN REGULATIONS IS DRIVEN BY CONSUMERS

People have argued that organic agriculture is a strongly consumer-driven sector (Fromartz 2007). The reason why organic agriculture is defined in a limited way in regulations can directly be traced back to the primary motivations of consumers to buy organic produce. Organic regulations focus on the discussion and regulation of 'natural' versus 'chemical' inputs, because they are primarily formulated to meet the consumer demand for healthy, chemical-free 'natural' food.

Studies on organic consumers typically identify a large range of motives for buying organic food but the most common reason is for health and pleasure (Zanoli & Naspetti 2002; Hughner *et al.* 2007). The healthiness of organic food is typically associated with the absence of chemical residues, as well as a higher nutritional value of organic food (Hughner *et al.* 2007). This focus on health as the main motive for organic consumers is consistent across different regions of the world (Davies *et al.* 1995; Chang & Zepeda 2005; Dahm *et al.* 2009; Sirieix *et al.* 2011).

The importance of consumer perceptions and demand for the formulation of organic standards are sometimes very clearly stated in organic regulations. Several regulations (e.g. Mexico and Australia) state the production of food of high nutritional quality as the first principle of organic agriculture. While many of the regulations mention that processing aids and food additives used should not impair the 'authenticity' of the organic product (e.g. FAO & WHO 2001, p. 11; Aus 2009, p. 39; IFOAM 2007, p. 58 & p. 64). The Australian standard for example explains that: "The use of additives and processing aids of non-agricultural origin included in the Annexes, takes into account the expectations of consumers that processed products from organic production systems should be composed essentially of ingredients as they occur in nature" (Aus 2009, p. 39).

In many countries the formulation of organic standards has been the outcome of a long process during which different stakeholder groups were consulted, and public comments received (Vos 2000; Padel *et al.* 2009). A first draft of the US NOP, for example, received more public comments than any previous USDA regulation. Most of these comments concerned the list of allowed substances (Friedland 2005).

In the EU a revision of organic standards is currently under way. A first draft was released for comments in early 2014, and received strong criticism from farmer groups. The draft included more strict rules on contamination of organic products (e.g. requiring residue-testing for baby food, and lowering the levels of allowed residues to be found in organic products), as well as the elimination of exemptions allowed in the current version (e.g. the use of in-conversion feed or of non-organic seeds), as well as a strengthening of the control system. As justification for revising the standards, the European Commission stated the interest of consumers in pesticide-free food and the need to improve consumer confidence in organic products (EU 2014b).

5.6 PUTTING THE ENVIRONMENT INTO ORGANIC REGULATIONS

If organic agriculture is to be a more sustainable farming system contributing to positive environmental and social change (Allen & Kovach 2000), environmental best practices need to be regulated more explicitly. An organic standard that is more strongly aimed at achieving environmental sustainability could, for example, require a minimum amount of leguminous crops in rotations, require a detailed crop rotation plan[35] specifying a minimum diversity of crops required in a rotation, require the use of a diverse set of crop varieties to ensure high genetic diversity, or limit the amount of off-farm nutrient inputs. Some practices that are already required in some countries (e.g. the setting aside of a certain portion of the farmland as conservation area in Australia, the prohibition of clearing of primary vegetation in Uganda and India, or the need for multi-storey cropping systems including native species in areas where the primary vegetation is rainforest in the Mexican regulation) should be adopted in other countries. In order to better represent the ideas of organic pioneers, organic standards should focus on requiring closed nutrient cycling by, for example, encouraging integrated crop-livestock systems, allowing the use of (appropriately treated) human wastes and municipal composts, limiting the amount of off-farm inputs, or by monitoring soil fertility standards.

Better specifying environmental best practices in organic regulations would not only increase the sustainability of organic farming systems, but could also contribute to increasing consumer trust in the organic label and could allow for increased growth of the organic sector by meeting the demands of a more diverse group of consumers. Even though 'health' is the most common motive for organic consumers, altruistic values of environment, animal welfare and societal well-being are still of importance to at least some organic consumers today (Zanoli & Naspetti 2002); 30% of English respondents (Hutchins & Greenhalgh 1995), 50% in Germany (Oltersdorf 1983), and 85% in Ireland (Davies *et al.* 1995) stated, for example, that they bought organic food mainly or partly for environmental reasons. Stobbelaar *et al.* (2007) found that environmental friendliness was the characteristic that adolescents in the Netherlands associated most strongly with organic agriculture, even over being healthier.

Even though organic regulations are formulated primarily with the consumer in mind, this does not mean that they actually succeed in providing a clear label that consumers understand and trust. One of the main barriers to organic consumption is confusion and lack of knowledge about the different organic labels used and their meaning (Hutchins &

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[35] As the Mexican regulation already does.

Greenhalgh 1995; Padel & Foster 2005; Janssen & Hamm 2012). Consumers typically only understand the key characteristics of organic farming – which is free of pesticides, chemical fertilizers, and antibiotics – but do not know about any further differences between organic and conventional food, or about the certification process (Hill & Lynchehaun 2002; Padel & Foster 2005). But studies have shown that consumers are willing to pay higher prices for products with a clearly identified additional value (Zander & Hamm 2010). The more information is provided about an organic product, the more people are willing to buy it and pay a higher price for it (Soler *et al.* 2002; Stolz *et al.* 2011). Organic literacy is therefore key to further acceptance of organic food - "retailers need to educate consumers about the organic story" (Hill & Lynchehaun 2002, p. 533). Setting clear environmental standards that can be communicated to consumers therefore has the potential to lead to a wider acceptance of organic products as well as to increase the willingness of consumers to pay organic premium prices.

5.7 CONCLUSIONS

Organic agriculture appears to be caught between different and often opposing interests and watered-down by a multitude of different meanings. The result is a rather one-dimensional interpretation of organic agriculture in regulations. As the organic market continues to grow, and as more farmers enter organic production, and a larger, and more diverse group of consumers demand cheap chemical-free food, there is a risk that organic agriculture will be reduced even more to the lowest common denominator between the different interest groups, i.e. absence of synthetic substances. The original idea of organic being environmentally friendly farming is in danger of being lost.

Organic regulations are the place where organic agriculture is defined today. Organic regulations should therefore be very clear about what the goal of organic agriculture is. If organic agriculture is to primarily deliver chemical-free food to consumers, organic regulations should include more product standards (e.g. food safety, residue-free food) rather than prescribing process standards, as they do today. If organic agriculture is, instead, to stay truer to its original ideas and include a holistic understanding of ecosystem and human health and more sustainable (soil) management practices, organic regulations should include more environmental best practices in its process standards. Organic regulations need to find the delicate balance between being simple enough so they can be easily standardized and monitored, but complex enough to incorporate diverse view points and context dependencies; and all of this has to be achieved without watering down organic standards to an ‘organic lite’ with which no one is satisfied and that is not trusted by consumers.

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SUPPLEMENTARY MATERIAL

Table S5.1. Sensitivity analysis of comparison of organic principles between regulations. Weighting method 1 uses relative word count as weighting factor; weighting method 2 uses the square of the relative word count as weighting factor; scoring 1 method uses scores of 0, 0.5 and 1; scoring method 2 uses scores if 0 or 1.

Method	Mex	IFOAM	Aus	Ugan	India	EU	US	FAO
Researcher 1, scoring 1, unweighted	2	7	5	3	4	1	8	5
Researcher 2, scoring 1, unweighted	2	1	3	4	4	7	6	8
Researcher 1, scoring 1, weighting 1	2	6	7	5	3	1	8	4
Researcher 2, scoring 1, weighting 1	3	2	4	6	1	8	5	7
Researcher 1, scoring 1, weighting 2	3	5	6	7	2	1	8	4
Researcher 2, scoring 1, weighting 2	3	2	4	8	1	6	5	7
Researcher 1, scoring 2, unweighted	3	6	6	1	4	1	8	4
Researcher 2, scoring 2, unweighted	2	1	2	2	5	6	7	8

Table S5.2. Sensitivity analysis of the comparison of organic principles within regulations. Weighting method 1 uses relative word count as weighting factor; weighting method 2 uses the square of the relative word count as weighting factor; scoring 1 method uses scores of 0, 0.5 and 1; scoring method 2 uses scores if 0 or 1.

Method	Natural	Human	Animal	Soil	Local	Biodiv	Water
Researcher 1, scoring 1, unweighted	1	2	3	5	5	4	7
Researcher 2, scoring 1, unweighted	1	5	2	4	7	3	6
Researcher 1, scoring 1, weighting 1	1	2	3	4	5	6	7
Researcher 2, scoring 1, weighting 1	1	3	2	4	6	5	7
Researcher 1, scoring 1, weighting 2	1	2	3	4	5	6	7
Researcher 2, scoring 1, weighting 2	1	3	2	4	5	6	7
Researcher 1, scoring 2, unweighted	1	2	3	5	5	4	7
Researcher 2, scoring 2, unweighted	1	5	2	4	7	3	6

Table S5.3. Comparison of regulation of human wastes in different organic regulatory texts.

	US	**EU**	**FAO**	**IFOAM**	**Aus**	**India**	**Uganda**	**Mexico**
Sewage sludge	Not allowed	Not part of list of allowed substances, not allowed	Not mentioned specifically, included in human excrements	Not mentioned specifically, included in human excrements	After treatment; to non-edible crops & pastures; to crops for human consumption only through trickle irrigation & precluding contact with edible parts	From separated sources, monitored for contamination	/	Not allowed
Human excrements	/	Not part of list of allowed substances, not allowed	Only from separated sources, monitored for contamination, treated to eliminate risks, not on edible crops	Only on non-edible crops; exceptions may be made	/	Not allowed	Not allowed	If composted not applied t edible crops
Municipal solid wastes (i.e. urban composts)	Not mentioned specifically, included in compost	Only from separated sources, after treatment, monitored for contamination, below defined limits of metal concentrations	Sorted, composted or fermented	From separated sources, monitored for contamination	Not mentioned specifically, included in compost	From separated sources, monitored for contamination	From separated sources, monitored for contamination	Only after treatment, monitored fo contaminatio below define limits of met concentratio

Table S5. 4. Comparison of regulation of environmental best practices, as identified by Altieri & Rosset (1996, see reference in main article), in different organic regulatory texts.

Sustainable management practice	US		EU	
	Regulated	**Wording**	**Regulated**	**Wording**
Living mulch*	Not discussed	/	Not discussed	/
Dead soil cover/mulch	Use suggested	§205.206 Weed problems may be controlled through (1) Mulching with fully biodegradable materials	Not discussed	/
Cover Crops	Use required	§205.203 The producer must manage crop nutrients and soil fertility through rotations, cover crops, and the application of plant and animal materials. §205.205 The producer must implement a crop rotation including but not limited to sod, cover crops, green manure crops, and catch crops that provide the following functions that are applicable to the operation: (...)	Not discussed	/
Conservation tillage	Use suggested (unclear wording)	§205.203 The producer must select and implement tillage and cultivation practices that maintain or improve the physical, chemical, and biological condition of soil and minimize soil erosion.	Use suggested (unclear wording)	EU 2007, Article 12 - (a) organic pla production shall use tillage and cultivation practices that maintain or increase soil organic matter, enhance stability and soil biodiversity, and pr soil compaction and soil erosion;
Alley cropping	Use suggested for perennial crops	Definitions - Perennial cropping systems employ means such as alley cropping, intercropping, and hedgerows to introduce biological diversity in lieu of crop rotation.	Not discussed	/
Agroforestry	Not discussed	/	Not discussed	/
Living Barriers**	Not discussed	/	Not discussed	/

Rotations	Use required	§205.203 The producer must manage crop nutrients and soil fertility through rotations, cover crops, and the application of plant and animal materials. §205.205 The producer must implement a crop rotation including but not limited to sod, cover crops, green manure crops, and catch crops that provide the following functions that are applicable to the operation: (a) Maintain or improve soil organic matter content; (b) Provide for pest management in annual and perennial crops; (c) Manage deficient or excess plant nutrients; and (d) Provide erosion control.	Use required	EU 2007, Article 12 -(b) the fertility biological activity of the soil shall be maintained and increased by multiar crop rotation including legumes and green manure crops (…);
Crop Associations	Use suggested for perennial crops	Definitions - Perennial cropping systems employ means such as alley cropping, intercropping, and hedgerows to introduce biological diversity in lieu of crop rotation.	Not discussed	/
Cultivar Mixtures	Not discussed	/	Not discussed	/
Animal integration	Not discussed	/	Not regulated	EU 2008, preamble - The holistic approach of organic farming requires livestock production related to the la where the produced manure is used nourish the crop production.

Table S5.4 continued.

Sustainable management practice	Australia		India	
	Regulated	Wording	Regulated	Wording
Living mulch*	Not discussed	/	Not discussed	/
Dead soil cover/mulch	Use suggested	3.8 Where used, mulches should be of natural materials. 3.8.1 Pests, diseases and weeds must be controlled by any combination of the following: (h) mulching and mowing	Use suggested	3.2.5 Weeds, pests and diseases should be controlled by a number of preventive cultural techniques which limit their development, e.g. suitable rotations, green manures, a balanced fertilising programme, early and predrilling seedbed preparations, mulching, mechanical control and the disturbance of pest development cycles.
Cover Crops	Not discussed	/	Use suggested	3.2.3 Diversity in crop production is achieved by a combination of: - an appropriate coverage of the soil during the year of production which diverse plant species
Conservation tillage	Use suggested (unclear wording)	3.5.1 The fertility and the biological activity of the soil must be maintained or increased by any combination of the following methods: (e) tillage techniques which preserve or improve soil structure.	Not discussed	/
Alley cropping	Not discussed	/	Not discussed	/
Agroforestry	Not discussed	/	Not discussed	/
Living Barriers**	Use suggested	3.4.2 Operators must develop 5% of their property as treed areas, grasslands or other reserves which are non-cultivated and nonintensively grazed within five years from the date the production unit attains in-conversion status. 3.4 An organic production unit can enhance biodiversity by: (c) provision of wind breaks and non-cultivated buffer zone areas.	Not discussed?	3.1.3 Areas which should be managed properly and linked to facilitate biodiversity: - Extensive pastures, meadows, extensive grassland, extensive orchards, hedges, hedgerows, groups of trees and/or bushes and forest lines. The certification programme shall set standards for a minimum percentage of the farm area to facilitate biodiversity and nature conservation.

Rotations	Use required	3.7.4 Crop rotations aid long-term soil fertility and ensure healthy plants. Operators shall include deep rooted and leguminous species within crop rotations.	Use suggested (crop diversity in space or time)	3.2.3 Diversity in crop production is achieved by a combination of: - a versatile crop rotation with legumes3.2.3.1. Where appropriate, the certification programme shall require that sufficient diversity is obtained in time or place in a manner that takes into account pressure from insects, weeds, diseases and other pests, while maintaining or increasing soil, organic matter, fertility, microbial activity and general soil health. For non perennial crops, this is normally, but not exclusively, achieved by means of crop rotation.
Crop Associations	Use suggested (unclear wording)	3.7 The proper choice of variety, stimulation of soil fertility, careful sowing and cultivation techniques (e.g. rotation, variety, use of mixed cropping, plant spacing, use of green manures) hinders the incidence of pests and diseases.	Use suggested (crop diversity in space or time)	3.2.3.1. Where appropriate, the certification programme shall require that sufficient diversity is obtained in time or place in a manner that takes into account pressure from insects, weeds, diseases and other pests, while maintaining or increasing soil, organic matter, fertility, microbial activity and general soil health. For non perennial crops, this is normally, but not exclusively, achieved by means of crop rotation.
Cultivar Mixtures	Not discussed	/	Not discussed	/
Animal integration	Not regulated	3.8 Livestock are an integral part of a broad acre organic farming system.	Not regulated	3.1.1 For a sustainable agro-ecosystem to function optimally, diversity in crop production and animal husbandry must be arranged in such a way that there is an interplay of all the elements of the farming management.

Table S5.4 continued.

Sustainable management practice	IFOAM		FAO	
	Regulated	Wording	Regulated	Wording
Living mulch*	Not discussed	/	Not discussed	/
Dead soil cover/mulch	Use suggested	4.5 Pests, diseases and weeds should be managed by the knowledgeable application of one, or a combination, of the following measures: (j) mulching and mowing;	Use suggested	Annex 1.A.6 - Pests, diseases and weeds should be controlled by any one, or a combination, of the following measures: - mulching and mowing;
Cover Crops	Use suggested	2.2 Operators should minimize loss of topsoil through minimal tillage, contour plowing, crop selection, maintenance of soil plant cover and other management practices that conserve soil. 4.3 Diversity in crop production is achieved by a combination of: (b) appropriate coverage of the soil with diverse plant species for as much of the year as possible.	Not discussed	/
Conservation tillage	Use suggested	2.2 Operators should minimize loss of topsoil through minimal tillage, contour plowing, crop selection, maintenance of soil plant cover and other management practices that conserve soil.	Not discussed	/
Alley cropping	Not discussed	/	Not discussed	/
Agroforestry	Not discussed	/	Not discussed	/
Living Barriers**	Not discussed	/	Not discussed	/

Rotations	Use required	4.3 Diversity in crop production is achieved by a combination of: (a) a diverse and versatile crop rotation that includes green manure, legumes and deep rooting plants; 4.3.1 Diversity in plant production and activity shall be assured by minimum crop rotation requirements and/or variety of plantings. Minimum rotation practices for annual crops shall be established unless the operator demonstrates diversity in plant production by other means.	Use suggested	Annex 1.A.5 - The fertility and biological activity of the soil should be maintained or increased, where appropriate, by: a) cultivation of legumes, green manures or deep-rooting plants in an appropriate multi-annual rotation programme;
Crop Associations	Use suggested (unclear wording)	4.3.1 Diversity in plant production and activity shall be assured by minimum crop rotation requirements and/or variety of plantings. Minimum rotation practices for annual crops shall be established unless the operator demonstrates diversity in plant production by other means.	Not discussed	/
Cultivar Mixtures	Use suggested (unclear wording)	4.3.1 Diversity in plant production and activity shall be assured by minimum crop rotation requirements and/or variety of plantings. Minimum rotation practices for annual crops shall be established unless the operator demonstrates diversity in plant production by other means.	Not discussed	/

Animal integration	Not discussed	/	Not regulated	Annex 1.B.2 - Livestock can make an important contribution to an organic farming system by: a) improving and maintaining the fertility of the soil; b) managing the flora through grazing; c) enhancing biodiversity and facilitating complementary interactions on the farm; and d) increasing the diversity of the farming system.

Table S5.4 continued.

Sustainable management practice	Uganda Regulated	Uganda Wording	Mexico Regulated	Mexico Wording
Living mulch*	Not discussed	/	Not discussed	/
Dead soil cover/mulch	Use suggested	2.6.2 Pests, diseases and weeds should be managed by the knowledgeable application of one, or a combination, of the following measures: - Mulching and mowing	Use suggested	ARTÍCULO 47.- Los operadores orgánicos que te en su unidad de producción hierbas no deseadas realizarán preferentemente su retiro manual o mecánico de la hierbas y utilizarán herramientas adecuadas, acolchados, cubiertas (contra biotransmisores), cultivos de cobertura tales com leguminosas y vegetales silvestres.
Cover Crops	Use suggested	2.4.2 Diversity in crop production is achieved by a combination of: - appropriate coverage of the soil with diverse plant species for as much of the year as possible	Use required	ARTÍCULO 24.- De acuerdo con las condiciones factores ambientales, así como las particulares d unidad de producción, se deberá prevenir o redu erosión del suelo utilizando técnicas agroecológi apropiadas de conservación como son entre otra Los cultivos de cobertura. ARTÍCULO 27.- Los operadores orgánicos, deber aplicar prácticas agronómicas para que el suelo permanezca cubierto con una capa vegetal la ma parte del tiempo, de acuerdo a sus condiciones agroecológicas.
Conservation tillage	Use suggested	1.2.2 Operators should minimise loss of topsoil through minimal tillage, contour ploughing, crop selection, and rotation maintenance of soil plant cover and other management practices that conserve soil.	Use suggested	ARTÍCULO 24.- De acuerdo con las condiciones factores ambientales, así como las particulares d unidad de producción, se deberá prevenir o redu erosión del suelo utilizando técnicas agroecológi apropiadas de conservación como son entre otra La labranza de conservación. ARTÍCULO 42.- La producción vegetal orgánica estar orientada a: II. Fomentar e implantar práct labranza y cultivo que mantengan, mejoren o incrementen la materia orgánica del suelo que refuercen la estabilidad y biodiversidad edáficas, prevengan la compactaci erosión del suelo;

Alley cropping	Not discussed	/	Use required (in areas where native vegetation is forest)	ARTÍCULO 26.- En las zonas donde la vegetació original o nativa la constituyan bosques o selvas, operación orgánica deberá establecer en las área cultivo, sistemas diversificados con dos o más est vegetales de especies nativas, especialmente en l cultivos perennes.
Agroforestry	Not regulated	2.6.2 Pests, diseases and weeds should be managed by the knowledgeable application of one, or a combination, of the following measures: - Diversified ecosystems. For example buffer zones to counteract erosion, agro-forestry, rotating crops, intercropping etc.	Use required (in areas where native vegetation is forest)	ARTÍCULO 26.- En las zonas donde la vegetació original o nativa la constituyan bosques o selvas, operación orgánica deberá establecer en las área cultivo, sistemas diversificados con dos o más est vegetales de especies nativas, especialmente en l cultivos perennes.
Living Barriers**	Not discussed?	1.1.2 The operators should maintain a significant portion of their farms in order to facilitate biodiversity and nature conservation of their areas - In general all areas which are not under rotation and are not heavily manured: extensive pastures, meadows, extensive grassland, extensive orchards, hedges, hedgerows, edges between agriculture and forest land, groups of trees and/or bushes, and forest and woodland	Use suggested	ARTÍCULO 24.- De acuerdo con las condiciones factores ambientales, así como las particulares d unidad de producción, se deberá prevenir o redu erosión del suelo utilizando técnicas agroecológi apropiadas de conservación como son entre otra barreras vivas o muertas;

Rotations	Use required (crop diversity in space or time)	2.4.2 Diversity in crop production is achieved by a combination of: - a diverse and versatile crop rotation that includes green manure, legumes and deep rooting plants 2.4.3.1 Diversity in plant production shall be assured by a crop rotation and/or variety of plantings through interplanting. 2.6.2 Pests, diseases and weeds should be managed by the knowledgeable application of one, or a combination, of the following measures: - Choice of appropriate species and varieties appropriate rotation programs	Use required (crop diversity in space or time)	ARTÍCULO 38.- Las rotaciones de cultivos, asoci y/o cultivos mixtos e intercalados, deben ocupar lugar prioritario en los planes orgánicos, como u estrategia para evitar agotar los nutrientes del su ayudar al desarrollo de la resistencia natural a pl enfermedades del suelo. ARTÍCULO 39.- La planeación de las rotaciones, asociaciones y/o cultivos mixtos e intercalados, estar orientada a prevenir la erosión, mantener l fertilidad del suelo, reducir el lavado o lixiviació nutrientes y los problemas ocasionados por plag enfermedades y hierbas no deseadas. ARTÍCULO 41.- El operador deberá plasmar en s Orgánico, de rotación de sus cultivos, la naturale las especies, la presencia de hierbas, las condicio locales y las necesidades de producción o consu entre otras y para el caso de las parcelas utilizad pastoreo, las rotaciones deben incluir a las leguminosas, así como de la promoción de los sis agrosilvopastoriles.
Crop Associations	Use required (crop diversity in space or time)	2.4.3.1 Diversity in plant production shall be assured by a crop rotation and/or variety of plantings through interplanting. 2.6.2 Pests, diseases and weeds should be managed by the knowledgeable application of one, or a combination, of the following measures: - Diversified ecosystems. For example buffer zones to counteract erosion, agro-forestry, rotating crops, intercropping etc.	Use required (crop diversity in space or time)	ARTÍCULO 40.- Para el caso de que no sea posib rotación, se debe promover la diversificación de especies mediante asociaciones y/o cultivos mixt intercalados, para mejorar la fertilidad del suelo biodiversidad.
Cultivar Mixtures	Use suggested	2.1.2 A wide range of crops and varieties should be grown to enhance the sustainability, self-reliance and biodiversity value of organic farms. Plant cultivars suitable for organic production should be selected to maintain both genetic diversity and biodiversity.	Not discussed	/

Animal integration	Not discussed	/	Use required	ARTÍCULO 28.- La producción animal orgánica contribuir al equilibrio de la producción vegetal forestal, satisfaciendo las necesidades de nutrien las especies vegetales.

6. SYNTHESIS AND CONCLUDING REMARKS

"*When we discover in this world no rock or earth to stand or walk upon but only shifting sea and sky and wind, the mature response is not to lament the loss of fixity but to learn to sail.*" - James Boyd White

6.1 REFLECTION ON METHODS

I want to start this synthesis of my thesis with a brief reflection on methods. My thesis has been a very instructive journey, not necessarily because of the answers I found, but mostly because of the limitations in my ability to understand our world that I was confronted with. I set out with a question, looking for answers. But on the way I did not necessarily find new answers but rather I found many more new questions and new doubts about the answers I already thought I had. Now, at the end of a six year process, I feel less certain about most things than I was at the beginning of this journey.

I therefore want to briefly reflect here on some of the most important things I learned while researching and writing this thesis, trying to summarize some of my thoughts on scientific inquiry and the ways we can know the world. In doing this I will not refer to the big thinkers who have written about these issues in more thoughtful, intelligent and sophisticated ways. I do not think I could do justice to them due to my limited and incomplete exposure to their work. Instead, this is a personal reflection.

6.1.1 QUANTITATIVE VERSUS QUALITATIVE METHODS

In this thesis I have tried to integrate both quantitative and qualitative methods. I have had both positive and frustrating experiences with both of these tools of inquiry.

Quantitative methods can be very insightful as they allow depicting patterns across a multitude of data points. Especially tools like meta-analysis, which represent a synthesis of thousands if not millions of individual measurements, can be very powerful as they allow examining a question across various different contexts and thus allow finding patterns that were not visible when studying a single case. Think of the beauty of a nice graph depicting a clear pattern across a multitude of data points!

Quantitative methods are, however, also frustrating because you know that they are overlooking and hiding so many of the complexities and nuances of the story. With quantitative methods you can get at the question of what is happening, the data will tell you about patterns in the world, but it is very difficult to understand the 'Why?'. You also know that the patterns revealed by number crunching and statistical analysis are telling a very simplified story, missing out on many details and exceptions to the general rule. The quantitative graph allows you to see the general pattern, but you are not necessarily able to understand what is causing this pattern, nor are you able to understand what is happening in the particular case of that single outlier in the right-top corner of the graph.

My fieldwork using qualitative methods (Chapter 4) has been one of the most instructional and informative experiences I have ever had. I learned so much, I could ask any questions I wanted, I could follow my curiosity, and try to really understand the system I was working in. But qualitative methods are also frustrating at times - you can learn about all the intricacies and complexities of a system, but it is very difficult to make any generalizations. By revealing all the nuances and myriads shades of grey in the picture, qualitative methods make it difficult to find those general patterns that quantitative methods are so good at detecting. For all the beauty and fascination of the individual trees you become blind for the forest in its entirety.

Considering the limitations of quantitative and qualitative methods by themselves, you would think that a combination of the two should be very useful as it can complement the strengths of both approaches. But unfortunately it is not that easy.

In my experience, the combination of qualitative and quantitative methods in the same study can be very difficult. If the study is aimed primarily at providing qualitative data, then the quantitative data collected alongside the qualitative will not be as useful for making generalizations, as the study design was not set out with a quantitative analysis in mind. While the qualitative part of the study also becomes weaker when the researcher tries to increase the sample size to collect more quantitative data, which comes at the expense of the quality of the individual interviews conducted. In addition, the rich content of individual interviews makes it more difficult to find generalizations, as your knowledge of the nuances of each story makes you aware what a simplification the larger black and white picture actually is. The more exceptions to the rule you see, the more sceptical you become as to the validity of the rule. In reality, almost none of the points in a quantitative graph are actually directly on the regression line.

6.1.2 BIAS AND PARADIGMS

One of the biggest strengths of qualitative and social modes of inquiry is, in my opinion, its high awareness of bias. Bias comes into play at every step of the scientific process. No matter whether it is using qualitative or quantitative methods - you can only see the things that you are looking for; you can only understand processes that you have some prior knowledge about; and you interpret what you see based on your personal values and beliefs. Quantitative methods try to reduce this bias by reverting to the apparent objectivity of statistical algorithms and testable hypotheses. But this purported objectivity leads to an unawareness of bias and a lack of critical examination of the role of the researcher in the research process, and of the importance of unquestioned paradigms inherent in each discipline.

In the discussion of organic agriculture and sustainable food security I purposefully drew a boundary, limiting my analysis to an agriculture perspective of the issue. But agriculture is, of course, not separated from the broader environmental, social, and political food system it is embedded in. By drawing this boundary I, by default, excluded important variables from the equation. By focusing on agriculture (i.e. an anthropogenically managed ecological system) I simplified the question of global sustainable food security to a mostly biological issue, that can supposedly be examined through scientific methods of inquiry, rather than a political issue that requires social modes of inquiry. By drawing this boundary I am assuming that management practices are central to addressing sustainability and food security challenges, thus subscribing to a certain paradigm. Even though I tried to conduct my thesis research through an interdisciplinary lens, the inclusion of farmer livelihood and policy aspects still is limited to a farm-level analysis, focusing on agricultural production systems, and thus represents a simplification of the issue to (more tangible) questions of management practices and their consequences rather than (more complex) broader political and social questions of distribution, power, and justice.

One way of dealing with bias is to attempt to be aware of it, and to clearly state the assumptions and paradigms our research is based on. Even just posing the question of yield performance is based, for example, on the premise that yields matter. The choice of this topic (rather than say the examination of resilience) takes a productionist view of agricultural systems, assuming that the productivity is at least as important as other potential variables of interest. In addition, analysing yields emphasises production strategies rather than distribution strategies to address global sustainable food security. Another paradigm underlying the agricultural perspective I am taking is the assumption that we need to improve farmer livelihoods. This assumes that smallholder agriculture is viable and deserves support in an increasingly globalized and industrialized world. Finally, my thesis is based on the assumption that we need to decrease the environmental footprint of agriculture, which assumes that the health of the environment has an intrinsic or extrinsic (i.e. anthropogenic) value. The analyses conducted in this thesis are thus the result of a certain system of beliefs, and are only valid within this system.

6.1.3 SCIENCE WITH SUBOPTIMAL TOOLS

Given the limitations of the scientific tools that we use to understand the world around us, how can we actually learn anything about it? The first, I think, is to acknowledge the limitations in our ability to understand the world. To acknowledge how difficult it is to be able to make any conclusions at all. To acknowledge that science is an inherently iterative process, where an end is never reached, but where every new conclusion is actually just a hypothesis to be confirmed or rejected by further research, and where every new answer opens up even more new questions. The second approach that allows us to produce better and more reliable knowledge given the limitations of the scientific methods we use is triangulation and repetition. Triangulation by using different scientific methods and different theoretical frameworks, by looking at the problem through different researchers' eyes, and by approaching a question from different directions. Repetition is equally important. Repetition of a study in different places, at different times, by different people and different research groups. Only when our conclusions hold up after triangulation and repetition, might we be able to have a certain degree of confidence in them. In this thesis I have tried to apply both triangulation and repetition, trying to use different tools, different disciplinary perspectives, as well as by compiling databases of repeated measurements of a variable of interest and analysing them through meta-analyses. But on all four core topics of this thesis further triangulation and repetition is definitely needed to bolster our certainty in the conclusions made.

But where does this leave us? How can we make any policy recommendations, and what value does our scientific endeavour actually have, being such a slow-moving and uncertain process in this fast-paced world where we constantly need to make decisions and choose between multiple options? Well, the simple answer is that we do not need to have absolute certainty in order to act. We do need to have a certain amount of knowledge and understanding of a system before we can take actions. Sometimes, if we are faced with a highly complex system that we know very little about, following the precautionary principle, inaction might be the best action. But usually the best we can do in this world of uncertainties is to act while using the best knowledge we have. We might make some wrong decisions that turn out to do more harm than good, and we will make many imperfect ones, that could have turned out much better had we been more knowledgeable. But not knowing anything with absolute certainty is no excuse for inaction.

Scientists, in my opinion, have two key responsibilities. On the one hand, they need to be more careful about the conclusions they make, acknowledging the limitations and difficulties of the scientific process. On the other hand, scientists need to become more comfortable with providing advice under uncertain circumstances and in the face of incomplete evidence and incomplete understanding. We need to learn to be confident sailors who can navigate the uncertain and stormy waters we are sailing in, despite imperfect sailing charts and imperfect sailing tools.

In the following I will try to attempt exactly this – I will try to distil the key conclusions resulting from my thesis research to concrete recommendations that can be used to inform our actions, while highlighting uncertainties and identifying places where further research is needed.

6.2 SCIENTIFIC CONTRIBUTIONS AND FUTURE DIRECTIONS

6.2.1 THE FOOD SECURITY IMPACT OF ORGANIC AGRICULTURE

Organic agriculture and food production

My first manuscript chapter concludes that yields of organic agriculture are, on average, substantially lower, but that the yield difference depends on many factors like crop type, location, specific management practices, and duration of organic management. Having been published quite prominently in the journal *Nature*, this analysis provoked a rather large number of responses from the scientific community.

A study from UC Berkeley criticised the statistical methods used in this paper (Ponisio *et al.* 2015). Their new analysis, using different analytical tools, as well as an expanded dataset, comes to qualitatively similar conclusions about the overall yield difference, but different conclusions on some of the factors influencing the organic yield gap. Our own (unpublished) re-analysis of our dataset addressing their criticism (but excluding the additional data they collected) led, however, to the exact same results we had originally published. Another analysis, that was published basically at the same time as our original paper, also came to qualitatively similar conclusions (i.e. a yield gap of 20% but with substantial variation between different crop groups and regions, de Ponti *et al.* 2012).

Given that the factors influencing the organic yield gap varies between different meta-analyses, I would be cautious about any strong conclusions on whether, for example, the yield gap is higher in developed or in developing countries. The key conclusions we can, however, make are that (1) currently there is a substantial yield gap between organic and conventional agriculture, but that (2) this yield gap can be reduced substantially for certain crop types or using certain management practices. This implies that we need to better understand what currently limits yield in organic systems and address those limitations. We also strongly need more comparative analyses of the productivity of organic versus low-input conventional systems in developing countries.

In addition to this debate about the factors influencing the size of the yield gap, several scientists also questioned the validity of the question examined in the paper. Holt-Giménez *et al.* (2012) argued that we were missing the point, as food security was not an issue of production but of distribution. They therefore argued that yields of organic systems had no relevance for food security, but that agroecological systems like organic agriculture had a better potential of addressing other important food security questions like accessibility and sustainability. Connor (2013), instead, argued that we were missing the point by comparing crop yields rather than system yields between organic and conventional agriculture. He argued that the actual productive difference between organic and conventional farming systems is in fact higher, as organic farming systems rely on nitrogen inputs from biological nitrogen fixation, which requires additional land area.

Both of these responses to our paper offer valid arguments. However, their criticism is based on the assumption that our paper was trying to analyse the potential of organic agriculture to contribute to global food production and global food security. That, however, was never the intention of our paper. In this thesis I never attempted to answer the question I posed in its entirety, but rather I tried to contribute to several knowledge gaps on particular subsets of that question, acknowledging the limits of the analysis in each chapter.

Organic agriculture and food access

My thesis does partly address some aspects of the food access and distribution dimensions of food security. In the chapter on farmer livelihoods I posed the question whether organic agriculture provides a viable livelihood to farmers, and what motivates farmers to adopt organic management (Chapter 4). Again, this chapter does not provide a conclusive answer to the question of organic agriculture and food access, nor does it provide a conclusive answer to the question of organic agriculture and farmer livelihoods, but the chapter addresses some aspects of these questions and provides insights into some of the problems and benefits experienced by organic farmers in Kerala.

One of the key arguments by proponents of organic agriculture is that it is a more accessible means of increasing crop production in smallholder systems due to its lower reliance on external inputs (Holt-Giménez *et al.* 2012). Others further suggest that the premium received for organic products can improve farmer incomes and livelihoods (Scialabba & Hattam 2002; Bolwig *et al.* 2009). Our case study in Kerala shows that both of these propositions can be true, but only under certain conditions. The success of organic agriculture for farmers depends on the degree to which they depend on labour and external nutrient sources, as well as their commitment to organic principles. Certified organic production does not always provide a viable livelihood in a challenging economic context. Our case study shows that organic agriculture can, under some circumstances, actually exasperate existing problems in the food systems (e.g. low yields, low labour availability, high dependence on foreign markets) for farmers. As a management system that is embedded in the existing food system with all its problems of access, justice and sustainability, organic agriculture is not, by itself, able to address many of the problems of global sustainable food security we are currently facing.

Given the on-going debates about (1) the potential contribution of organic agriculture to food access and distribution, and (2) the organic nitrogen availability and total system performance of organic versus conventional agriculture, I believe it is not possible yet to draw general conclusions on whether organic agriculture would be able to feed the world, nor whether organic agriculture would be able to improve the situation of farmers. First, there is a strong need for a better quantification of the nitrogen availability, as well as the total land requirement of organic food production. Secondly, rather than seeking a simple answer to the question of farmer livelihoods, we should try to improve our understanding of situations where organic agriculture can provide a viable and sustainable means of livelihood for farmers, and situations where organic agriculture does not find acceptance amongst farmers and worsens existing problems in the food system.

6.2.2 THE ENVIRONMENTAL IMPACT OF ORGANIC AGRICULTURE

Much has been written about the environmental performance of organic agriculture (Pimentel *et al.* 2005; Mondelaers *et al.* 2009; Gomiero *et al.* 2011; Tuomisto *et al.* 2012). But most of these reviews do not provide a very rigorous (or quantitative) synthesis of the scientific literature. Here I attempt to summarize the evidence we have to date, as well as the confidence we have in this evidence, indicating how thesis Chapters 2 and 3 have contributed to our understanding of the relative environmental performance of organic agriculture. I will not examine findings from primary studies here, but only refer to conclusions from qualitative and quantitative reviews on the topic.

The impact of agriculture on the environment stems from two sources: from conversion of natural land for crop cultivation (land use) as well as from management of cultivated land (management).[36] It is therefore important to examine both the environmental impacts of a farming system per unit area (i.e. local impacts stemming from management), as well as the impacts per unit output (i.e. global impacts stemming from both management and land use).

On a per unit area basis organic agriculture has often been shown to have environmental benefits compared to conventional agriculture on multiple ecosystem services (see Fig. 6.1b): It reduces the application of pesticides and can increase species abundance and richness (Bengtsson *et al.* 2005; Hole *et al.* 2005; Tuck *et al.* 2014), it increases soil organic matter and soil carbon (Mondelaers *et al.* 2009; Leifeld & Fuhrer 2010; Tuomisto *et al.* 2012), it reduces greenhouse gas emissions and energy use (Gomiero *et al.* 2008; Lynch *et al.* 2011), and typically shows reduced nitrate leaching (Mondelaers *et al.* 2009; Tuomisto *et al.* 2012). On some of these ecosystem services (e.g. biodiversity, soil organic carbon) the evidence on this per unit area benefit is quite strong, as the issue has been examined with rigorous quantitative reviews of the scientific literature (e.g. Leifeld & Fuhrer 2010; Tuck *et al.* 2014). On other issues, instead (e.g. nitrate leaching, greenhouse gas emissions), no rigorous summaries of the scientific literature have been conducted to date, and the better environmental performance of organic agriculture has been questioned (Kirchmann & Bergström 2001; Cassman *et al.* 2003). Critiques of organic agriculture argue, for example, that the use of tillage due to the avoidance of herbicides in organic systems leads to increased soil erosion and greenhouse gas emissions (Trewavas 2001, 2004). Others criticize that the use of organic fertilizers potentially enhances rather than reduces the nitrogen loss from the system due to higher asynchrony between crop nitrogen demand and nitrogen availability (Pang & Letey 2000; Trewavas 2004).

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[36] When talking about agricultural change these two impacts of agriculture have often been termed ‘extensification’ (i.e. expansion of agricultural land) vs. ‘intensification’ (i.e. increasing crop yields on existing agricultural land). As I am not directly talking about agricultural change here I am using the terms ‘land use’ and ‘management’ instead.

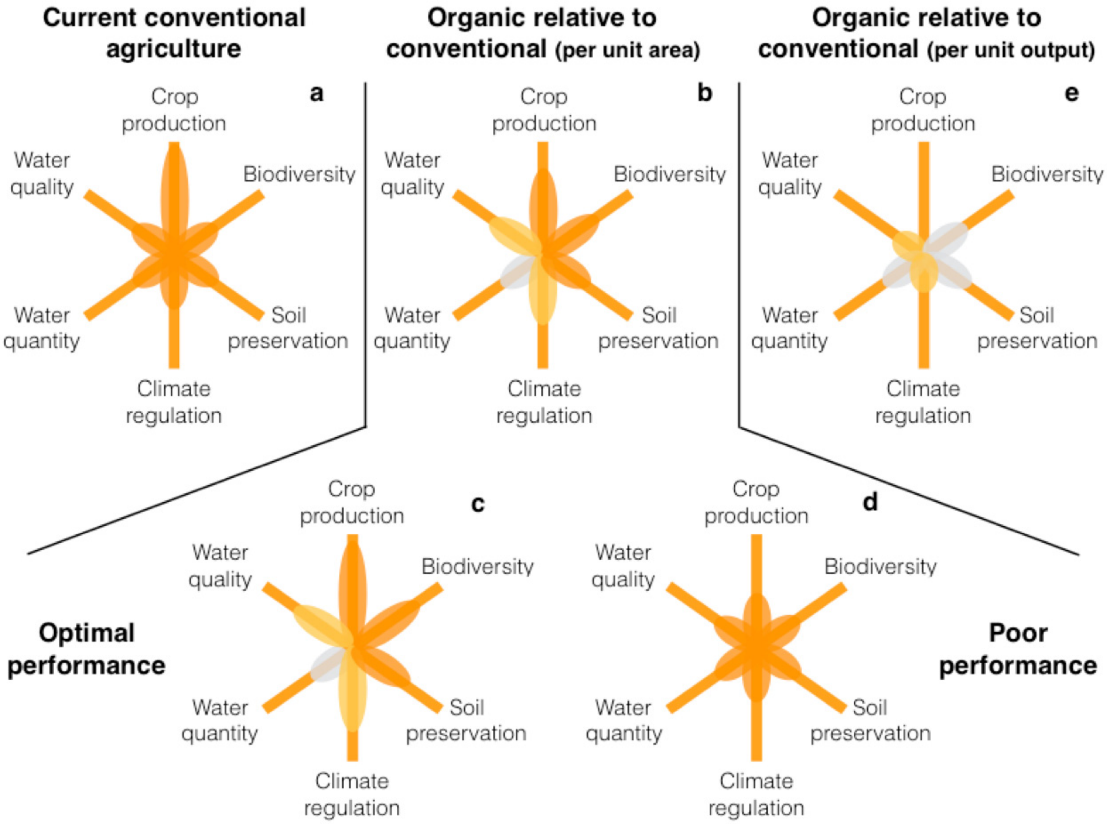

Figure 6.1. Environmental performance of conventional (a), and organic (b-e) farming systems on several ecosystem services of interest. Organic performance is assessed relative to conventional agriculture. Conventional performance is adapted from Foley *et al.* (2005). Panels **b**, **c** and **d** show organic performance per unit land area, panel **e** per unit food output. Panel **b** shows average performance, panel **c** shows optimal, and panel **d** poor performance per unit area (i.e. no difference compared to conventional systems, except for lower crop production). Dimensions with strong evidence are shown in orange, dimensions with higher uncertainties are shown in yellow, and dimensions that are based on educated guesses are shown in light grey. Values are based on several different quantitative reviews of the literature: yields from Seufert *et al.* (2012); biodiversity (i.e. influence on species richness) from Bengtsson *et al.* (2005) and Tuck *et al.* (2014); soil preservation (i.e. influence on soil organic matter content) from Tuomisto *et al.* (2012) and Mondelaers *et al.* (2009); climate regulation (i.e. the inverse of greenhouse-gas emissions) from Gomiero *et al.* (2008); water quality (i.e. the inverse of nitrate leaching) from Tuomisto *et al.* (2012) and Mondelaers *et al.* (2009). Note that water quantity is included in this diagram, as it represents an important sustainability issue in agriculture, but it was not possible to quantify the relative impact of organic agriculture on this variable, as organic management does not include any particular water management requirements (see Chapter 5), and as this topic has not received any discussion in the scientific literature yet.

The better environmental performance of organic agriculture is particularly uncertain if examining ecosystem services on a per unit output basis (Fig. 6.1e). When including the typically lower productivity of organic agriculture (see Chapter 2), and the potentially larger land area required to produce the same amount of food with organic methods, the environmental benefits of organic agriculture are highly uncertain, even on environmental variables that show a clearly better performance per unit area (e.g. biodiversity).

So far I have discussed the environmental performance of organic agriculture at average performance levels. One important contribution of this thesis is, however, to try and provide context regarding situations where organic agriculture performs well and where it does not. On each ecosystem service examined there is high variability in the impact of organic management (Mondelaers *et al.* 2009; Leifeld & Fuhrer 2010). It is thus crucial to understand what drives this variability and what factors influence the performance of organic agriculture. Under optimal conditions organic agriculture can provide high yields (de Ponti *et al.* 2012; Seufert *et al.* 2012; Ponisio *et al.* 2015), as well as environmental services (Fig. 6.1c), while under less optimal conditions organic agriculture performs more poorly, showing considerably lower yields than conventional agriculture but without any positive impact on other ecosystem services (Fig. 6.1d). Table 6.1 attempts to summarize some of the conditions we have identified to date that influence the better or poorer performance of organic agiculture on several environmental dimensions.

This brief overview highlights that even though we typically consider organic agriculture as a farming system with a clear environmental benefit, our actual knowledge on the impact of organic agriculture on numerous important ecosystem services is surprisingly limited. The impact of organic agriculture on water quality, water quantity, and climate regulation, the factors that influence the performance of organic agriculture on these variables, as well as the performance of organic agriculture on a per unit output basis need particular attention in future research.

Given this uncertainty about the environmental performance of organic agriculture it is important not only to close existing knowledge gaps, but also to assess why the environmental benefits of organic agriculture are sometimes so ambiguous, and how organic systems can be improved to provide increased environmental benefits. Chapter 5 of this thesis concludes that organic regulatory texts are formulated mostly with avoidance of chemical inputs in mind, while not including many environmental best practices. Including environmental best practices more specifically in organic regulations could thus be an important step to improving the environmental performance of organic agriculture.

Table 6.1. Conditions under which organic agriculture performs well, and performs more poorly on different ecosystem services.

	Better performance	Poorer performance	Source
Crop production	Legumes and perennials	Annuals and non-legumes	Chapter 2, this thesis
	Rain-fed agriculture	Irrigated agriculture	
	Good management	Bad management	
	Long-term management	Short-term management	
	High N inputs	Low N inputs	
	Diversified system	Monocultures	Ponisio *et al.* (2015)
Biodiversity	Generally low biodiversity	Generally high biodiversity	Chapter 3, this thesis
	Homogeneous landscapes[1]	Heterogeneous landscapes[1]	
	Plants	Birds	
	Arable systems	Grassland systems	
	Within fields	Outside fields	
Soil preservation	High fertilizer inputs Diversified system	Low fertilizer inputs Monocultures	Leifeld & Fuhrer (2010)
Water quality	?	?	
Water quantity	?	?	
Climate regulation	?	?	

[1] For plants and arthropods

6.3 OVERALL CONCLUSIONS

I started this thesis with the goal of informing the polarized debate, and attempting to address some of the unresolved arguments on organic agriculture (see Chapter 1). But instead of resolving any of the arguments, my different thesis chapters have revealed a much more uncertain reality than I had anticipated. None of the arguments raised by proponents or critics of organic agriculture can be dismissed. At the same time, however, neither of the two sides is right either. We cannot conclude that organic agriculture will be able to solve global food security, or provide more sustainable agriculture. But we also cannot dismiss organic agriculture as a backward system that will not be able to contribute to global food security and sustainability. Organic agriculture shows some clear benefits and promising characteristics – for example its positive influence on local biodiversity (Chapter 3), or its potential for high productivity under some circumstances (Chapter 2), but also its potential to provide poor farmers with a means of improving their livelihoods (Chapter 4). But organic agriculture also involves many unresolved questions and potential issues, for example regarding nitrogen availability and the total land area required, or its influence on nitrogen losses from the system, but also by being embedded in the existing food system and potentially exasperating rather than addressing some of the dysfunctionalities of the current system.

So where does this leave us? If none of the arguments around organic agriculture could be resolved, what is the contribution of this thesis? I believe that the key contribution of this thesis is to add some more nuances of grey to the often black and white debate about organic agriculture. Throughout this thesis I tried to identify both strengths and weaknesses of organic agriculture rather than taking a stance in favour or against it. The identification of such strengths and weaknesses allows, on the one hand, promoting organic agriculture in those circumstances where organic management performs well on a specific variable of interest (e.g. for yields in rainfed systems, for plant and arthropod biodiversity in homogeneous landscapes, for bird biodiversity in forested landscapes, or for farmer livelihoods when producing for domestic markets). On the other hand, it allows identifying the circumstances where organic agriculture performs poorly and where either the weaknesses of organic agriculture should be understood and addressed (e.g. the nitrogen limitation of organic yields, or the low premium prices received by organic farmers in Kerala), or where we might conclude that other strategies might be more effective at improving food security and sustainability (e.g. considering the high labour dependence of export organic agriculture in a state where agricultural labour scarcity is a big problem).

From a policy perspective, I believe that we can conclude that organic agriculture offers many promises for addressing issues in our current food system. It should therefore be included in any discussion and effort to improve global sustainable food security. A further expansion of organic agriculture, as well as an inclusion of successful organic management practices in conventional farming would most likely represent an important step towards a more sustainable food system. In addition, as I argued in Chapter 5 of this thesis, a renewed focus of organic regulations on clear environmental goals and environmentally beneficial farming practices could further increase the sustainability of organic farming systems.

But we should also not expect that organic agriculture will be the holy grail to solve all our food system and agriculture problems. This would not only be highly unlikely (given that organic agriculture currently only covers about 1% of global agricultural area), with a rather uncertain outcome (given the ambivalences about the social and environmental benefits of current organic agriculture), but it would also be foolish, as putting all your eggs in one basket is never a wise choice.

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“I know that I do not know.”