Sustainable Intensification and Agroecology

Transitioning towards sustainable agriculture

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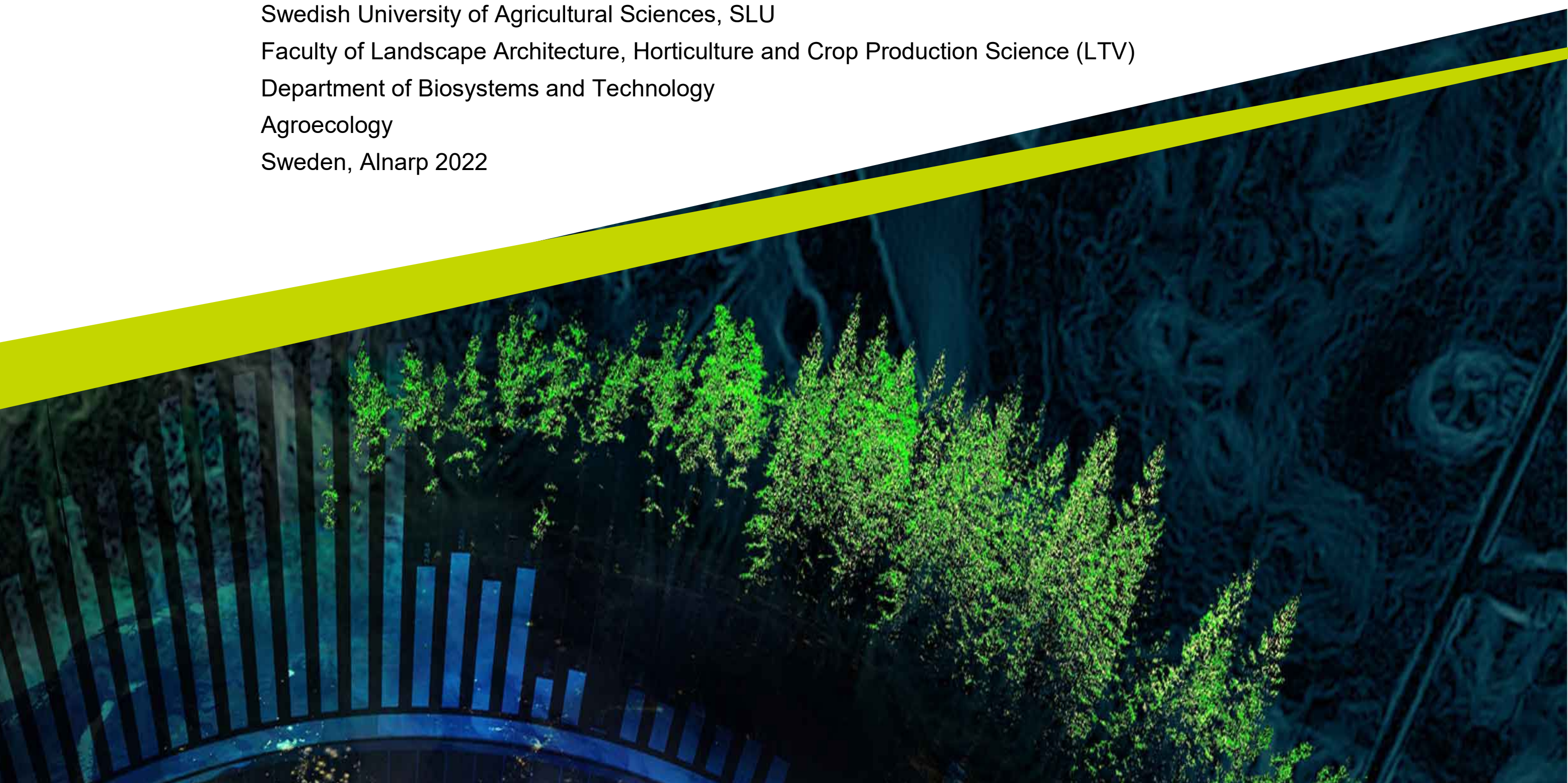

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Abstract

Agroecology and sustainable intensification are presented by their respective proponents as solutions to improve the sustainability of agricultural production. The present research investigates the similarities and differences of the two approaches and their potential to contribute to sustainable development in praxis. A comparative analysis of practices contained in the FAO 10 elements of agroecology and 13 agroecological principles with those in sustainable intensification found that the two approaches are very similar. The main difference lies on their focuses: the focus on goals in sustainable intensification, and the focus on means in agroecology, as well as differing scopes: farm scale in sustainable intensification, and food system scale in agroecology. It followed that sustainable intensification is limited to showing sustainable development only retrospectively, while agroecology can inform practices for sustainable farm development. It is proposed that sustainable intensification could benefit by a broadened definition which includes social elements. Due to the similar aims of both the concepts to increase agricultural sustainability, proponents of sustainable intensification and agroecology are best advised to focus on similarity, rather than difference.

Keywords: 10 elements of agroecology, 13 agroecological principles, agriculture, agroecology, sustainable intensification, transition

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Abbreviations

BASF	Badische Anilin und Soda Fabrik
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
EIQ	Environmental Impact Quotient
EMÜ	Eesti Maaülikool (Estonian University of Life Sciences)
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
IEEP	Institute for European Environmental Policy
IFAD	International Fund for Agricultural Development
IFOAM	International Federation of Organic Agriculture Movements
OECD	Organisation for Economic Co-operation and Development
SAFA	Sustainability Assessment of Food and Agriculture systems
SDGs	Sustainable Development Goals
SI	Sustainable Intensification
SLU	Swedish University of Agricultural Sciences
TAPE	Tool for Agroecology Performance Evaluation
U.N.	United Nations
USDA	U.S. Department of Agriculture

Foreword

The aim of this foreword is to describe and reflect upon my learning process during the two-year master's programme in Agroecology. In particular, it aims to provide insights into the knowledge, understanding, skills, and abilities I gained from the programme. To provide some context, I would first like to provide some insights on how I came to join the programme.

In 2018, I graduated from Malmö University with a Bachelor of Arts in Human Rights. During these transdisciplinary studies, I gained insights into human rights through the perspectives of political science, philosophy, religious studies, international law, international relations, and sociology. I also had the opportunity to take courses related to business administration, innovation, digital service management, and sustainable development. Throughout these broad studies I gained particular interest in global sustainable development, which is closely related to human rights. However, it is one thing to establish that we should have a right, yet, how to attain it on the other hand, poses very different challenges. The 'right to food', as a positive right, is one which depends on the state's capacity to provide food. Food production is thus fundamental to ensure that people can enjoy a right to food.

I was intrigued by this pragmatic aspect of human rights and the relationship with the environment. To gain more knowledge about the practical aspects of food production I enrolled in the Agroecology Master's programme at SLU. I arrived with the ambition to learn more about the intersection of the political and environmental elements of food production. However, I did not find the same structured approach of looking at one issue from the perspectives of different disciplines. Nevertheless, while the programme fell short of the political science lens I had been used to, it offered me the new perspective of the practitioner. I had to challenge my previous top-down approach which meant solving sustainability problems through state intervention. Now, I learned to apply a bottom-up approach, where transformative change is initiated by the people.

One fundamental concept of the programme was that of systems thinking. I learned about the complexity of ecosystems and how to harness concepts for applications in farming systems. Yet, a farming system is itself part of a larger production and consumption system with many socio-economic elements and drivers.

The programme managed well to balance the different backgrounds of students. Particularly the group-based assignments helped to enable an environment where we could learn from each other. While I had to compensate for an initial deficit in natural sciences, others were not familiar with social sciences. For me, the constant exchange, being challenged, and studying in diverse teams meant a steep learning curve.

Through the many case studies, I learned to explore the complexity of farming systems, their threats, opportunities, and impact, and based on this, to formulate recommendation which could lead to improved environmental, economic, and social performance. I also learned the systematic approach of assess farming systems based on indicators, and similarly arrive at recommendations to improve the system.

While doing this, the perspective of the farmer was central. Here, I was constantly challenged. First, conducting interviews was a challenge in itself - where the programme offered me the possibility to practice and gain confidence. During interviews with practitioners, I learned about their challenges, while my own perspective was challenged as well. I found that often something sounds like a great solution in theory but poses its own challenges in practice.

Nevertheless, the programme paid special attention to equipping us students with the ability and skills to find solutions which work in practice. In line with this, we spend much time to collaboratively explore and study participatory approaches and project management. Here particularly, the bottom-up approach could shine again. In an enabling environment those working the closest with the problem can bring about profound change or solutions that work. Now, I recognise the importance of multi-stakeholder partnerships and feel equipped with the necessary understanding to initiate such participatory approaches.

This thesis is the result of my learning in the agroecology programme. I believe it represents well the different aspects I reflected upon in this foreword. More than that, I believe this thesis also represents the hope I place in agroecology to contribute to human rights, beyond the provision of food.

1. Introduction

The planetary boundaries define a conceptual space in which humanity can operate sustainably (Rockström et al. 2009). Agriculture puts tremendous pressure on these planetary boundaries to the point where only a radical transformation of the food system will be enough to significantly reduce this pressure (Altieri 2012; Campbell et al. 2017). In addition, there is consensus that a continuation and upscaling of current agricultural practices to meet the demands of a growing population is no sustainable option (United Nations 2019). Considering a growing world population and a simultaneous shift in consumption, increased food production is often stated as a necessity which forms an underlying premise for the need of sustainable intensification of agriculture: producing more without using additional land and without causing additional harm to the environment (Garnett et al. 2013; Godfray & Garnett 2014; Cook et al. 2015). The World Bank, for example, estimated a need to increase food production by 75 percent between 2010 and 2050 to meet the needs of the future population (Fay & World Bank 2012).

But how do we generally produce in a sustainable way? What is 'sustainable' in the context of agriculture?

To make informed decisions on how to improve the sustainability of farming systems, sustainability assessments have taken a prominent role in providing data (Chopin et al. 2021). However, a lack of consistent approaches among farm sustainability assessments has been criticised, together with a call for harmonisation of existing assessment approaches (de Olde et al. 2017). Nevertheless, such an attempt to homogenise and compare farms is questionable, considering differing conditions and the context specificity of agroecosystems. This is because the farming context is essential for understanding and improving agroecosystem (Godfray et al. 2010; Garnett et al. 2013; Gliessman 2015). Thus, it is not surprising that this problematic aspect of sustainability assessments based on indicators has been criticised: while indicators have an important function to inform policy decisions, they "tend to ignore individual specificity and context in favour of superficial but standardized knowledge" (Merry 2011:586).

Nevertheless, the understanding and improving of agroecosystems are key for their sustainable development, while uniform indicator-based approaches are inherently not equipped to do justice to farming system complexity and context specificity. For example, to circumvent this problem, the assessment tool SAFA (sustainability assessment of food and agriculture systems), which was developed by the FAO, includes this ever so important step of contextualisation. Here, the assessor is supposed to select indicators and define their rating system based on the context (FAO 2014). While this, on one side, is desirable for above mentioned reasons, it also makes it difficult to compare results of different SAFA assessments. Röös et al. (2019) criticised that for comparison between farms, assessors, and time, the indicators would need to be further concretised. Yet, comparability is not a specified aim of the SAFA tool and for previously mentioned reasons should be secondary at best (FAO 2013, 2014).

Above-described tensions connected to sustainability assessments point to an underlying problem of different aims. People in science, policy, and practice have very different needs regarding the information they expect from sustainability assessments. To satisfy differing needs, we should consider all available options to inform the sustainable development of farms. As discussed, assessments and the use of indicators is one prominent way to address the question of improving sustainability. However, because of the difficulties connected to indicator-based assessments, the present work is deliberately avoiding, where possible, to look on sustainability improvements though the lens of performance based on indicators. Therefore, as an alternative approach guiding principles of farm sustainability will be the primary tool. More specifically, these principles are seen as a tool which informs actions that could be taken to improve sustainability. The major difference to an indicator-based approach is the aim to inform, rather than assess sustainable development.

The research presented here aimed to investigate the similarities and differences of two distinct approaches to improving the sustainability of farming systems. One approach is guided through specifying means, in form of elements or principles, namely the FAO *10 Elements of Agroecology* (FAO 2018) and *13 Agroecological Principles* (Wezel et al. 2020). The other approach*, Sustainable Intensification*, is emphasising outcomes rather than providing a specific blueprint. In addition, the research aimed to investigate how the FAO 10 elements of agroecology and sustainable intensification can be employed to support the transition of farming systems, utilising a large-scale case farm in Estonia

In the following section, some context for the debate around agricultural sustainability will be given.

1.1 Agricultural Sustainability

Before comparing the two approaches to improving sustainability, it is necessary to have a closer look on the concept of sustainability and establish what definition is being used here.

As Bell and Morse (2008) point out, most authors bemoan the lack of consensus and broad concept of sustainability and then go on to use their own preferred definitions, thereby further adding to the lack of consensus. This section thus tries to give a short general account of sustainability and at the same time take a closer look at the concepts used by the authors relevant for the present study.

It has been suggested by Bell & Morse (2008) that the current understanding of sustainability is based on six separate roots. Two of those roots are particularly relevant for the discussion of sustainability in the context of agriculture.

The first root is centred around the concept of carrying capacity, the idea that an ecological system can sustain a limited number of individuals based on their resource use (Bell & Morse 2008:6). The concept of planetary boundaries, referred to in the introduction, which was developed by Rockström et al. (2009) is an example for the continuation of the carrying capacity concept on a global scale. Sustainability here describes a state where these boundaries, or the carrying capacity are not crossed.

The second root is expressed as critique of technology as being potentially dangerous to the environment. Common examples brought up within this view are pesticide use and genetic engineering (Bell & Morse 2008:8). The probing assessment of the new genomic technique i.e. CRISPR by Clément and Ajena (2021) in relation to environmental, but also social implications.

We can find both these roots in the sustainability definitions of Jules Pretty and Steven Gliessman, prominent figures advocation for sustainable intensification and agroecology respectively in Table 1:

Table 1: Attributes of sustainability of agricultural systems (Pretty 2008) and the food system (Gliessman 2015). The attributes are quotes from the respective publications.

Pretty (2008:451)	**Gliessman (2015:16)**
Key principles of sustainability: • "Integrate biological and ecological processes such as nutrient cycling, nitrogen fixation, soil regeneration, allelopathy, competition, predation and parasitism into food production processes, • Minimize the use of those non-renewable inputs that cause harm to the environment or to the health of farmers and consumers, • Make productive use of the knowledge and skills of farmers, thus improving their self-reliance and substituting human capital for costly external inputs, and • Make productive use of people's collective capacities to work together to solve common agricultural and natural resource problems, such as for pest, watershed, irrigation, forest and credit management."	Minimum criteria of a sustainable food system: • "Have minimal negative effects on the environment and release insignificant amounts of toxic or damaging substances into the atmosphere, surface water, or groundwater; • Minimize the production of greenhouse gases, work to mitigate climate change by increasing the ability of managed systems to store fixed carbon, and facilitate human adaptation to a warming climate; • Preserve and rebuild soil fertility, prevent soil erosion, and maintain the soil's ecological health; • Use water in a way that allows aquifers to be recharged and the water needs of the environment and people to be met; • Rely mainly on resources within the agroecosystem, including nearby communities, by replacing external inputs with nutrient cycling, better conservation, and an expanded base of ecological knowledge; • Work to value and conserve biological diversity, both in the wild and in domesticated landscapes; • Guarantee equality of access to appropriate agricultural practices, knowledge, and technologies and enable local control of agricultural resources; • Eliminate hunger, ensure food security in culturally appropriate ways, and guarantee every human being a right to adequate food; • Remove social, economic, and political injustices from food systems."

Gliessman (2015) discusses sustainability in the context of food systems. According to him, the term sustainability has become increasingly vague, ambiguous, and confusing" (Gliessman 2015:16). He noted that one weakness of the concept is that it depends on a future scenario, which cannot be proved in the present, making it impossible to say that one practice or another is indeed sustainable. What should sustainability entail is "a system of food production, distribution, and consumption that will endure indefinitely because it does not sow the seeds of its own demise" (Gliessman 2015:16).

For Pretty (2008), sustainability includes resilience, the capacity to buffer shocks and stresses), and persistence (the capacity to continue over long periods), as well as wider economic, social and environmental outcomes. This rather broad view on sustainability is a results from the position that "precise and absolute definitions of sustainability, and therefore sustainable agriculture, are impossible" (Pretty 1995:1248). Similar to the view of Gliessman, Pretty (1995) also recognizes the complexity of the much contested sustainability concept, and stresses that a definition should not prescribe precisely defined technologies, practices or policies, as this would lead to limited options for future generations.

1.2 Agroecology

Agroecology has gained increasing attention since it first emerged in the 1930s. The collection of definitions listed in Table 2 shows a number of definitions which vary in detail and scope, and thus create room for interpretation and difference. The list shows the diversity of definitions applied by different stakeholders. This variety is a result of to the historical development of agroecology and its roots in science, practice and as a social movement. Much has been written about agroecology, and the present paper does not seek to be repetitive. For a more detailed and comprehensive review of the evolution of agroecology, for example Francis et al. (2003) or Wezel and Soldat (2009) are a good source.

The definition used in this work, and one which encompasses the dimensions of science, practice, and social movement is the following:

> "Agroecology is the integration of research, education, action and change that brings sustainability to all parts of the food system: ecological, economic, and social. It's transdisciplinary in that it values all forms of knowledge and experience in food system change. It's participatory in that it requires the involvement of all stakeholders from the farm to the table and everyone in between. And it is action-oriented because it confronts the economic and political power structures of the current industrial food system with alternative social structures and policy action. The approach is grounded in ecological thinking where a holistic, systems-level understanding of food system sustainability is required (Gliessman 2018:599)."

To operationalise agroecology and leverage it for sustainable development the FAO (2018) developed the '10 Elements of Agroecology'. The tool can serve as a guide on different levels, such as policy creation or management and planning. It has recently also been used as an analytical tool to investigate the compatibility of new plat breeding technology with agroecology (Clément & Ajena 2021). The '13 Agroecological Principles' were developed in close proximity to the 10 element of agroecology and draw on a large body of scientific literature. The 10 elements of agroecology consist of: 1. Diversity, 2. Co-creation and sharing of knowledge, 3. Synergies, 4. Efficiency, 5. Recycling, 6. Resilience, 7. Human and social values, 8. Responsible governance, 9. Culture and food traditions, 10. Circular and solidarity economy (Barrios et al. 2020).

The 13 Agroecological Principles consist of: 1. Recycling, 2. Input reduction, 3. Soil health, 4. Animal health, 5. Biodiversity, 6. Synergy, 7. Economic diversification, 8. Co-creation of knowledge, 9. Social values and diets, 10. Fairness, 11. Connectivity, 12. Land and natural resource governance, 13. Participation (Wezel et al. 2020).

Table 2: Definitions of Agroecology in chronological order.

Source	Definition
(Altieri 2000; Altieri et al. 2005)[1]	"The Science of Agroecology is defined as the application of ecological concepts and principles to the design and management of sustainable agroecosystems."
(OECD 2001)	"Agro-ecology is the study of the relation of agricultural crops and environment."
(Francis et al. 2003)	"Agroecology is the integrative study of the ecology of the entire food system, encompassing ecological, economic and social dimensions."
(Gliessman 2004)	"Agroecology is a scientific discipline that seeks to provide an objective, ecologically based assessment of the structure, function, multidimensionality, and special scale of food systems. It is a complex science, one that links the ecological, economic, social, ethical, and legal aspects of food production. All spatial scales are considered, from farm field to global, and systems approaches are emphasized."
(USDA 2007)	"Agroecology can be defined broadly or narrowly. Loosely defined, agroecology often incorporates ideas about a more environmentally and socially sensitive approach to agriculture, one that focuses not only on production, but also on the ecological sustainability of the productive system. This definition implies a number of features about society and production that go well beyond the limits of the agricultural field. At its most narrow, agroecology refers to the study of purely ecological phenomena within the crop field, such as predator/prey relations, or crop/weed competition."
(Third World Network 2015)	"Agroecology is a science that draws on social, biological and agricultural sciences and integrates these with traditional knowledge and farmer's knowledge."
(The Nyéléni Declaration 2015)	"Agroecology is a way of life and the language of Nature that we learn as her children. It is not a mere set of technologies or production practices. It cannot be implemented the same way in all territories. Rather it is based on principles that, while they may be similar across the diversity of our territories, can and are practiced in may different ways, with each sector contributing their own colors of their local reality and culture, while always respecting Mother Earth and our common, shared values. The production practices of agroecology (such as intercropping, traditional fishing and mobile pastoralism, integrating crops, trees, livestock and fish, manuring, compost, local seeds and animal breeds, etc.) are based on ecological principles like building life in the soil, recycling nutrients, the dynamic management of biodiversity and energy conservation at all scales. Agroecology drastically reduces our use of externally-purchased inputs that must be bought from industry. There is no use of agro-toxines, artificial hormones, GMOs or other dangerous new technologies in agroecology."

[1] This definition was listed twice in the FAO database, including the two different references.

(Agroecology Europe 2016)	“Agroecology is considered jointly as a science, a practice and a social movement. It encompasses the whole food system from the soil to the organization of human societies. It is value-laden and based on core principles. As a science, it gives priority to action research, holistic and participatory approaches, and transdisciplinarity that is inclusive of different knowledge systems. As a practice, it is based on sustainable use of local renewable resources, local farmers’ knowledge and priorities, wise use of biodiversity to provide ecosystem services and resilience, and solutions that provide multiple benefits (environmental, economic, social) from local to global. As a movement, it defends smallholders and family farming, farmers and rural communities, food sovereignty, local and short food supply chains, diversity of indigenous seeds and breeds, healthy and quality food. Agroecology acknowledges that the whole is more than the sum of its parts and hence fosters interactions between actors in science, practice and movements, by facilitating knowledge sharing and action.”
(Carrefour Group 2018)	“What exactly is Agro-ecology? It's a new mode of agricultural production that does not harm the environment. Agroecology uses resources and mechanisms which – by their very nature – are provided by Nature itself. Flora and fauna, together with the power of nature are all used in agroecology. These methods effectively build on interactions between plants, animals, human beings and the environment… in order to create healthier food. From an environmental perspective, it is more reasonable: less of the planet's natural resources are used. And it's healthier for us because chemical fertilisers, insecticides, pesticides and antibiotics are all reduced or even done away with altogether. Agroecology is also a new approach to agriculture which combines ecological, economic and social considerations. It's a change that commits crop and livestock farmers on a path towards better environmental protection and more effective climate adaptation, in particular by adopting practices that generate less CO2 and use fewer inputs.”
(Gliessman 2018:599)[2]	“Agroecology is the integration of research, education, action and change that brings sustainability to all parts of the food system: ecological, economic, and social. It’s transdisciplinary in that it values all forms of knowledge and experience in food system change. It’s participatory in that it requires the involvement of all stakeholders from the farm to the table and everyone in between. And it is action-oriented because it confronts the economic and political power structures of the current industrial food system with alternative social structures and policy action. The approach is grounded in ecological thinking where a holistic, systems-level understanding of food system sustainability is required.”

[2] Although not part of the FAO list of definitions, this definition was added as it represents the most recent definition by Gliessman.

1.3 Sustainable Intensification

Jules Pretty is one prominent proponent of sustainable intensification who has published a number of articles on the topic over the years. Since he started to discuss sustainable intensification (1997), he has continuously made changes to the concept. The first definition appeared in (Pretty 2008:451): “Intensification using natural, social and human capital assets, combined with the use of best available technologies and inputs (best genotypes and best ecological management) that minimize or eliminate harm to the environment, can be termed ‘sustainable intensification.”

Later the definition reads as follows (Pretty et al. 2011:7): “Sustainable agricultural intensification is defined as producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services.”

The term sustainable intensification has gained popularity in recent years and is now widely used to promote sustainable development of farming systems. Institutions like FAO, IFAD, EU, World Bank, Bill & Melinda Gates Foundation, as well as corporations like Bayer, BASF, Yara, Syngenta, Nutrien, Corteva, and Cargill are promoting sustainable intensification as the way forward (Fay & World Bank 2012; Official Journal of the European Union 2014; Syngenta 2019; BASF 2021; BAYER 2021; Corteva 2021; FAO 2021; IEEP 2021; IFAD 2021; Nutrien 2021). While there are various definitions of sustainable intensification, they all include the basic understanding that the overarching goal is to produce more, without using more resources or causing additional environmental harm.

Proponents of sustainable intensification commonly assume that in order to meet future demand, more food needs to be produced (Foley et al. 2011). Yet, most recently, as we have already seen an increase in food production that has tripled over the last 50 years, this increase in itself, rather than a potentially future increase are reason enough to think about the way such increase is accomplished (Pretty 2018). Aligned with the idea of carrying capacity and planetary boundaries, supporters of SI recognise that this increase in production should not be based on an increased area of production, and thus call for the intensification of current agricultural land. At the same time, environmental pressure should not increase, but better be reduced by these intensification efforts. The concept of sustainable intensification as such seeks to reach the point where more can be produced while respecting the planetary boundaries. Table 3 lists the definitions of sustainable intensification by various authors and stakeholders and shows that this increase in production with less pressure is a central element.

In a recent publication, Pretty (2018) clarified that there are three components to SI: efficiency, substitutions, and redesign. He stressed that efficiency and substitution are important, but not sufficient “for maximizing coproduction of favourable agricultural and beneficial environmental outcomes without redesign” (2018:1). The next section will look closer on the origin of the three components efficiency, substitutions, and redesign.

Table 3: Definitions of sustainable intensification in chronological order.

Source	Definition
(Pretty 1997:248–249)	“Substantial growth is possible in currently unimproved or degraded areas whilst at the same time protecting or even regenerating natural resources … Such sustainable agriculture seeks the integrated use of a wide range of methods and technologies to manage pests, nutrients, soil and water. It seeks to foster increased diversity of enterprises within farms combined with increased linkages and flows between them. By-products or wastes from one component or enterprise become inputs to another. As natural processes increasingly substitute for external inputs, gradually, the impact on the environment is reduced. Sustainable agriculture is … not a simple model or package to be imposed. It is more a process of learning.”
(Pretty 2008:451)	“Intensification using natural, social and human capital assets, combined with the use of best available technologies and inputs (best genotypes and best ecological management) that minimize or eliminate harm to the environment, can be termed ‘sustainable intensification’.”
(Royal Society 2009:ix)	“There is a pressing need for the ‘sustainable intensification’ of global agriculture in which yields are increased without adverse environmental impact and without the cultivation of more land.”
(Foresight 2011:35)	“Sustainable intensification means simultaneously raising yields, increasing the efficiency with which inputs are used and reducing the negative environmental effects of food production. It requires economic and social changes to recognise the multiple outputs required of land managers, farmers and other food producers, and a redirection of research to address a more complex set of goals than just increasing yield.”
(Pretty et al. 2011:7)	“Sustainable agricultural intensification is defined as producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services.”
(FAO 2011:9)	“Sustainable intensification has been defined as producing more from the same area of land while reducing negative environmental impacts and increasing contributions to natural capital and the flow of environmental services.”
(Firbank et al. 2013:59)	“Sustainable intensification is a process, rather than a condition at any time. … A farm was considered to be practicing sustainable intensification if food pro- duction per unit area had increased during the study period, and that none of the environmental variables had deteriorated.”
(Godfray & Garnett 2014:4)	Sustainable intensification “argues (i) that increased production must play at least some role in meeting the food security challenge of he next fifty years; (ii) that the vast majority of this increase must come from existing agricultural land; (iii)

	that increasing the sustainability of food production is of equal importance; and (iv) that we must consider a broad range of tools and production methods to achieve these goals”.
(Syngenta Foundation 2016)	“Sustainable intensification is the broad term for an approach to agriculture that increases food production from existing farmland without increasing impact on the environment.”
(Rockström et al. 2017:7)	“Adopting practices along the entire value chain of the global food system that meet rising needs for nutritious and healthy food through practices that build social–ecological resilience and enhance natural capital within the safe operating space of the Earth system.”
(Pretty 2018:1)	“SI comprises agricultural processes or systems in which production is maintained or increased while progressing toward substantial enhancement of environmental outcomes. It incorporates these principles without the cultivation of more land and loss of unfarmed habitats and with increases in system performance that incur no net environmental cost. … The concept is open; emphasizes outcomes rather than means; can be applied to any size of enterprise; and does not predetermine technologies, production type, or design components.”
(Pretty et al. 2018:441–442)	“SI is defined as an agricultural process or system where valued outcomes are maintained or increased while at least maintaining and progressing to substantial enhancement of environmental outcomes. It incorporates the principles of doing this without the cultivation of more land (and thus loss of non-farmed habitats), in which increases in overall system performance incur no net environmental cost. … SI is an umbrella term that includes a wide range of different agricultural practices and technologies, the precise extent of existing SI practice has been largely unknown.”

1.3.1 Estonia and Estonian Agriculture

The Republic of Estonia regained independence in 1991 and joined the European Union in 2004. The time frame between 1988 and 2008 can be divided into three distinct transitional phases. Throughout these phases, Estonian agriculture experienced many influences and rapid changes, such as the privatisation of collective farms and a decline of agricultural production. Following the EU accession and the systematic implementation of the common agricultural policy, Estonian agriculture regained previous production levels. Today, the retirement of the founding generation of the privatised farms poses a major risk for Estonian agriculture (Viira et al. 2009).

In 2021, the area utilised for agriculture in Estonia was 986,672 ha, of which 2020,796 ha were managed organically. 367,117 ha were dedicated to cereal grain production, of which there three most important crops were wheat (179,998 ha), barley (121,522 ha) and oats (40,008 ha). Dry pulses were cultivated on 48,972 ha, including field peas (33,096 ha) and field beans (15,829 ha). Besides that, rape and turnip rape seeds were grown on 78,848 ha (Statistics Estonia 2022b). The rapid structural change makes Estonia an interesting case to be studied in relation to a sustainable transition.

1.4 Objective

Currently, many of our national and global efforts are directed to reach sustainability. But if it is impossible to define sustainability, or sustainable agriculture in a precise way, how can we know how to get there? If currently our way of doing things is seen as unsustainable, how can we know what we must change, so we can alter them to be more sustainable? The present research aims to investigate two distinct approaches to these questions: sustainable intensification and agroecology.

Sustainable intensification emphasises sustainability as an outcome, whereas agroecology also specifies means to reach sustainability in form of principles or elements. As such, the research will compare those approaches to identify similarities and differences. As both approaches are widely used, this research aims to contribute to a better understanding of their distinctive and similar attributes, and as such to contribute to a more refined discourse.

While "the precise extent of existing sustainable intensification practice has been largely unknown" (Pretty et al. 2018:442), the present research also present an opportunity to further clarify practices contained within the concept.

Mockshell and Kamanda (2018) previously reviewed the differences between 'sustainable agricultural intensification' and 'agroecological intensification'. However, the large number of literature and concepts in their study contributes to - rather than clarifies - the existing ambiguities. For example, despite employing a discourse analysis, the study is not clearly distinguishing between terms like 'agricultural intensification', 'sustainable intensification', and 'sustainable agricultural intensification' or 'ecological intensification' and 'agroecological intensification’. Lyu et al. (2021) found in their extensive review of ‘agriculture intensification’, ‘sustainable intensification’, ‘ecological intensification’, and ‘agroecological intensification’ that ‘sustainable intensification is the “most widely and frequently used” (Lyu et al. 2021:5) term, whereas it is also a controversial concept which lacks a precise definition.

Furthermore, for the purpose of actionability, it is necessary to define outcomes in concrete terms. The United Nations (U.N.) approach to sustainable development through the definition of 17 Sustainable Development Goals (SDGs) is one example. With 169 clearly defined targets and subsequent indicators they are guiding global sustainable development. Similarly, it is necessary to clearly define targets and goals to reach a sustainable global food system which align and with the SDGs (including but not limited to Goal 2: Ending hunger and malnutrition; Goal 6: Addressing water scarcities; Goal 13: Reducing climate impacts; Goal 14: Protecting life in water; Goal 15: Protecting life on land) (United Nations 2019). The U.N. commissioned Global Sustainable Development Report warned that a “focus on increased production alone, will make it impossible to meet” those targets (United Nations 2019:64).

It is not surprising then that the FAO followed the example of its parent organisation and developed tools like SAFA (FAO 2014) or TAPE (FAO 2019), which both define clear elements of sustainability and provide indicators to assess and guide progress towards a sustainable state and address the sustainable development of the global food system in the four dimensions governance, environment, economy, and social wellbeing.

Lampkin et al. (2015) previously investigated in detail the role of agroecology in sustainable intensification. As such, there is a need to reassess the relationship of sustainable intensification and agroecology considering also recent developments.
Therefore, the present work draws on more recently published sustainable intensification literature and developed agroecological elements and principles.

With the previous work in mind, the present research is an attempt to further clarify the opportunities of different approaches. Moreover, besides a theoretical investigation of the problem there is also the aspiration to synthesize the topic and draw a link to the practical applicability of the concepts in a holistic way, which has implications for the farm level, as well as regional and national levels. Thus, the research aims to show implications of taking these two different approaches, namely emphasising outcomes, or providing guidance through principles and elements. To better relate the concepts to praxis, the implications will be regarded with the help of a large-scale farm case in Estonia.

As such, this work seeks to address a knowledge gap regarding the recent relationship of sustainable intensification and agroecology, as well as their relevance for a sustainable transition of farming systems in praxis.

1.5 Research Questions

Following the above outlined objectives, two research questions were defined. The first question aiming at the theoretical comparison, the second at establishing practical relevance:

1. In how far is sustainable intensification compatible with agroecology, represented by the FAO's 10 elements of agroecology and the 13 agroecological principles – what are similarities and differences?
2. How can the FAO 10 elements of agroecology and sustainable intensification be employed to support the transition of large-scale agricultural operations in Estonia?

2. Methods and Materials

This work can be divided into two fronts. One front will be focused on the comparison of sustainable intensification and agroecology. The second front will look on how the concepts can be employed to support the transition of large-scale farms. Figure 1 provides an overview of the structure.

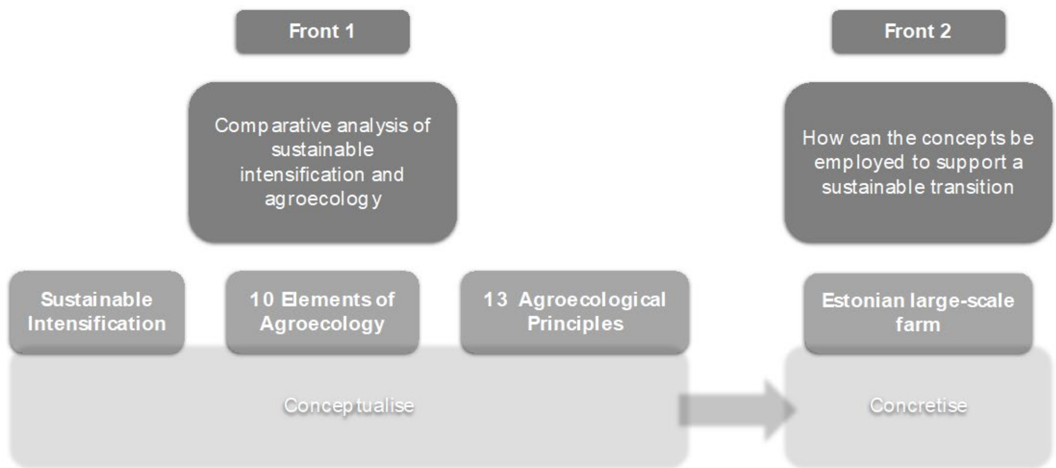

Figure 1: Structural overview of the thesis.

2.1 Establishing a theoretical foundation

Initially, a review of definitions of *Agroecology* and *Sustainable Intensification* was conducted. The FAO Knowledge Hub, which offers a collection of total 19 definitions of *Agroecology*, served as a first source for definitions of *Agroecology*. Here, only definitions in English were included, yielding 9 distinct definitions. In addition, a more recent definition by Gliessman (2018) was included to complement the already existing definition by Gliessman (2004). Definitions of *Sustainable Intensifications* were collected throughout the literature review. The literature review built on a systematic search for the term "sustainable intensification" on Google Scholar and Web of Knowledge, whereby articles with a high number of citations and recent publication date were selected for review aiming to focus on popular and current publications. As such, the collected definitions did not result in a complete list of all definitions ever created but focused on recent definitions of influential publications. Therefore, and because the collection process was tied to the review of the concepts, a high level of relevance should be given.

Agroecology was conceptualised in this study with help of the *10 Elements of Agroecology* and the *13 Principles of Agroecology*. Here the FAO publication (FAO 2018) as well as the corresponding research article by Barrios et al. (2020) served as sources for the 10 elements of agroecology. In addition, these publications served also to identify the corresponding practices contained in the agroecological elements. The list of 10 elements served as a starting point and practices were subsequently attributed following the descriptions in the literature. For example, the description of the element ‘diversity’ included practices like ‘diversifying knowledge’; ‘diversifying functions’; ‘diversifying activities and livelihood options’; ‘diversifying of products & services’ etc. The paper by Wezel et al. (2020) provided the *13 Principles of Agroecology,* as well as information about their relationship to the 10 elements of agroecology. In some cases where attribution of practices to elements and principles differed, this was indicated by stating the principle in which the practice would be contained. For example, the element ‘diversity’ included the practice ‘diversifying of knowledge, whereas ‘diversifying of knowledge’ is contained in the principle number 8 ‘co-creation of knowledge’. It could be expected that the 10 elements and the 13 principles are well aligned, as their main difference is the method of how they were defined. While a multi-stakeholder process, including experts, practitioners, and delegates from all regions of the world, initiated by the FAO led to the definition of the 10 elements of agroecology, the 13 agroecological principles are a result of consolidating the existing literature (Barrios et al. 2020; Wezel et al. 2020).

For *Sustainable Intensification* the publications by Pretty (1997, 2008, 2018), and Pretty et al. (2011, 2018) served as the main sources for conceptualisation. These publications also served together with the publication by Rockström et al. (2017) to identify corresponding practices, which can be attributed to the 10 elements of agroecology. Initially, all publications included in Table 3 were reviewed for their potential to serve as a source for practices, however, those not mentioned above were excluded because they did not mention practices in much detail, and thus could not contribute to identifying practices.

The list of agroecological practices, which was created before reviewing the sustainable intensification literature, was used to identify matching practices in the sustainable intensification literature. While identifying corresponding practices, some leeway was granted. For example, the sustainable intensification practice of “avoiding the unnecessary use of external inputs” (Pretty et al. 2011:8) was assumed to correspond with the agroecological practice ‘optimising external input use’. Admittedly, there is some margin of error to be expected with this ‘soft-approach’ method. When sustainable intensification practices were not described in detail, correspondence of practices was assumed to exist, even when the practice was not explicitly mentioned. The general rule was to apply a positive ‘bias’ towards sustainable intensification. One example for such a case would be the agroecological practice of ‘addressing underlying power balances, such as norms, relationships, institutional structures, discrimination, and imbalance’. This practice was found in the sustainable intensification literature in Pretty (1997) in form of actively supporting the involvement of women as producers. While it was not explicitly stated that the aim is to address power balances, norms, relationships, discriminations, and imbalance, the practice is contributing to this aim and was thus included.

The information resulting from the conceptualisation, including elements, principles, and practices was entered into a structured table (Table 6) to allow for comparison between the concepts. Following the method of first identifying the agroecological practices, the results only show which agroecological practices are contained in the sustainable intensification concept, not vice versa. While this is one limitation of the present work, such an approach was unavoidable, because it was the only way to align with the scope of sustainable intensification, which does not prescribe any specific practice. This would also mean that there is no limitation to a list of practices potentially included in SI.

2.2 Case study

To illustrate, contextualise, and relate the findings of the theoretical analysis to the real world, the case of a farming system in Estonia was utilised. Therefore, information about a single farm case was drawn from different sources. Information collected during the EU funded research project SoildiverAgro by the Estonian University of Life Sciences served as an initial source. This data was compiled in a database and contained information about management of three fields (Field A, Field B, Field C) on the farm between 2015 and 2020. More specifically it included information about crop, yield (t/ha), fertilizer input (product name; kg/ha), as well as herbicide, fungicide, and insecticide inputs (product name; l/ha). This data was used to identify and calculate the amount of NPK fertilizer and active ingredients for pesticides.

In addition to the data from the field diary, statistical data for crop production in Estonia in the form of an Excel table was used for comparison. Source for this data was the official statistical database Statistics Estonia (2022a). This data was retrieved in raw format and visualised in graphs with Excel. The data was used to identify trends, if any, regarding yield, fertilizer use, pesticide use, and land use.

Additional information about the farming system was gathered through a one-hour long video interview with the farmer. The interview, which was conducted in English, followed a semi-structured approach outlined in Table 4. The aim was to establish a basic understanding of the farming system, how it relates to sustainable intensification and the 10 elements of agroecology, as well as the future farm development. The interview was recorded with consent of the farmer and transcribed to extract the relevant information.

To answer the second research question about the feasibility of sustainable intensification and the 10 elements of agroecology being employed to drive sustainable development of the farm, the results of the conceptual analysis were discussed in the context of the large-scale Estonian farm case.

Table 4: Interview guide which was used during the semi-structured interview with the farmer.

Interview Guide

1. Introduction
    a. Technical aspects (duration, recording)
    b. What is the research and what the interview will be about
    c. Short explanation of SI and 10 Elements
2. Background of farmer and farm
    a. Education, ownership etc.
    b. Farming system - components
3. SI efforts
    a. Efficiency
    b. Substitution
    c. Re-design
4. 10 Elements of Agroecology
5. Future vision of the farm
6. Problems, Obstacles, Tensions
    a. What do you disagree with? What is not possible?
7. Enabling environment
    a. What is needed? Socially and politically
8. Conclusion

3. Results and Discussion

3.1 Transitional stages: Efficiency, redesign, substitution

Stuart Hill (1985) presented a first model including the stages of efficiency, redesign, and substitution as temporal stages of transitioning towards a sustainable food system detailed in Figure 2. In his initial presentation of the model, the redesign of agroecosystems also included the integration of the farm level with the food system (in Figure 2 see the box with the darkest shade). Hill and MacRae (MacRae et al. 1990; Hill & MacRae 1996) subsequently elaborated on the model and presented a general framework for transitioning towards sustainable agriculture. Their framework is based on the observation, that most successful transitions follow the progression of efficiency, substitution, and redesign. In contrast to Hill's initial framework, Hill and MacRae's later made no explicit reference to the framework's integration with the food system.

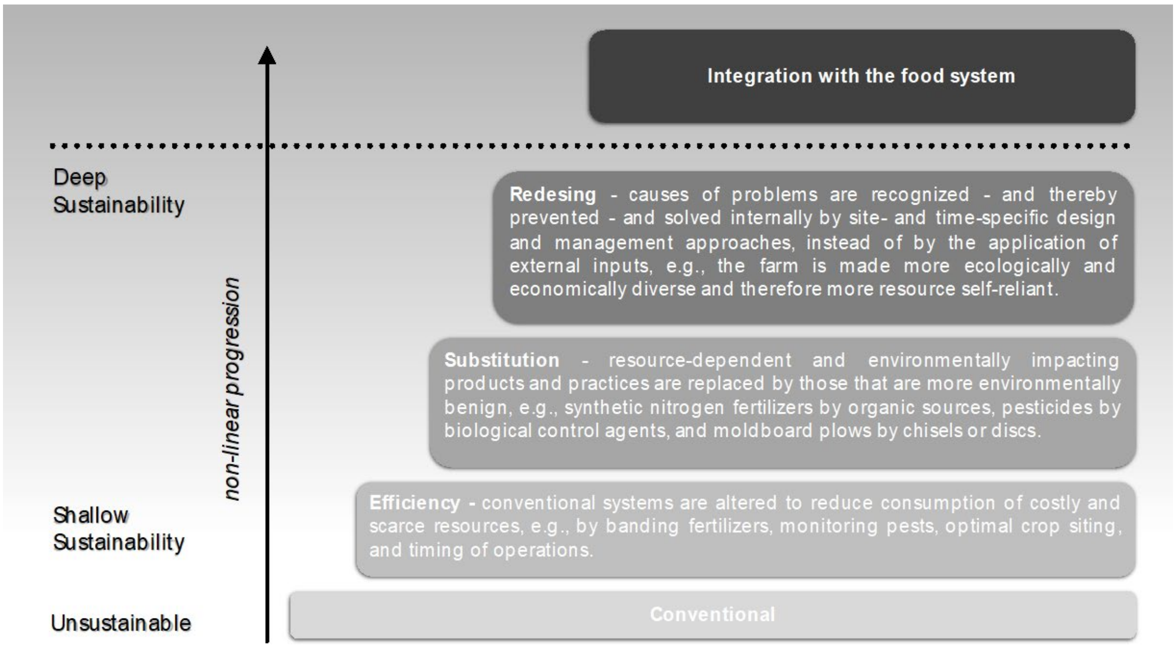

Figure 2: Efficiency-substitution-redesign-model progression towards increased sustainability of farming systems following MacRae et al. (1990) and Hill (1985).

This efficiency-substitution-redesign framework has been influential also for Gliessman's work on the agroecological conversion (Gliessman 2015) and Pretty's work on sustainable intensification of agriculture (Pretty 2018; Pretty et al. 2018).

The direct comparison between Gliessman's levels of agroecological conversion and Pretty's transition stages[3] of sustainable intensification in Figure 3 shows that the initial goals are identical. Both concepts are goal oriented, meaning they formulate primary outcomes and do not prescribe certain means on how these outcomes should be reached. Both concepts build on efficiency, substitution, and redesign of the agroecosystem at field and farm level.

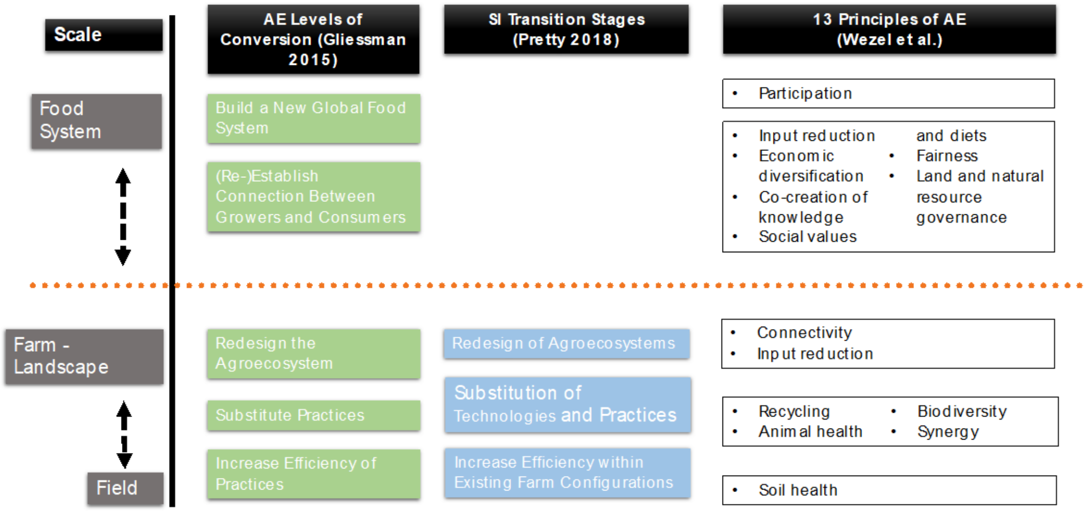

Figure 3: Comparative model of scales included in Gliessman's (2015), Pretty's (2018) respective conceptions of conversion and transition, and Wezel et al.'s (2020) 13 principles of agroecology.

Another way to compare the concepts is based on their scale. While sustainable intensification does not go beyond the farm and landscape scale, the agroecological transition includes also changes to the food system which go beyond the boundaries of an individual farming system or the landscape. However, the first three levels do not go beyond the farm/landscape in both concepts.

The 13 principles of agroecology also include an indication of the scale at which a principle is applied. Some of the principles are applied at various scales. For example, the increase of efficiency, the first transitional stage, includes the principles of input reduction and recycling (Wezel et al. 2020). In contrast to Pretty (2018) and Gliessman (2015), who envisioned this to be taking place at the field, farm or landscape level, the authors of the 13 principles of agroecology included this also at the food system scale.

Table 5 puts together a comparison of the different stages and their attributes. It should be noted again, that Gliessman (2015) included two more levels, which are not included in the table: Level 4 – "Re-establish a more direct connection between those who grow the food and those who consume it" , and level 5 – "On the foundation created by the sustainable farm-scale

[3] Stages and levels are used here as synonymous terms.

agroecosystems of Level 3 and the sustainable food relationships of Level 4, build a new global food system, based on equity, participation, and justice, that is not only sustainable but also helps restore and protect earth's life-support systems. (Gliessman 2015:279)"

Interestingly, Gliessman did not include social aspects in the first three levels. This is contrasted by the Hill and MacRae and Pretty, who included 'knowledge/skill', 'human capital in the form of knowledge and capacity to adapt and innovate' or 'identifying and mitigating negative unintended consequences for human, social and economic capital' in the redesign stages.

Table 5: Comparison of non-exhaustive and exemplary practices within the three transitional stages following Hill and MacRae (1996), Gliessman (2015), and Pretty / Pretty et al. (2018).

	Hill and MacRae (1996:83–84)	**Gliessman (2015:278–279)**	**Pretty (2018:1)* and Pretty et al. (2018:442)****
Redesign	• "Integrated use of local inputs, reduced demand" • "Bio-ecological" • "Knowledge/skill intensive" • "Broad focus, farm as ecosystem (integrated design and management)" • "Prevention, selective and ecological controls (pests as indicators)"	• Prevent problems "by internal site- and time-specific design and management approaches" • "Diversification of farm structure and management through the use of rotations, multiple cropping, and agroforestry"	• Harnessing ecological processes such as predation, parasitism, allelopathy, herbivory, N fixation, pollination, trophic dependencies etc. (*) • "Create and make productive use of human capital in the form of knowledge and capacity to adapt and innovate" (**) • Identify and mitigate negative unintended consequences for human, social and economic capital (**)
Substitution	• "Solar and renewable" • "Biological and natural materials" • "Alternative inputs" • "Benign factory" • "Biocontrol and more benign alternative interventions"	• "Nitrogen-fixing cover crops and rotations" • "Biological control agents" • "Reduced or minimal tillage"	• "Development of new crop varieties and livestock breeds" (**) • "RNA-based gene-silencing pesticides" (**) • Replacement of soil (hydroponics) (**) • No-tillage systems (direct seeding and weed management) (**)
Efficiency	• "Conservation" • "Physical/chemical/biological (slow release, band)" • "Efficient use" • "Efficient factory" • "Efficient control (monitor pest, Integrated Pest Management)"	• "Optimal crop spacing and density" • "Improved machinery" • "Pest monitoring for improved pesticide application" • "Improved timing of operations" • "Precision farming for optimal fertilizer and water placement"	• "Targeting and rationalizing inputs of fertilizer, pesticide, and water" (**) • Precision farming (sensors, detailed soil mapping, drone mapping, scouting for pests, weather and satellite data, information technology, robotics, improved diagnostics, delivery systems) (**) • "Automatic control and satellite navigation" (**)

3.2 Comparison between the 10 Elements of Agroecology, 13 Agroecological Principles, and Sustainable Intensification

The first column of Table 6 shows the result of identifying practices which are contained in each of the 10 elements of agroecology. A total of 50 practice categories were identified in the two publications detailing the 10 elements of agroecology, resulting in a comprehensive list. However, based on the limited literature used to identify the practice, the list does not claim to be exhaustive. The remaining columns indicate with a checkmark whether the practice is contained in the 13 agroecological principles and sustainable intensification. In four cases a practice was better placed in a different principle which was subsequently indicated. The analysis of the SI literature, detailed in Appendix 2, Table 9, showed that 49 out of 50 practices could be included in sustainable intensification. The only practice which could not be found was 'encouraging fair prices for consumers' in the element 'circular and solidarity economy'. Therefore, the two concepts show great similarity of included practices. This is a surprising result in one way but could also be expected in another. It is surprising because of the limited aim of sustainable intensification to increase production without using more land or causing additional harm to the environment. Yet, because the concept does not aim to prescribe certain practices, it is also not surprising that many practices can be included. On the flip side, this shows that the agroecological practices also contribute to sustainable intensification in its narrow definition.

To be clear, none of the three concepts prescribe certain practices, while all recognise the need to consider and adapt to the local context. However, the concepts differ in the degree to which they suggest practices. While sustainable intensification entails nothing but 'intensifying', the more detailed definition of agroecology through elements or principles provides guidance and suggestions for practices. This distinction between defining a desired *outcome* (i.e. an intensified production), or defining a pathway *leading* to an outcome (i.e. through principles) is a major difference between the sustainable intensification paradigm and agroecology.

When comparing the 10 elements of agroecology with the 13 principles, the most obvious is the differing number. There are three more principles than elements, meaning that either the principles cover more aspects or are more refined. As the direct comparison in Table 6 (green rows) shows, often more than one principle can be attributed to an element. The comparison did not find that principles cover more, rather the differing number results from a different approach of defining the principles. For example, 'resilience' is an emerging property resulting from specific attributes. While it was defined as an element of agroecology, it is seen as an expected outcome of attributes following several principles (Wezel et al. 2020).

Rockström et al. (2017) recognise that previous definitions of sustainable intensification are reduced to the simple principle of producing more without using more land or causing more harm to the environment, and conclude that these definition are "not concrete enough or only partial" (Rockström et al. 2017:7). Thus, they include in their definition of sustainable intensification of agriculture a socio-ecological element, which includes "conducive legal and institutional frameworks, incentives, rights, infrastructure, and support services" for farmers (Rockström et al. 2017:7). As such, they define sustainable intensification as "adopting practices along the entire value chain of the global food system that meet rising needs for nutritious and healthy food through practices that build social–ecological resilience and enhance natural capital within the safe operating space of the Earth system" (Rockström et al. 2017:7). While their description of strategies to reach this cover practices within the elements of 'responsible governance', they did not mention practices within the elements of 'human and social values', 'co-creation and sharing of knowledge' or 'culture and food traditions'. However, overall, and perhaps this is owed to the strong focus on the environment (i.e. biophysical processes of the earth system) by the concept of planetary boundaries[4] also developed by Rockström et al. (2009), they mention many of the practices of the ecologically oriented elements (diversity, synergies, efficiency, recycling, resilience) and do not refer to many practices in the social elements i.e. co-creation and sharing of knowledge, human and social values, and circular and solidarity economy.

With the inclusion of 'organic agriculture' as an example of sustainable intensification, Pretty et al. (2018) include many of the agroecological elements by default. There are also some contradictions, for example in relation to the use of synthetic pesticides or genetically modified organisms, which one hand are excluded in organic agriculture following the IFOAM definition (Luttikholt 2007), but are seen as examples of application of sustainable intensification or at least not ruled out (Pretty 2008, 2018). Yet, while it might seem like an inconsistency at first, it reflects the aspiration of sustainable intensification of being technology neutral and not prescribing a certain practice over another, as specified by Pretty at al. (2018:442):"SI seeks synergies between agricultural and landscape-wide system components, and can be distinguished from earlier manifestations of intensification because of the explicit emphasis on a wider set of environmental as well as socially progressive outcomes." Such view is shared by Godfray and Garnett (2014) who additionally stressed that outcomes of sustainable intensification will to a high degree be location specific. Yet, the implications for 'socially progressive outcomes' following a definition which is focusing on producing more with less harm is very limited.

[4] The nine planetary boundaries proposed by Rockström et al. (2009) are climate change, ocean acidification, stratospheric ozone depletion, atmospheric aerosol loading, biogeo-chemical flows: interference with P and N cycles, global fresh water use, land-system change, rate of biodiversity loss, and chemical pollution.

Table 6: List of practices contained within the 10 Elements of Agroecology in comparison with the 13 Agroecological Principles and sustainable intensification.

10 Elements of Agroecology Practices[5]	**13 Agroecological Principles**[6]	**Sustainable Intensification**[7]
Diversity	Soil health (#3) Biodiversity (#5) Economic diversification (#7)	8 out of 8 practices
Diversifying species and genetic resources/ Enhancing functional biodiversity / managing biodiversity/ vertical, spatial, temporal diversity (agroforestry, intercropping, crop rotation) / local breeds adapted to specific environments (crop-livestock systems, fish polyculture, integrated multi-trophic aquaculture, rotational crop-fish systems	✓	✓
Diversifying knowledge	Contained in co-creation of knowledge (#8)	✓
Diversifying functions	✓	✓
Diversifying activities and livelihood options	✓	✓
Diversifying of products & services	✓	✓
Enhancing and sustaining pollination	✓	✓
Enhancing and sustaining biological regulation of pests and diseases	✓	✓
Provisioning of favourable soil conditions for plant growth / Soil management (minimize soil erosion, enhance carbon storage, promote nutrient balance and cycles, preserve soil biodiversity)	✓	✓
Co-creation and sharing of knowledge	Co-creation and sharing of knowledge (#8)	5 out of 5 practices
Co-creating and sharing	✓	✓

[5] Extracted from FAO (2018) and Barrios et al. (2020) following their elaboration on the 10 Elements of Agroecology.
[6] Adopted correspondence to the FAO 10 elements from Wezel et al. (2020). The number (#) of the principle in the original publication is in brackets.
[7] Based on Table 8.

✓ Practice is contained.

Encouraging transdisciplinary engagement	✓	✓
Blending of knowledge (including traditional and indigenous knowledge)	✓	✓
Adapting to local context and realities	✓	✓
Sharing innovations through formal and non-formal education and inclusion of various actors	✓	✓
Synergies	Soil health (#3) Synergy (#6)	3 out of 3 practices
Using of integrated holistic approaches (intercropping, organic matter management, crop-livestock integration)	✓	✓
Synchronizing productive activities at landscape level (e.g. periodic pruning of hedgerows for erosion control and feed provision)	✓	✓
Involving actors at multiple scales (for partnerships, cooperation and responsible governance)	Contained in connectivity (#11)	✓
Efficiency	Input reduction (#2)	3 out of 3 practices
Improving use of natural resources (solar radiation atmospheric carbon and nitrogen)	✓	✓
Moving towards information-based (sensors, soil mapping) and knowledge-based production systems	✓	✓
Optimizing external input use	✓	✓
Recycling	Recycling (#1)	5 out of 5 practices
Recycling biomass	✓	✓
Recycling nutrients	✓	✓
Recycling water	✓	✓
Recycling food waste / waste (e.g. biochar)	✓	✓
Minimising of losses / Closing nutrient and energy cycles	✓	✓

✓ Practice is contained.

Resilience	Soil health (#3) Animal health (#4)	6 out of 6 practices
Diversifying of interacting organisms	✓	✓
Enhancing ecological resilience	✓	✓
Enabling self-regulation of the agricultural system / maintaining functional balance	✓	✓
Adopting management practices aiming to improve animal health	✓	✓
Enhance socio-economic resilience	Contained in economic diversification (#7)	✓
Diversifying and integrating (in animal production systems / at landscape level)	✓	✓
Human and social values	Social values and diets (#9) Fairness (#10) Participation (#13)	8 out of 8 practices
Tailoring practices to fit the environmental, social, economic, cultural, and political context	✓	✓
Emphasising dignity, equity, inclusion, justice, gender equality	✓	✓
Putting aspirations and needs of producers at the heart of the food system	✓	✓
Addressing underlying power balances, such as norms, relationships, institutional structures, discrimination, and imbalance	✓	✓
Building autonomy and adaptive capacity	✓	✓
Empowering women / rural youth / (marginalised groups)[8]	✓	✓
Empowering people to become their own agents of change	✓	✓
Culture and food traditions	Social values and diets (#9)	2 out of 2 practices
Supporting diversified diets	✓	✓

[8] This practice was grouped by Barrios et al. (2020) under *Culture and food traditions.* Marginalised groups is an addition by the author.

✓ Practice is contained.

Co-creating and sharing of knowledge processes	Contained in co-creation and sharing of knowledge (#8)	✓
Responsible governance	Land and natural resource governance (#12)	5 out of 5 practices
Developing effective and innovative policies, institutions, and markets that enable transformative change	✓	✓
Embodying transparent, accountable, and inclusive governance mechanisms	✓	✓
Supporting producers during food and agricultural re-design processes	✓	✓
Granting equitable access to land	✓	✓
Branding of agroecological produce	✓	✓
Circular and solidarity economy	Economic diversification (#7) Connectivity (#11)	4 out of 5 practices
(Re-)connecting producers and consumers	✓	✓
Encouraging recycling, shorter food circuits	✓	✓
Prioritising local markets and economic development	✓	✓
Strengthening the resilience of the local fabric	✓	✓
Encouraging fair prices for consumers	✓	--

✓ Practice is contained.

3.2.1 Comparing the scope

For sustainable intensification, a detailed indication regarding the scope can be found in Pretty et al. (2018) who state that “the concept is open, emphasizing outcomes rather than means, applying to any size of enterprise and not predetermining technologies, production type or particular design components (Pretty et al. 2018:441–442).”

This view is echoed by the U.N. Global Sustainable Development Report 2019, which was prepared by an independent group of scientists to support policymakers and other stakeholder in implementing the 2030 Agenda. The report stressed that due to differing socioeconomic and agroecological factors, there would be not one approach to achieve the sustainable development goals such as improved nutrition and farmer livelihood, reduced food insecurity, reduced land and input use, as well as reduced environmental externalities (United Nations 2019:69). Interestingly, the report stated that “in some cases, sustainable intensification and precision agriculture will be the best approach, in others, organic or agroecology systems, as key elements of a climate smart approach to agriculture, will provide the greatest net benefits” (United Nations 2019:69). Seemingly, the report sought to be inclusive and neutral towards different approaches and thus included various approaches. However, as the analysis of sustainable intensification and agroecology showed, the two approaches overlap in many ways. Thus, to distinguish their effectiveness there is a risk to underline their dissimilarities rather than similarities and thus to contribute to a discourse with is focused on difference and superiority, rather than similarity and unity. Godfray and Garnett warned that “the word ‘intensification’… is often associated with specific farming practices, and these connotations are responsible for some negative reactions to calls for SI” (2014:5).

Agroecology, on the other side, whether it is expressed through principles or elements, takes an approach which is more specific. The 13 agroecological principles aimed to provide a set of recommendations for policymakers based on scientific literature. Similarly, the 10 elements of agroecology were designed with the aim to guide the FAO’s work in assisting Member States in agroecology related questions ranging from practice to policy (Wezel et al. 2020).

Following the aim of both approaches to have a guiding function, it is inevitable that they are more specific. While sustainable intensification is describing a relativistic goal, the elements or principles are specifying means. This means that sustainable intensification and agroecology are operating with two different approaches, which do not interfere per se. This is exemplified by the fact, that agroecological approaches are repeatedly mentioned as examples for sustainable intensification (Pretty et al. 2011; Pretty 2018). Vice versa, as the analysis of agroecological practices within sustainable intensification shows, almost all of them can contribute to sustainable intensification. Both approaches also stress the importance of context in finding the right practice to improve sustainability.

However, while sustainable intensification is seen as “a necessary but not sufficient component of transformation in the wider food system (Pretty et al. 2018:442), or “as part of a multipronged strategy to achieving sustainable food security rather than an all-encompassing solution (Garnett et al. 2013:33), agroecology has a somewhat broader scope of also addressing the wider food system. One should not be blinded by the simple comparison of practices, which does not show the lack of addressing issues of the wider food system though sustainable intensification. This has partly to do with the scale at which the practices can be applied. While the practices which can be found in the sustainable intensification literature were applied at field, farm or landscape scale, within the scope of Agroecology, they are also intended to be used on a global scale. This shows, however, that sustainable intensification has the potential to be broadened so it has the potential to overcome current limitations and thus contribute more broadly to the sustainable development of a global food system. Therefore, one suggestion could be to broaden the definition, as done by Rockström et al. (2017), which could build on the current definition by Pretty (2018) and include also specifically a social element and thus increase the scope of sustainable intensification beyond the farm and landscape level:

> SI comprises agricultural processes or systems in which production is maintained or increased while progressing toward substantial enhancement of environmental *and social* outcomes. It incorporates these principles without the cultivation of more land and loss of unfarmed habitats and with increases in system performance *and human well-being* that incur no net *external costs*.

In a critical paper, Pablo Tittonell (2014) argued that SI is too loosely defined, allowing almost every model or technology to be included, and instead we should aim at ecological intensification, designing systems that are "sustained by nature and sustainable in their nature" (Tittonell 2014:59). Further, Cook et al. (2015) also took a closer look on the concept and suggested that SI alone is not equipped to cover sustainability of the whole food system, but is one tool among others that should be utilised. This, however, is not a contested view as proponents of sustainable intensification admit, that more action is needed in addition to sustainable intensification of agriculture to address broader sustainability issues (Garnett et al. 2013).

The question is why the scope of sustainable intensification is limited in the first place and why it does not address broader sustainability issues related to agriculture. What would be the risk of broadening the concept?

It has been suggested that term 'sustainable intensification' is used by agrochemical companies and trade associations as a Trojan Horse (Godfray & Garnett 2014:6) to continue business as usual. Perhaps one problem with including also social outcomes into the definition would be, that it would not be enough to focus on the first two transitional stages of increased efficiency or substitution. An extended definition of sustainable intensification would thus be helpful in refuting such criticism and also recognise the need for a broader transformation of the food system.

This suggestion is further strengthened by a study which investigated 30 experts' perception of sustainable intensification. Petersen & Snapp (2015) found that experts do not perceive the term as a significant departure from current agricultural practices. Furthermore, the participants raised concerns about insufficient attention to the potential of biological processes in agricultural production systems. Following this, it seems necessary to clarify the scope of sustainable intensification and clearly distinguish it from current conventional agricultural practices.

However, it is important to note that, overall, sustainable intensification and agroecology show more similarities than dissimilarities.

3.3 The farm case in Estonia

3.3.1 Description of the farming system

The farmer's[9] family has a history in farming. The farmer acquired a formal education for farming and has run an own farming business for 16 years. At time of the interview, the farmer was taking an additional education on running the farm as a business at university.

The large conventional farm includes 2500 hectares of cultivated land, of which about 700 hectares are owned by the farmer and the remaining land is rented. The farmer expressed the wish to buy more land, however, the current price would be too expensive. Nevertheless, the farmer stated that renting land does not affect the way the land is managed. While there are no animals integrated in the farming system, the main crops cultivated on the farm are wheat, barley, oil seed rape, beans, peas, and varying cover crops such as clover sunflower.

Inputs, such as seed and synthetic fertilizer, are purchased from two dealerships, one of which is operating across the Nordics and Baltic States, while the other one is local.

The farmer stated the wish to use more organic fertilizer, following which 5000 cubic meters of chicken manure were bought from an Estonian source, and 2000 tons of compost were acquired from a source in the Netherlands. Besides these inputs, the farmer also ordered a shipping container of humic acid, fulvic acid, and amino acid from China. The farmer stated that the compost was ordered from the Netherlands, because it was not available in Estonia. The reason for ordering fertilizer from China was a cheaper price of about a factor of five.

To manage the nutrient input, the farmer is monitoring soil nutrient content through soil sampling and measuring of harvested biomass, with the aim to have a slightly higher input than what was harvested.

The farm utilizes precision farming whereas all tractors are equipped with GPS for traffic control. During a five-year period (2015-2020), the fields were cultivated following a strip-till approach. However, the strip-till equipment was sold in 2020. One reasons for the sell-off was the British make of the equipment and a rising price in spare parts following Brexit. Another reason was the result on the field, which was described by the farmer as bumpy and causing machinery to break more often due to an uneven field surface and resulting higher tear and wear.

At time of the interview, the farmer utilised a multipurpose cultivator which allows for shallow and deep cultivation. The farmer stated a cultivation depth of 10 cm for wheat and 15

[9] All personal data has been anonymized to protect the privacy of the farmer.

cm for oil seed rape. The famer's attitude towards inversion ploughing was negative. However, a deep cultivator, which reaches 50 centimetres deep, is used to break deep compaction as needed.

After harvesting, the compost and manure are spread on the field and incorporated with the cultivator. The default four-year crop rotation (Figure 4) includes a cover crop, followed by winter oil seed rape, winter wheat, and if possible, winter wheat again or alternatively spring wheat. In 2020, the farmer also grew barley and peas, however, the conditions were described as difficult not suited for these crops by the farmer. In contrast, the success with growing only wheat and oil seed rape is more predictable, also from an economic perspective. Here, 50 per cent of the crop is pre-sold and the other half is sold after harvest.

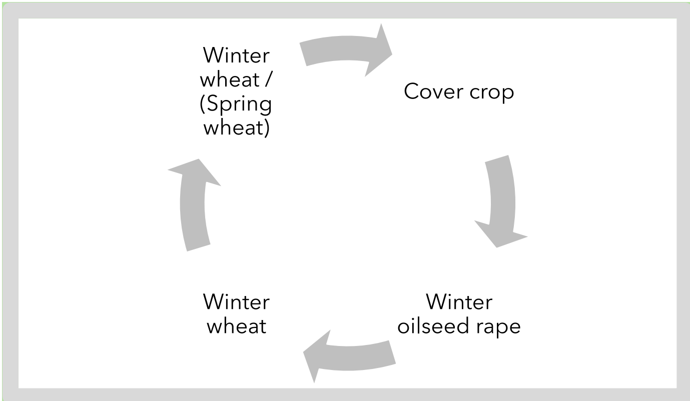

Figure 4: Default four-year crop rotation of the farm

The farmer has used various cover crops, but now clover is the default. While the farmer stated that sunflower was good for the soil and had good root mass, the expenses are seen as too high compared to clover. Another difficulty was the seeding of a mix of cover crops, including beans and peas, because the available machinery had problems with the differing seed size. Nevertheless, the farmer acknowledged the benefits of diversity for the soil and would prefer a mix of cover crops if it was technically feasible.

For some time, the farmer also tried direct seeding, but while it was beneficial for the soil, the economic results were not good enough to justify a continuation.

At field borders, next to drainage ditches, the farmer uses a 6-meter-wide strip to grow clover. This field border is used for traffic to avoid traffic on the field where the actual crop is grown, and the clover is harvested for composting.

The farmer stated that most of other Estonian famers are not using the same amount of organic fertiliser and rely mostly on synthetic fertilizer. The farmer is taking inspiration for this approach of using organic fertilizer based on YouTube videos from U.S. universities which have much more experience. Although the farmer has a network with other farmers, the farmer stated that the knowledge available online is not available in Estonia. When adapting practices from overseas, the main challenge experienced by the farmer is access to appropriate machinery, not available in Estonia. To buy machinery, it needs to be ordered abroad from other countries in Europe or the U.S.

The farmer is also cooperating and participating in research projects with the Estonian University of Life Sciences (EMÜ). For example, one ongoing research project investigates the use of charcoal, which is produced from biomass of hay and straw, to reduce the amount of synthetic fertilizer. In the future, the farmer would like to produce also compost on the farm, utilising leftover biomass.

When asked about how agriculture could be better regulated, the farmer stated that more organic fertilizer should be used, as well as more precision farming to monitor the soil nutrients. Generally, the focus on making profit would be too high, not allowing to invest in improving the ecological state of the field. The farmer proposed that the provision of EU subsidies could be tied more closely to performed measures, rather than what is reported in the system. Here, the suggestion came up to use the technology of GPS, hour meters etc. to monitor the actual work which is performed on the field.

3.3.2 Guiding the transition in large scale Estonian farms

As the previous discussion showed, sustainable intensification and agroecology are united by many common practices. This section seeks to discuss how the two concepts can be employed to support the transition of large-scale farms in Estonia. First, the farm case will be regarded considering the definition for sustainable intensification, which "comprises agricultural processes or systems in which production is maintained or increased while progressing toward substantial enhancement of environmental outcomes. It incorporates these principles without the cultivation of more land and loss of unfarmed habitats and with increases in system performance that incur no net environmental cost" (Pretty 2018:1). The first part of this section will thus look on the relationship of yield, cultivation area, and environmental impact.

Figure 5 shows a clear trend for an increasing yield in Estonia during the last 20 years for the selected crops. These are the same crops as grown on the fields of the farm case and shows an intensified production as well as a positive trend.

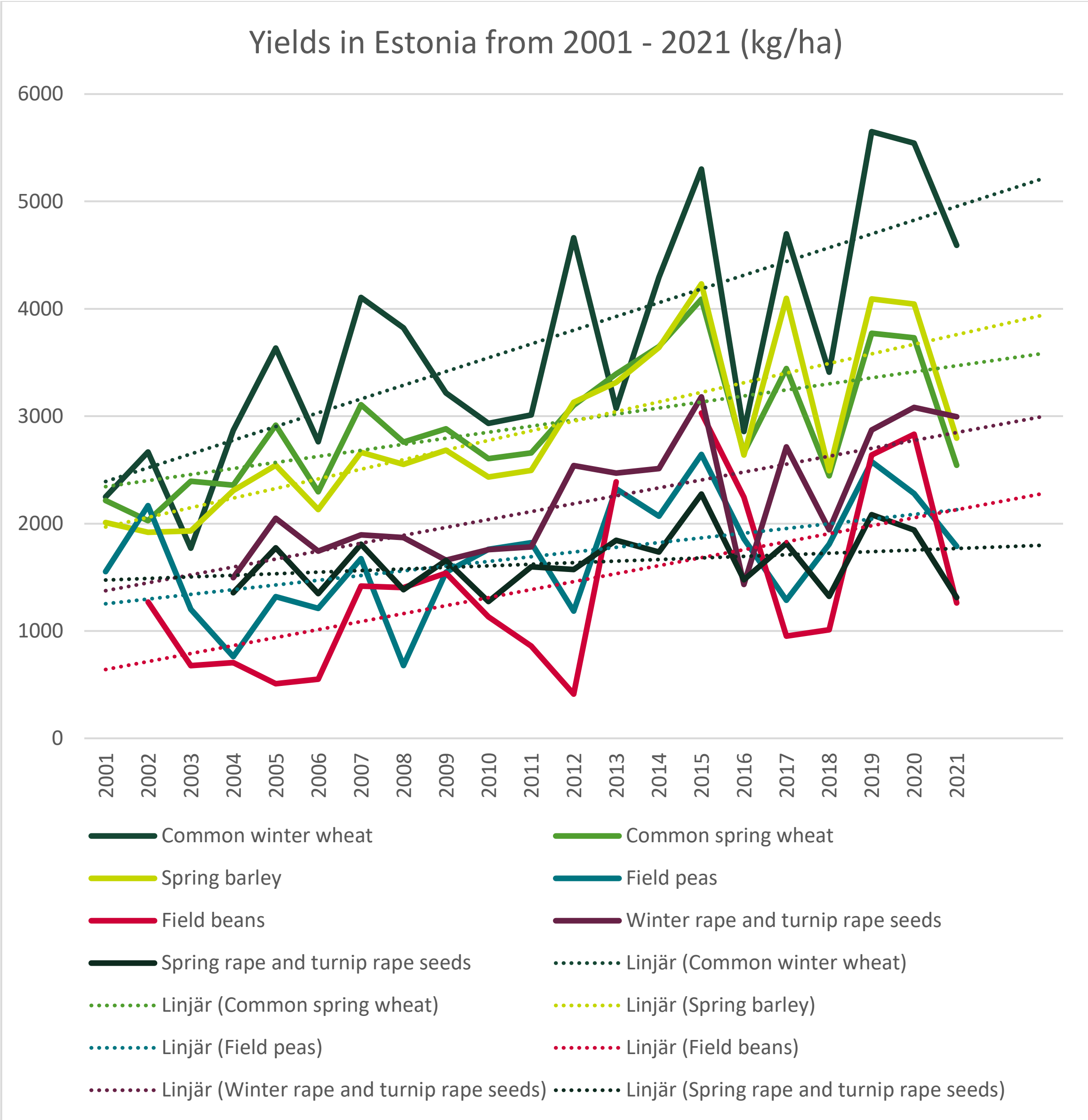

Figure 5:Average yields for organic and conventional production of selected crops in Estonia from 2001 to 2021. Data adopted from Statistics Estonia (2022a).

Figure 6 and Figure 7 show the use of mineral fertilizer and pesticides for the same crops. Data was available for fertilizer use until 2014, for active ingredient in pesticides from 2013 to 2015, and 2020. In both cases it was distinguished between the total cultivated area, which also includes organic production, and conventionally production. In the case of mineral fertilizer use, this results in a negative trend of mineral fertilizer use for total production area, but a positive trend for mineral fertilizer use on conventionally cultivated land. This difference can be explained by an increasing number of organically managed area, where no mineral fertilizer is used. For pesticide use, which is expressed through the amount of active ingredient, the same approach shows different results. Here, the trend is positive, meaning more active ingredient was used, even when the organic production area is included. There could be two explanations for this. Either the very limited amount of allowed pesticide in organic production (regulated in EC 889/2008) and their active ingredients are included in the statistical data, or the pesticide use on conventionally managed fields increased disproportionally to the land area of organic production (European Commission 2008). In any case, the use of active ingredient shows a positive trend.

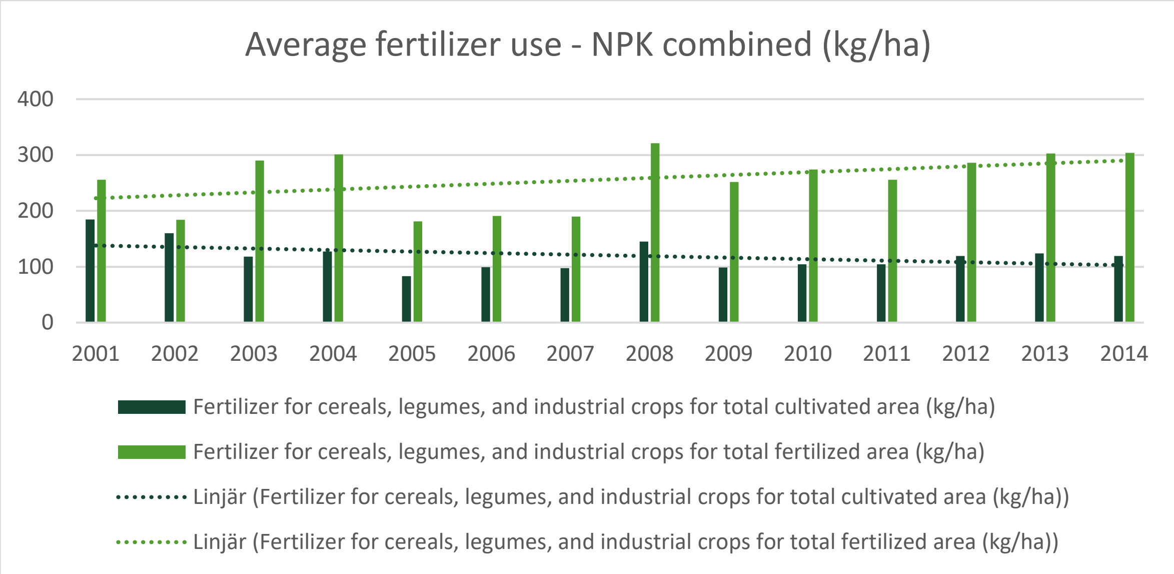

Figure 6: NPK use per year for cereals, legumes, and industriual crops for total cultivated area and conventionally cultivated area in Estonia. Data adopted from Statistics Estonia (2022a).

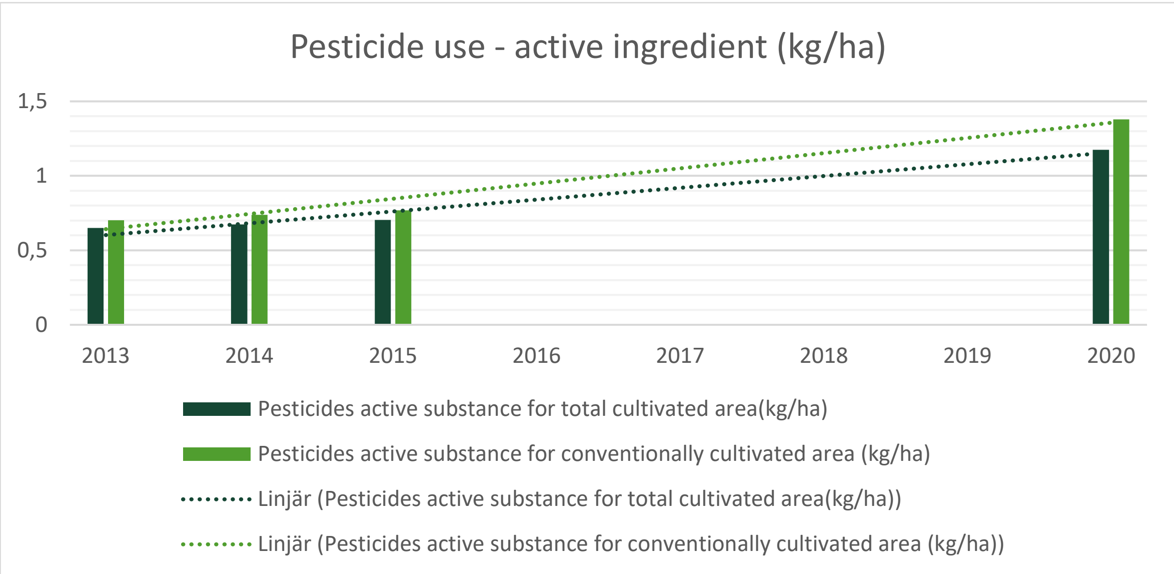

Figure 7: Pesticide use expressed though the relative amount of active ingredient per year for total cultivated area and conventionally cultivated area for cereals, legumes, and industrial crops in Estonia. Data adopted from Statistics Estonia (2022a).

The increased use of synthetic fertilizer increases the risk of nutrient leakage into the environment. It also means a higher need for energy in the production process and thus potentially higher greenhouse gas emissions.

Pesticides are designed to be hostile to life. Thus, the use of more active ingredients means there is a higher risk of being unsustainable. More use means that more product needs to be manufactured, posing additional risks. The more is released in the environment the higher is the risk of potentially harmful effects. However, the extend of such effects is impossible to determine and related also to the environmental context in which they are released. It is also important to consider that not all active ingredients have the same toxicity. One approach to be more precise in determining the environmental impact of different pesticides is to calculate an EIQ (Environmental Impact Quotient) for each product based on a number of factors e.g. toxicity to mammals, birds, aquatic life, time it needs to break down in different environments, application time etc. (Leach & Mumford 2008, 2011) However, the method of determining an EIQ is not without controversy, and has been shown to be a poor measure, especially for herbicides (Kniss & Coburn 2015).

Therefore, while recognising the limitations of such a simple approach, only the amount of active ingredient was used as a proxy for increased adverse effects on the environment without taking into account any other factors.

The results show the trending yield increase in Estonia, as shown in Figure 5, came with increased use of synthetic fertilizer and pesticides. Following the associated risks for the environment, this development cannot be seen as sustainable intensification, especially so for conventionally cultivated land. Interestingly, when only synthetic fertilizer is considered, the increase in yield came at a net negative trend of fertilizer use. This is probably owed to the increasing area of organic agriculture. As can be seen in Figure 8, the total cultivated area for the selected crops has been increasing.

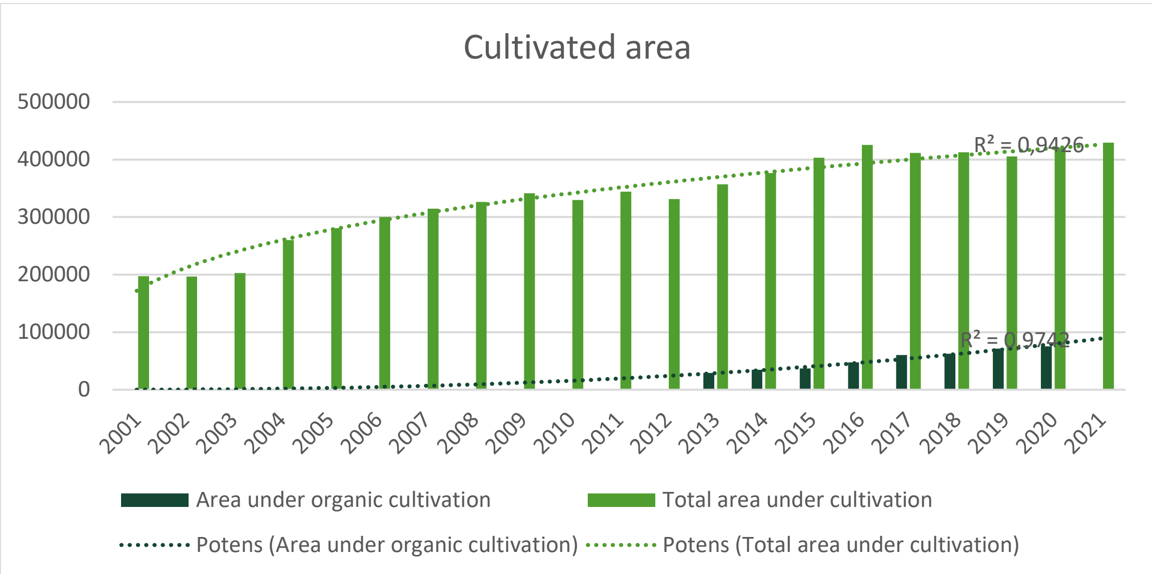

Figure 8: Total area under cultivation and organic area under cultivation for cereals, legumes, and industrial crops. Data adopted from Statistics Estonia (2022a).

For the farm case, data for three fields was available with yields for the crops grown during 2015 – 2019 (Field A) and 2017 – 2020 (Field B and C). To get insights about the performance of each field, the yield per year and crop was compared to the average yield for the same crop in the region of Estonia where the field is located. The results show that all three fields yielded between 17 % and 47 % above the regional average in the given period (Figure 9).

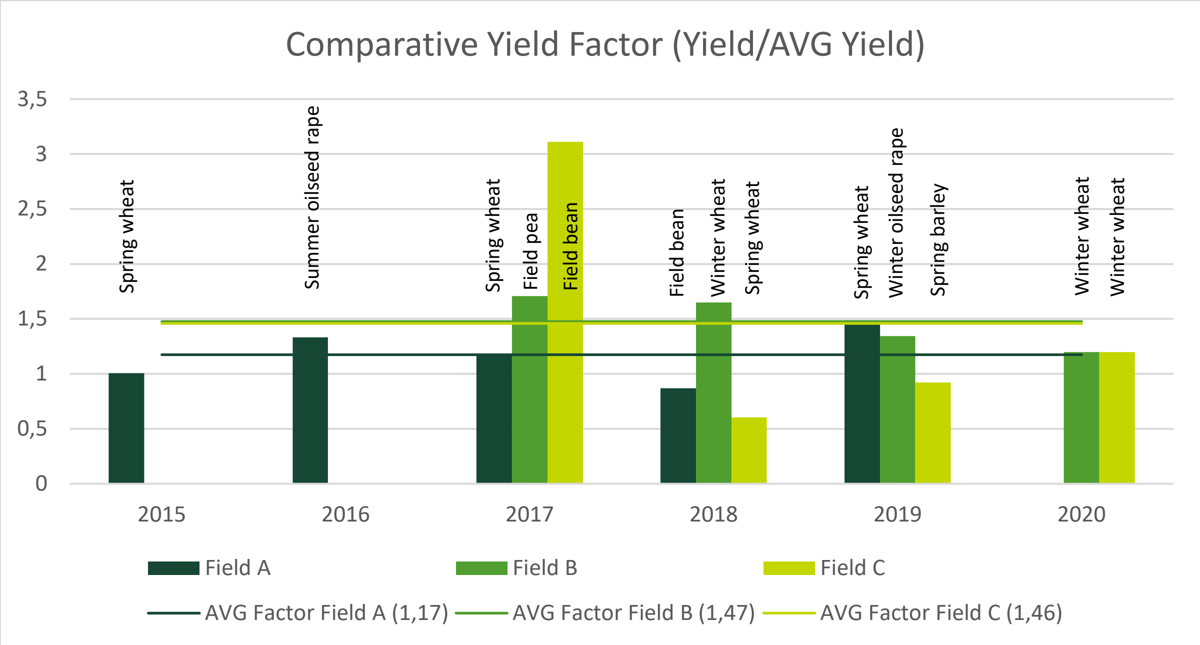

Figure 9: The comparative yield factor shows by which factor the yield on the field per crop and year deviated from the average yield for the same year and crop in the region.

The Estonian average for NPK fertilizer in 2014 was about 300 kg/ha (Figure 6) with a rising trend. As Figure 10 shows, the average for the fields are194 kg/ha, 265 kg/ha, and 225 kg/ha and remain below the Estonian average trend.

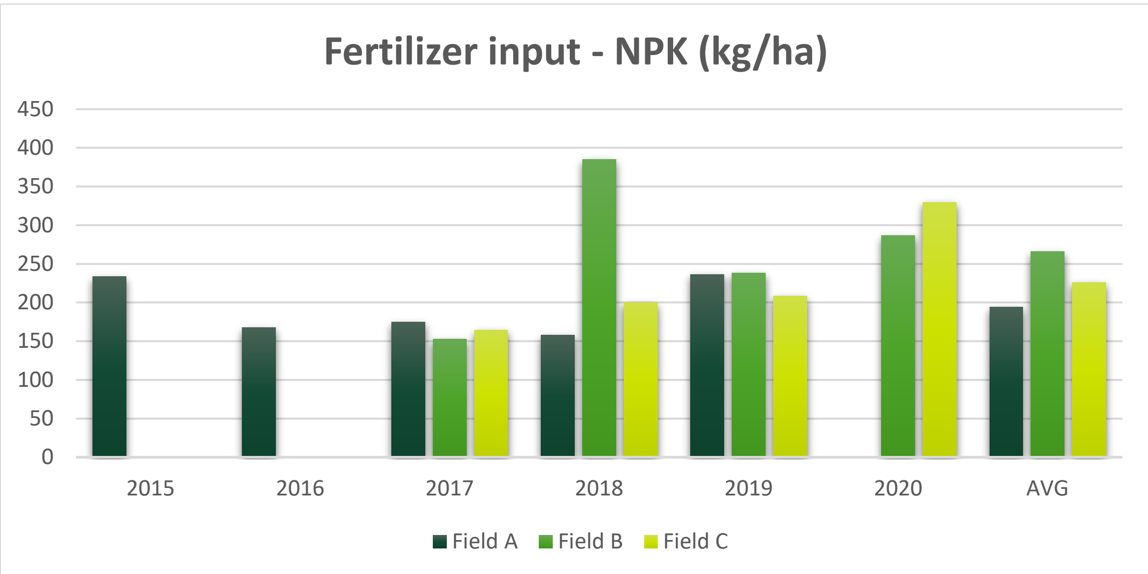

Figure 10: Fertilizer input of NPK per field and year. NPK is expressed as sum of pure N, P_2O5, and K_2O input.

The Estonian average for active ingredient on in 2015 was at 0.75 kg/ha. In 2020 the average in Estonia was at 1.4 kg/ha. There is no data for 2016 – 2019 (Figure 7). Figure 11 shows the average for the fields for the period where data was available to be at 0.54 kg/ha, 0.72 kg/ha, and 1.16 kg/ha. This suggests that the pesticide use was below the Estonian average, similar to the fertilizer use.

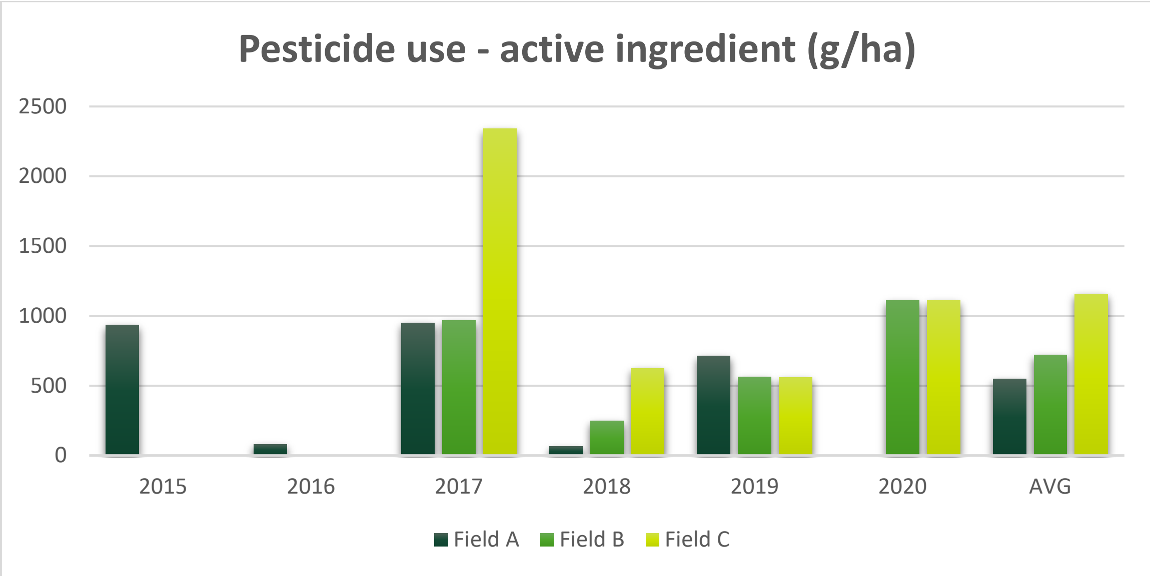

Figure 11: Pesticide use expressed through the relative amount of active ingredient applied per field and year.

This comparison shows that the fields in the case farm performed better than the Estonian average in terms of yield, despite lower input of fertilizer and pesticides. Due to the limited time-period for which data was available, and the fluctuation of pesticide use it is not possible to determine whether the performance of the fields over time improved. It would be possible for farmers to collect the data used for this analysis and track the progress of their farm towards sustainable intensification. However, due to ever changing field conditions, a proper conclusion regarding the progress can only be drawn after sufficient time. Of course, using fertilizer and pesticide input as a proxy for environmental risk is rather limited. More data on the environmental state, such as biodiversity or structural diversity as well as data on losses to the environment, such as leakage into waterbodies and airborne emissions would be more precise. However, such data would also be considerably more difficult to collect. This shows that sustainable intensification, in its simplest definition, poses some difficulties in terms of how to observe and measure it. At best, sustainable intensification can be determined retrospectively and with some delay, as the data set needs to be large enough to reach statistical significance.

The transitional stages might be helpful to concretise the process of sustainable intensification further. As the interview with the farmer shows, there are certain elements of the efficiency, substitution, and redesign stages in progress, detailed in Figure 12. This could explain the better performance of the sample fields compared to the Estonian average at this point. The use of GPS controlled field traffic and soil nutrient analysis for targeted nutrient input, controlled input, and recycling of biomass are examples for the efficiency stage on the farm. Further, the experiment with strip till, and the rejection of inversion ploughing, as well as the increased use of organic fertilizer present examples for the substitution stage. However, the farmer gave up the strip till practice because of difficulties with the equipment. Indeed, MacRae et al. (1990) found the limited access to suitable equipment to be one factor which hinders conversion to sustainable agriculture.

It should also be noted that on the threefields of the case farm (A,B,C) no compost, chicken manure, or biochar was applied during the period of data collection. These practices would also count as substitution processes, and might potentially increase the yield, while saving on harmful inputs. Overall, the attempt to close nutrient cycles with on-farm resources and using natural N-fixation through legumes, as well as the strong focus on improving soil life and soil organic matter content are first signs of a system redesign. The collective creation and deployment of new knowledge by the farmer and the Estonian University of Life Sciences through research projects are also signs of a system redesign within the sustainable intensification concept.

For reference, Table 5 listed the practices contained in the transition stages within sustainable intensification provided in Pretty (2018) and Pretty et al. (2018). Following this limited list, the capacity of the sustainable intensification concept to provide guidance in more specificity is rather limited. In comparison, the practices provided by Gliessman (2015) for the agroecological transition stages efficiency, substitution, and redesign would be equally limited.

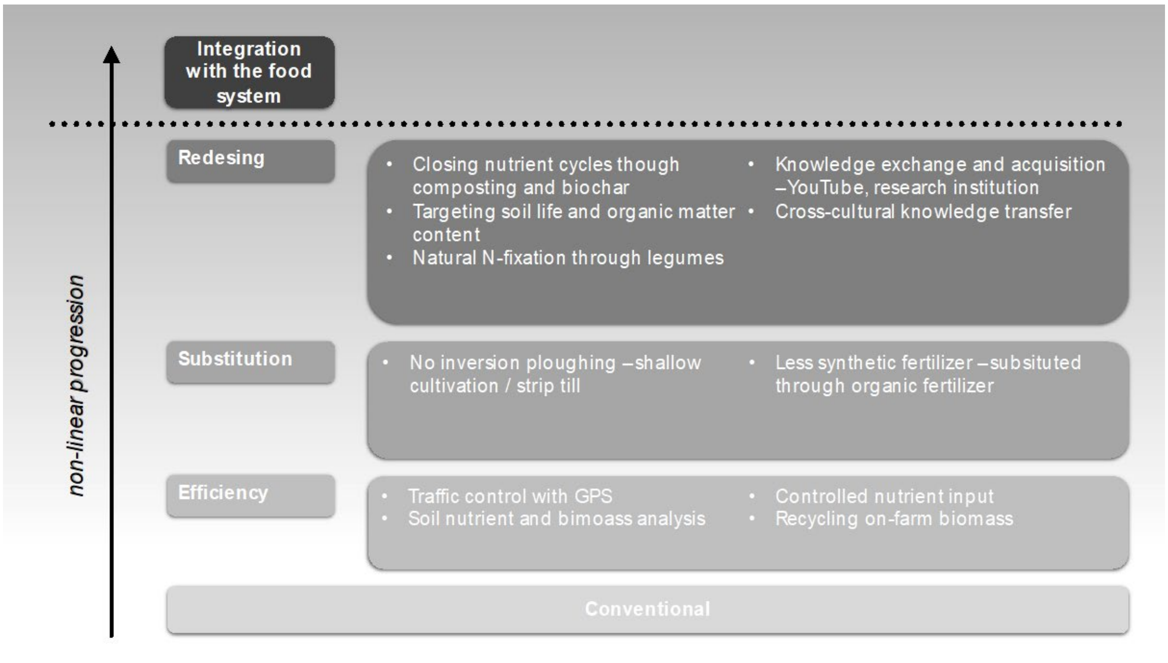

Figure 12: Transitional stages of sustainable intensification of the farm case

However, the 10 elements of agroecology and 13 agroecological principles provide more detailed accounts of the specific practices, which could be used as a benchmark. Figure 13 shows practices which are entailed in the 10 elements of agroecology and currently a part of the farm management.

Diversity	Crop diversity: wheat, barley, oilseed rape, beans, peas, cover crops (sunflower, clover, etc.) Soil cultivation without ploughing	Resilience	Economic resilience – 50% pre-sale of crop Building soil life and organic matter
Co-creation and sharing of knowledge	Innovative and proactive knowledge aquisition and co-creation thorugh Youtube and formal education Adaptation to the Estonian context and reality Collarboration with research	Human and social values	Driving innovation, adapting management practices to market changes
Synergies	Composting, Biochar collaboration with research in innovative process	Culture and food traditions	Cross-culture knowledge exchange with USA and UK
Efficiency	Traffic control with GPS Soil nutrient analysis Compost and organic fertilizer input	Responsible governance	—
Recycling	Composting, biochar, reduced losses though controlled and monitored fertilizer input based on soil nutrint and biomass analysis Attempting on-farm nutrient cycling with biochar and composting	Circular and solidarity economy	—

Figure 13: Correlation of the 10 elements of agroecology with current farm management

While the set of practices identified earlier (Table 6) can inform about the current extent to which they are part of a farming system, they can also serve as a first set of potential further improvement. Farmers could use this list of practices in Table 6 as a guide and inspiration to explore potential improvements. As stated earlier, the context of a farming system should be kept in mind, meaning that not all practices will always be suited or indeed have a positive impact. In practice, this means that questions could be asked by practitioners to systematically explore the potential for improvements of farming systems. Such questions could read along the lines of those in Table 7, which provides a list of questions which were developed during this study.

In the context of the case farm, this means that there are many more practices which could potentially be incorporated into the farming system. For example, the agroecological element ‘diversity’ could inform a set of practices which goes beyond the already established practices of diversifying the crop rotation and improving the soil management. To target the further reduction of pesticide input, the improvement of functional diversity could be attempted. Natural predation of pests could be harnessed and result in decreased need for insecticides. Diversified cropping systems which are not only diverse in a temporal dimension but also in the spatial dimensions, such as intercropping (e.g. see Jensen et al. 2020), or agroforestry (e.g. see Smith et al. 2012; Zhu et al. 2020) could save on herbicide and fertilizer inputs though harnessing competition and natural nitrogen fixation.

Table 7: List of questions to explore potential practical implementation of agroecological practices

1	Which of the practices am I currently employing? • Which elements are well developed?
2	What is the benefit of employing these practices? • Does the practice have a positive social/environmental/economic impact? • Is there further potential to increase positive impact?
3	Which of the practices am I currently not employing? • Which elements are underdeveloped? • Why am I not employing these practices? • What do I know about the practices and what do I not know? • What is needed to employ the practice? • Can I do this on my own? Is there potential to collaborate – in which way and with whom?
4	What are the potential benefits/risks of employing a new practice? • Do I have enough information about the practice? • Is the practice suited for my context? • Is there flexibility to adapt the practice to my context? • What is the expected social/environmental/ economic impact?
5	Who is already employing a potential practice? • What are the learnings? • What is the context?

However, it is not enough to just provide field management practices. As the agroecological elements 'co-creation and sharing of knowledge', 'human and social values', 'culture and food traditions', 'responsible governance' and 'circular and solidary economy' show, the process of developing a farm includes also these social and political aspects. While the extent to which these elements can contribute to sustainable farm development depends on the context, they should at least be considered.

One example which shows the importance to include these elements is the uptake of agroforestry. The opportunities and benefits of agroforestry systems were already recognized by Pretty (1997) in his earliest publication on sustainable intensification. He criticised that despite a long ranging focus of research on agroforestry systems, the resulting systems were developed on research stations and are unsuited for the adoption of farmers. In contrast, where farmers were able to select components of the system and adapt them to their own conditions, some success had been achieved.

Thus, the practices are more likely to work for the farmers if they are developed in a co-creative process. During, the interview, the farmer was directly asked about the possibility to try an agroforestry system. However, while the farmer had seen such systems on a trip to the UK, the benefits were not known. The farmer stated that knowing the benefits would be a necessity to try such a system. As such, farmers should be encouraged to share their experiences and collaborate on the implementation of new practices. Here, a stronger use of online platforms to connect could be beneficial.

The interview with the farmer also showed that there is potential to improve the contributions to the sustainable development of the food system. There is currently no direct connection between the farmer and those who consume the produce. The farmer stated that the grain is loaded on a ship in the harbour, not knowing where it is going. While the reconnection is not the sole responsibility of those who produce, all actors need to be aware and should contribute to reach the full potential. The interview showed that the social impact of the farm is not fully explored. Here, the set of practices in could encourage to think about the social impact of the farming business and its role in developing a circular and solidarity economy, the contribution to local food traditions and culture, the shaping of responsible governance, and the strengthening of human and social values.

As the above elaboration shows, there is potential for more practices to be employed on the farm and to contribute to its sustainable intensification. However, it is not the aim of the present work to make recommendations which practices this should be. Such an attempt should be made only in close cooperation with the farmer. The discussion showed that the ability to guide sustainable farm development though the concepts of sustainable intensification and agroecology differ, especially when informing about potential practices to be implemented. This is despite their similarities, as the analysis of agroecological practices contained in sustainable intensification showed that the two concepts draw on almost the same practices.

The findings, although contextualised through the case of a large-scale Estonian farm, can potentially be transferred to other scales as well. As such, small-scale farming systems can utilise the same approach of taking agroecological practices and measuring sustainable intensification to further transition towards sustainability.

4. Conclusion

The work aimed to show similarities and difference of the FAO 10 elements of agroecology, 13 agroecological principles, and sustainable intensification. The comparison of practices within the concepts showed that agroecological practices contained in the 10 elements are also included in sustainable intensification almost entirely. The two concepts do not exclude each other, but rather take different approaches to solve the same problem. However, agroecology has a boarder ambition to improve the sustainability of the whole food system, while within the sustainable intensification paradigm a strong focus rests on improving the sustainability of production only, falling short of addressing many social issues.

The work also aimed to show how the FAO 10 elements and sustainable intensification can be employed to support the transition of large-scale agricultural operations in Estonia. The contextualisation of the concepts through the case farm showed that sustainable intensification can only be determined retrospectively and only after some time. The concept provides limited guidance on developing farms to be more sustainable through the transitional stages (efficiency, substitution, and redesign). Agroecological elements or principles can provide more substantial guidance through the proposition of specific practices.

Thus. the present research suggests that a focus on the similarities of the two approaches could be harnessed to accelerate the progress towards sustainability. Both approaches taken together can inform practices, as well as to assess and inform the progress towards sustainable intensification.

References

Agroecology Europe (2016). Our understanding of agroecology • Agroecology Europe. *Agroecology Europe*. https://www.agroecology-europe.org/our-approach/our-understanding-of-agroecology/ [2021-12-27]

Altieri, M.A. (2000). Agroecology: principles and strategies for designing sustainable farming systems. *Agroecology in action*,

Altieri, M.A. (2012). Convergence or Divide in the Movement for Sustainable and Just Agriculture. In: Lichtfouse, E. (ed.) *Organic Fertilisation, Soil Quality and Human Health*. Dordrecht: Springer Netherlands, 1–9. https://doi.org/10.1007/978-94-007-4113-3_1

Altieri, M.A., Nicholls, C.I., United Nations Environmental Programme, & Environmental Training Network for Latin America and the Caribbean (2005). *Agroecology and the search for a truly sustainable agriculture*. Mexico, D.F.: United Nations Environmental Programme, Environmental Training Network for Latin America and the Caribbean.

Barrios, E., Gemmill-Herren, B., Bicksler, A., Siliprandi, E., Brathwaite, R., Moller, S., Batello, C. & Tittonell, P. (2020). The 10 Elements of Agroecology: enabling transitions towards sustainable agriculture and food systems through visual narratives. *Ecosystems and People*, 16 (1), 230–247. https://doi.org/10.1080/26395916.2020.1808705

BASF (2021). *Land-Use Change*. https://agriculture.basf.com/global/en/sustainable-agriculture/agbalance/land-use_change.html [2021-06-10]

BAYER (2021). *Mitigating Climate Change A Carbon Zero Future for Agriculture. Cropscience*. https://www.cropscience.bayer.com/who-we-are/sustainable-agriculture/climate-change [2021-06-10]

Bell, S. & Morse, S. (2008). *Sustainability indicators: measuring the immeasurable?* 2nd. ed. London: Earthscan.

Campbell, B., Beare, D., Bennett, E., Hall-Spencer, J., Ingram, J., Jaramillo, F., Ortiz, R., Ramankutty, N., Sayer, J. & Shindell, D. (2017). Agriculture production as a major driver of the Earth system exceeding planetary boundaries. *Ecology and Society*, 22 (4). https://doi.org/10.5751/ES-09595-220408

Carrefour Group (2018). *What is agroecology? Carrefour Group*. https://www.carrefour.com/en/newsroom/what-agroecology [2021-12-27]

Chopin, P., Mubaya, C.P., Descheemaeker, K., Öborn, I. & Bergkvist, G. (2021). Avenues for improving farming sustainability assessment with upgraded tools, sustainability framing and indicators. A review. *Agronomy for Sustainable Development*, 41 (2), 19. https://doi.org/10.1007/s13593-021-00674-3

Clément, C. & Ajena, F. (2021). Paths of least resilience: advancing a methodology to assess the sustainability of food system innovations - the case of CRISPR. *Agroecology and Sustainable Food Systems*, 45 (5), 637–653. https://doi.org/10.1080/21683565.2021.1890307

Cook, S., Silici, L., Adolph, B. & Walker, S. (2015). *Sustainable intensification revisited*. London.

Corteva (2021). *Sustainable Intensification: Closing the Crop Yield Gap*. https://www.corteva.com/who-we-are/outlook/sustainable-intensification-closing-the-crop-yield-gap.html [2021-06-10]

European Commission (2008). *Règlement (CE) n o 889/2008 de la Commission du 5 septembre 2008 portant modalités d'application du règlement (CE) n o 834/2007 du Conseil relatif à la production biologique et à l'étiquetage des produits biologiques en*

ce qui concerne la production biologique, l'étiquetage et les contrôles. *OJ L*. http://data.europa.eu/eli/reg/2008/889/oj/fra [2022-02-22]
FAO (2011). *Save and Grow. A Policymaker's Guide to the Sustainable Intensification of Smallholder Crop Production*. Rome. http://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/421716/ [2021-06-09]
FAO (2013). SAFA: sustainability assessment of food and agriculture systems: indicators. Food and Agriculture Organisation of the United Nations.
FAO (2014). SAFA: sustainability assessment of food and agriculture systems: guidelines. Food and Agriculture Organisation of the United Nations.
FAO (2016). Zero Budget Natural Farming in India | FAO. http://www.fao.org/agroecology/detail/en/c/443712/ [2022-01-26]
FAO (2018). *The 10 elements of agroecology: Guiding the transition to sustainable food and agricultural systems*. Rome, Italy: FAO. http://www.fao.org/documents/card/en/c/I9037EN [2021-05-14]
FAO (2019). *Tool for Agroecology Performance Evaluation (TAPE) - Test version: Process of development and guidelines for application*. Rome, Italy: FAO. https://www.fao.org/documents/card/en/c/ca7407en/ [2022-02-11]
FAO (2021). *Plant Production and Protection Division: Sustainable Intensification in FAO*. http://www.fao.org/agriculture/crops/thematic-sitemap/theme/spi/scpi-home/framework/sustainable-intensification-in-fao/en/ [2021-05-27]
Fay, M. & World Bank (eds.) (2012). *Inclusive green growth: the pathway to sustainable development*. Washington, D.C: World Bank.
Firbank, L.G., Elliott, J., Drake, B., Cao, Y. & Gooday, R. (2013). Evidence of sustainable intensification among British farms. *Agriculture, Ecosystems & Environment*, 173, 58–65. https://doi.org/10.1016/j.agee.2013.04.010
Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D. & Zaks, D.P.M. (2011). Solutions for a cultivated planet. *Nature*, 478 (7369), 337–342. https://doi.org/10.1038/nature10452
Foresight (2011). *The Future of Food and Farming: Challenges and choices for global sustainability*. London: The Govermnet Office for Science.
Francis, C., Lieblein, G., Gliessman, S., Breland, T.A., Creamer, N., Harwood, R., Salomonsson, L., Helenius, J., Rickerl, D., Salvador, R., Wiedenhoeft, M., Simmons, S., Allen, P., Altieri, M., Flora, C. & Poincelot, R. (2003). Agroecology: The Ecology of Food Systems. *Journal of Sustainable Agriculture*, 22 (3), 99–118. https://doi.org/10.1300/J064v22n03_10
Garnett, T., Appleby, M.C., Balmford, A., Bateman, I.J., Benton, T.G., Bloomer, P., Burlingame, B., Dawkins, M., Dolan, L., Fraser, D., Herrero, M., Hoffmann, I., Smith, P., Thornton, P.K., Toulmin, C., Vermeulen, S.J. & Godfray, H.C.J. (2013). Sustainable Intensification in Agriculture: Premises and Policies. *Science*, 341 (6141), 33–34. https://doi.org/10.1126/science.1234485
Gliessman, S. (2018). Defining Agroecology. *Agroecology and Sustainable Food Systems*, 42 (6), 599–600. https://doi.org/10.1080/21683565.2018.1432329
Gliessman, S.R. (2004). Agroecology and Agroecosystems. *Agroecosystems Analysis*. John Wiley & Sons, Ltd, 19–29. https://doi.org/10.2134/agronmonogr43.c2
Gliessman, S.R. (2015). *Agroecology : the ecology of sustainable food systems*. 3rd. ed. Bosa Roca Fla: CRC Press.
Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M. & Toulmin, C. (2010). Food Security: The Challenge of Feeding 9 Billion People. *Science*, 327 (5967), 812–818. https://doi.org/10.1126/science.1185383
Godfray, H.C.J. & Garnett, T. (2014). Food security and sustainable intensification. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 369 (1639), 20120273. https://doi.org/10.1098/rstb.2012.0273
Hill, S. & MacRae, R. (1996). Conceptual Framework for the Transition from Conventional to Sustainable Agriculture. *Journal of Sustainable Agriculture - J SUSTAINABLE AGR*, 7, 81–87. https://doi.org/10.1300/J064v07n01_07

Hill, S.B. (1985). Redesigning the Food System for Sustainability. *Alternatives: Global, Local, Political*, 12 (3/4), 32–36

IEEP (2021). *Sustainable intensification of European agriculture*. https://ieep.eu/publications/sustainable-intensification-of-european-agriculture [2021-05-27]

IFAD (2021). *Climate and environment - preprod - ifad.org*. *IFAD*. https://www.ifad.org/en/ [2021-05-27]

Jensen, E.S., Carlsson, G. & Hauggaard-Nielsen, H. (2020). Intercropping of grain legumes and cereals improves the use of soil N resources and reduces the requirement for synthetic fertilizer N: A global-scale analysis. *Agronomy for Sustainable Development*, 40 (1), 5. https://doi.org/10.1007/s13593-020-0607-x

Kniss, A.R. & Coburn, C.W. (2015). Quantitative Evaluation of the Environmental Impact Quotient (EIQ) for Comparing Herbicides. *PloS one*, 10 (6), e0131200. https://doi.org/10.1371/journal.pone.0131200

Lampkin, N.H., Pearce, B.D., Leake, A.R., Creissen, H., Gerrard, C.L., Girling, R., Lloyd, S., Padel, S., Smith, J., Smith, L.G., Vieweger, A. & Wolfe, M.S. (2015). *The Role of Agroecology in Sustainable Intensification*. Organic Research Centre.

Leach, A.W. & Mumford, J.D. (2008). Pesticide Environmental Accounting: a method for assessing the external costs of individual pesticide applications. *Environ Pollut*, 151 (1), 139–47. https://doi.org/10.1016/j.envpol.2007.02.019

Leach, A.W. & Mumford, J.D. (2011). Pesticide environmental accounting: a decision-making tool estimating external costs of pesticides. *Journal für Verbraucherschutz und Lebensmittelsicherheit*, 6 (S1), 21–26. https://doi.org/10.1007/s00003-011-0674-7

Luttikholt, L.W.M. (2007). Principles of organic agriculture as formulated by the International Federation of Organic Agriculture Movements. *NJAS - Wageningen Journal of Life Sciences*, 54 (4), 347–360. https://doi.org/10.1016/S1573-5214(07)80008-X

Lyu, X., Peng, W., Yu, W., Xin, Z., Niu, S. & Qu, Y. (2021). Sustainable intensification to coordinate agricultural efficiency and environmental protection: a systematic review based on metrological visualization. *Journal of Land Use Science*, 0 (0), 1–26. https://doi.org/10.1080/1747423X.2021.1922524

MacRae, R.J., Hill, S.B., Mehuys, G.R. & Henning, J. (1990). Farm-Scale Agronomic and Economic Conversion from Conventional to Sustainable Agriculture11Ecological Agriculture Projects Research Paper No. 9. In: Brady, N.C. (ed.) *Advances in Agronomy*. Academic Press, 155–198

Merry, S.E. (2011). Measuring the World Indicators, Human Rights, and Global Governance. *Current Anthropology*, 52 (S3), S83–S95

Mockshell, J. & Kamanda, J. (2018). Beyond the agroecological and sustainable agricultural intensification debate: Is blended sustainability the way forward? *International Journal of Agricultural Sustainability*, 16 (2), 127–149. https://doi.org/10.1080/14735903.2018.1448047

Nutrien (2021). *Society*. *Nutrien*. http://www.nutrien.com/sustainability/priorities/society [2021-06-10]

OECD (2001). *OECD Glossary of Statistical Terms - Agro-ecology Definition*. https://stats.oecd.org/glossary/detail.asp?ID=81 [2021-12-27]

Official Journal of the European Union (2014). Opinion of the European Economic and Social Committee on the implications of climate and energy policy on agricultural and forestry sectors (exploratory opinion). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52014AE6932&qid=1639906820875#ntc3-C_2015291EN.01000101-E0003 [2022-02-02]

de Olde, E.M., Bokkers, E.A.M. & de Boer, I.J.M. (2017). The Choice of the Sustainability Assessment Tool Matters: Differences in Thematic Scope and Assessment Results. *Ecological Economics*, 136, 77–85. https://doi.org/10.1016/j.ecolecon.2017.02.015

Petersen, B. & Snapp, S. (2015). What is sustainable intensification? Views from experts. *Land Use Policy*, 46, 1–10. https://doi.org/10.1016/j.landusepol.2015.02.002

Pittelkow, C.M., Liang, X., Linquist, B.A., van Groenigen, K.J., Lee, J., Lundy, M.E., van Gestel, N., Six, J., Venterea, R.T. & van Kessel, C. (2015). Productivity limits and potentials of the principles of conservation agriculture. *Nature*, 517 (7534), 365–368. https://doi.org/10.1038/nature13809

Pretty, J. (2008). Agricultural sustainability: concepts, principles and evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363 (1491), 447–465. https://doi.org/10.1098/rstb.2007.2163
Pretty, J. (2018). Intensification for redesigned and sustainable agricultural systems. *Science*, 362 (6417). https://doi.org/10.1126/science.aav0294
Pretty, J., Benton, T.G., Bharucha, Z.P., Dicks, L.V., Flora, C.B., Godfray, H.C.J., Goulson, D., Hartley, S., Lampkin, N., Morris, C., Pierzynski, G., Prasad, P.V.V., Reganold, J., Rockström, J., Smith, P., Thorne, P. & Wratten, S. (2018). Global assessment of agricultural system redesign for sustainable intensification. *Nature Sustainability*, 1 (8), 441–446. https://doi.org/10.1038/s41893-018-0114-0
Pretty, J., Toulmin, C. & Williams, S. (2011). Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability*, 9 (1), 5–24. https://doi.org/10.3763/ijas.2010.0583
Pretty, J.N. (1995). Participatory learning for sustainable agriculture. *World Development*, 23 (8), 1247–1263. https://doi.org/10.1016/0305-750X(95)00046-F
Pretty, J.N. (1997). The sustainable intensification of agriculture. *Natural Resources Forum*, 21 (4), 247–256. https://doi.org/10.1111/j.1477-8947.1997.tb00699.x
Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F.S., Lambin, E., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., De Wit, C.A., Hughes, T., Van Der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P. & Foley, J. (2009). Planetary Boundaries Exploring the Safe Operating Space for Humanity. *Ecology and Society*, 14 (2). https://doi.org/10.5751/ES-03180-140232
Rockström, J., Williams, J., Daily, G., Noble, A., Matthews, N., Gordon, L., Wetterstrand, H., DeClerck, F., Shah, M., Steduto, P., de Fraiture, C., Hatibu, N., Unver, O., Bird, J., Sibanda, L. & Smith, J. (2017). Sustainable intensification of agriculture for human prosperity and global sustainability. *Ambio*, 46 (1), 4–17. https://doi.org/10.1007/s13280-016-0793-6
Röös, E., Fischer, K., Tidåker, P. & Nordström Källström, H. (2019). How well is farmers' social situation captured by sustainability assessment tools? A Swedish case study. *International Journal of Sustainable Development & World Ecology*, 26 (3), 268–281. https://doi.org/10.1080/13504509.2018.1560371
Royal Society (2009). *Reaping the benefits science and the sustainable intensification of global agriculture*. London: The Royal Society.
Smith, J., Pearce, B.D. & Wolfe, M.S. (2012). A European perspective for developing modern multifunctional agroforestry systems for sustainable intensification. *Renewable Agriculture and Food Systems*, 27 (4), 323–332. https://doi.org/10.1017/S1742170511000597
Statistics Estonia (2022a). *Agriculture | Statistical Database*. https://andmed.stat.ee/en/stat/majandus__pellumajandus__pellumajandussaaduste-tootmine__taimekasvatussaaduste-tootmine [2022-02-16]
Statistics Estonia (2022b). *Agriculture | Statistikaamet*. https://www.stat.ee/en/find-statistics/statistics-theme/agriculture-fisheries-and-hunting/agriculture [2022-02-16]
Syngenta (2019). Syngenta Public Policy Position on Diverse Agricultural Systems. Syngenta International AG. https://www.syngenta.com/sites/syngenta/files/presentation-and-publication/Syngenta-and-agricultural-systems.pdf [2021-06-10]
Syngenta Foundation (2016). *Sustainable Intensification*. *Syngenta*. https://www.syngentafoundation.org/sustainable-intensification [2022-01-23]
The Nyéléni Declaration (2015). Declaration of the International Forum for Agroecology, Nyéléni, Mali: 27 February 2015. *Development*, 58 (2), 163–168. https://doi.org/10.1057/s41301-016-0014-4
Third World Network, S.C.L. de A. (2015). *Agroecology key concepts, principles and practices: main learning points from training courses on agroecology in Solo, Indonesia (5-9 June 2013) and Lusaka, Zambia (20-24 April 2015.*
Tittonell, P. (2014). Ecological intensification of agriculture—sustainable by nature. *Current Opinion in Environmental Sustainability*, 8, 53–61. https://doi.org/10.1016/j.cosust.2014.08.006

United Nations (2019). *Global Sustainable Development Report 2019: The Future is Now– Science for Achieving Sustainable Development*. New York: United Nations Publications. https://sustainabledevelopment.un.org/content/documents/24797GSDR_report_2019.pdf [2021-05-31]

USDA (2007). *Sustainable Agriculture: Definitions and Terms. Related Terms | Alternative Farming Systems Information Center| NAL | USDA*. https://www.nal.usda.gov/legacy/afsic/sustainable-agriculture-definitions-and-terms-related-terms#term1 [2021-12-27]

Viira, A.-H., Poder, A. & Varnik, R. (eds.) (2009). 20 years of transition – institutional reforms and the adaptation of production in Estonian agriculture. *German Journal of Agricultural Economics*,. https://doi.org/10.22004/ag.econ.134882

Wezel, A., Herren, B.G., Kerr, R.B., Barrios, E., Gonçalves, A.L.R. & Sinclair, F. (2020). Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agronomy for Sustainable Development*, 40 (6), 40. https://doi.org/10.1007/s13593-020-00646-z

Wezel, A. & Soldat, V. (2009). A quantitative and qualitative historical analysis of the scientific discipline of agroecology. *International Journal of Agricultural Sustainability*, 7 (1), 3–18. https://doi.org/10.3763/ijas.2009.0400

Zhu, X., Liu, W., Chen, J., Bruijnzeel, L.A., Mao, Z., Yang, X., Cardinael, R., Meng, F.-R., Sidle, R.C., Seitz, S., Nair, V.D., Nanko, K., Zou, X., Chen, C. & Jiang, X.J. (2020). Reductions in water, soil and nutrient losses and pesticide pollution in agroforestry practices: a review of evidence and processes. *Plant and Soil*, 453 (1), 45–86. https://doi.org/10.1007/s11104-019-04377-3

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Appendix 1: Agroecological practices within the redesign stage

Table 8: Attribution of practices and agroecological elements to redesign sub-types of intervention following Pretty et al. (2018).

Practice	Agroecological Element	Redesign type	Redesign sub-types of intervention
• Sharing innovations through formal and non-formal education and inclusion of various actors • Enhancing and sustaining biological regulation of pests and diseases	• Co-creation and sharing of knowledge • Diversity	1. Integrated pest management	• Integrated pest management through farmer field schools • Integrated plant and pest management • Push–pull systems
• Diversifying species and genetic resources/ Enhancing functional biodiversity / managing biodiversity/ vertical, spatial, temporal diversity (agroforestry, intercropping, crop rotation) / local breeds adapted to specific environments (crop-livestock systems, fish polyculture, integrated multi-trophic aquaculture, rotational crop-fish systems • Provisioning of favourable soil conditions for plant growth / Soil management (minimize soil erosion, enhance carbon	• Diversity	2. Conservation agriculture	• Conservation agriculture practices[10] • Zero- and low-tillage • Soil conservation and soil erosion prevention

[10] Here defined as constituted by the three principles ”(1) direct planting of crops with minimum soil disturbance (that is, no-till), (2) permanent soil cover by crop residues or cover crops, and (3) crop rotation” (Pittelkow et al. 2015:365).

storage, promote nutrient balance and cycles, preserve soil biodiversity)			
• Provision of favourable soil conditions for plant growth / Soil management (minimize soil erosion, enhance carbon storage, promote nutrient balance and cycles, preserve soil biodiversity)	• Diversity		• Enhancement of soil health
• Health: Sustain the health of ecosystems and organisms (farming processing, distribution, consumption) • Ecology: Base production on ecological processes • Fairness: Equity, respect, justice, and stewardship • Care: Respond to internal and external demands and conditions	• Diversity • Efficiency • Resilience • Recycling • Human and social values • Culture and food traditions • Circular and solidarity economy	3. Integrated crop and biodiversity redesign	• Organic agriculture[11]
• Diversifying species and genetic resources/ Enhancing functional biodiversity / managing biodiversity/ vertical, spatial, temporal diversity (agroforestry, intercropping, crop rotation) / local breeds adapted to specific environments (crop-livestock systems, fish polyculture, integrated multi-trophic aquaculture, rotational crop-fish systems • Using of integrated holistic approaches (intercropping, organic matter management, crop-livestock integration) • Enhancing and sustaining biological regulation of pests and diseases	• Diversity • Synergies • Efficiency		• Rice–fish systems • Systems of crop and rice intensification • Zero-budget natural farming[12]

[11] Here defined as constituted by the four principles defined by the International Federation of Organic Agriculture Movements (IFOAM): health, ecology, fairness, and care. (Luttikholt 2007)

[12] Here defined as agriculture which is not dependent on purchasing inputs and chemicals. (FAO 2016)

• Optimising external input use			
• Adapting to local context and realities • Sharing innovations through formal and non-formal education and inclusion of various actors	• Co-creation and sharing of knowledge		• Science and technology backyard platforms
• Sharing innovations through formal and non-formal education and inclusion of various actors • Involving actors at multiple scales (for partnerships, cooperation and responsible governance)	• Co-creation and sharing of knowledge • Synergies		• Farmer wisdom networks • Landcare and watershed management groups
• Diversifying species and genetic resources/ Enhancing functional biodiversity / managing biodiversity • Integrated holistic approaches • Diversification and integration / (in animal production systems) • Crop-livestock integration	• Diversity • Synergies • Resilience • Synergies	4. Pasture and forage redesign	• Mixed forage–crop systems • Management intensive rotational grazing systems
• Adapting to local context and realities • Sharing innovations through formal and non-formal education and inclusion of various actors	• Co-creation and sharing of knowledge • Human and social values		• Agropastoral field schools

• Tailoring practices to fit the environmental, social, economic, cultural, and political context			
• Diversifying species and genetic resources/ Enhancing functional biodiversity / managing biodiversity • Diversifying functions • Diversifying of products & services	• Diversity	5. Trees in agricultural systems	• Agroforestry
• Empowering people to become their own agents of change	• Human and social values		• Joint and collective forest management
• Diversifying species and genetic resources/ Enhancing functional biodiversity / managing biodiversity/ vertical, spatial, temporal diversity (agroforestry, intercropping, crop rotation) / local breeds adapted to specific environments (crop-livestock systems, fish polyculture, integrated multi-trophic aquaculture, rotational crop-fish systems •	• Diversity		• Leguminous fertilizer trees and shrubs
• Tailoring practices to fit the environmental, social, economic, cultural, and political context • Embodying transparent, accountable, and inclusive governance mechanisms	• Human and social values • Responsible governance	6. Irrigation water management	• Water user associations • Participatory irrigation management • Watershed management
• Optimizing external input use	• Efficiency		• Micro-irrigation technologies
• Co-creation and sharing of knowledge processes	• Culture and food traditions	7. Intensive small and patch scale systems	• Community farms, allotments, backyard gardens, raised beds
• Encouraging recycling, shorter food circuits	• Circular and solidarity economy		• Vertical farms

• Empowering people to become their own agents of change • Supporting producers during food and agricultural re-design processes	• Human and social values • Responsible governance		• Group purchasing associations and artisanal small producers (in community-supported agriculture operations, tekei groups, guilds) • Micro-credit groups for small-scale intensification
• Diversifying species and genetic resources/ Enhancing functional biodiversity / managing biodiversity/ vertical, spatial, temporal diversity (agroforestry, intercropping, crop rotation) / local breeds adapted to specific environments (crop-livestock systems, fish polyculture, integrated multi-trophic aquaculture, rotational crop-fish systems • Using of integrated holistic approaches (intercropping, organic matter management, crop-livestock integration)	• Diversity • Synergies		• Integrated aquaculture

Appendix 2: Practices within Sustainable Intensification

Table 9: Agroecological practices found in sustainable intensification literature

Agroecological Practices[13]	Found in Sustainable Intensification Literature[14]
Diversity	
Diversifying species and genetic resources/ Enhancing functional biodiversity / managing biodiversity/ vertical, spatial, temporal diversity (agroforestry, intercropping, crop rotation) / local breeds adapted to specific environments (crop-livestock systems, fish polyculture, integrated multi-trophic aquaculture, rotational crop-fish systems	Pretty (1997), Pretty (2008), Pretty et al. (2011), Rockström et al. (2017), Pretty et al. (2018), Pretty (2018)
Diversifying knowledge	Pretty (1997), Pretty (2008),
Diversifying functions	Pretty (2008), Pretty et al. (2011), Pretty et al. (2018), Pretty (2018)
Diversifying activities and livelihood options	Pretty (2008),
Diversifying of products & services	Pretty et al. (2018)
Enhancing and sustaining pollination	Pretty (2018)
Enhancing and sustaining biological regulation of pests and diseases	Pretty (1997), Pretty (2008), Pretty et al. (2011), Rockström et al. (2017), Pretty et al. (2018), Pretty (2018)

[13] Extracted from FAO (2018) and Barrios et al. (2020) following their elaboration on the 10 Elements of Agroecology.

[14] Based on Pretty (2018) and Pretty et al. (2018).

Provisioning of favourable soil conditions for plant growth / Soil management (minimize soil erosion, enhance carbon storage, promote nutrient balance and cycles, preserve soil biodiversity)	Pretty (2008), Pretty et al. (2011), Rockström et al. (2017), Pretty et al. (2018), Pretty (2018)
Co-creation and sharing of knowledge	
Co-creating and sharing	Pretty (1997), Pretty (2008), Pretty et al. (2011), Pretty et al. (2018), Pretty (2018)
Encouraging transdisciplinary engagement	Pretty (1997), Pretty (2008), Pretty et al. (2011), Pretty et al. (2018)
Blending of knowledge (including traditional and indigenous knowledge)	Pretty (1997), Pretty et al. (2018)
Adapting to local context and realities	Pretty (1997), Pretty (2008), Pretty et al. (2011), Pretty et al. (2018), Pretty (2018)
Sharing innovations through formal and non-formal education and inclusion of various actors	Pretty (1997), Pretty et al. (2011), Pretty (2008), Pretty et al. (2018)
Synergies	
Using of integrated holistic approaches (intercropping, organic matter management, crop-livestock integration)	Pretty (2008), Pretty et al. (2011), Rockström et al. (2017), Pretty et al. (2018), Pretty (2018)
Synchronizing productive activities at landscape level (e.g. periodic pruning of hedgerows for erosion control and feed provision)	Pretty (2008), Pretty et al. (2011), Rockström et al. (2017), Pretty (2018)
Involving actors at multiple scales (for partnerships, cooperation and responsible governance)	Pretty (2008), Pretty et al. (2011), Pretty et al. (2018)
Efficiency	
Improving use of natural resources (solar radiation atmospheric carbon and nitrogen)	Pretty (1997), Pretty (2008), Pretty et al. (2011), Rockström et al. (2017), Pretty (2018)
Moving towards information-based (sensors, soil mapping) and knowledge-based production systems	Pretty et al. (2011), Pretty (2018)
Optimizing external input use	Pretty (1997), Pretty (2008), Pretty et al. (2011), Rockström et al. (2017), Pretty et al. (2018), Pretty (2018)
Recycling	
Recycling biomass	Rockström et al. (2017), Pretty et al. (2018)

Recycling nutrients	Pretty (1997), Pretty (2008), Rockström et al. (2017), Pretty et al. (2018)
Recycling water	Pretty (2008), Rockström et al. (2017)
Recycling food waste / waste (e.g. biochar)	Rockström et al. (2017), Pretty et al. (2018)
Minimising of losses / Closing nutrient and energy cycles	Rockström et al. (2017), Pretty et al. (2018), Pretty (2018)
Resilience	
Diversifying of interacting organisms	Pretty (1997), Rockström et al. (2017)
Enhancing ecological resilience	Rockström et al. (2017)
Enabling self-regulation of the agricultural system / maintaining functional balance	Pretty (1997), Rockström et al. (2017)
Adopting management practices aiming to improve animal health	Pretty et al. (2011), Pretty et al. (2018)
Enhance socio-economic resilience	Pretty et al. (2011)
Diversifying and integrating (in animal production systems / at landscape level)	Pretty et al. (2011), Rockström et al. (2017), Pretty et al. (2018)
Human and social values	
Tailoring practices to fit the environmental, social, economic, cultural, and political context	Pretty (1997), Pretty et al. (2011), Pretty et al. (2018)
Emphasising dignity, equity, inclusion, justice, gender equality	Pretty (1997), Pretty (2008), Pretty et al. (2011), Pretty et al. (2018)
Putting aspirations and needs of producers at the heart of the food system	Pretty (1997), Pretty et al. (2018)
Addressing underlying power balances, such as norms, relationships, institutional structures, discrimination, and imbalance	Pretty (1997), Pretty (2008), Pretty et al. (2011)
Building autonomy and adaptive capacity	Pretty (1997), Pretty (2008), Pretty et al. (2011), Pretty (2018)
Empowering women / rural youth / (marginalised groups)[15]	Pretty (1997), Pretty et al. (2011)
Empowering people to become their own agents of change	Pretty (1997), Pretty et al. (2011), Pretty et al. (2018), Pretty (2018)

[15] This practice was grouped by Barrios et al. (2020) under *Culture and food traditions.* Marginalised groups is an addition by the author.

Culture and food traditions	
Supporting diversified diets	Pretty et al. (2011), Pretty et al. (2018)
Co-creating and sharing of knowledge processes	Pretty (1997), Pretty (2008), Pretty et al. (2018), Pretty (2018)
Responsible governance	
Developing effective and innovative policies, institutions, and markets that enable transformative change	Pretty (2008), Pretty et al. (2011), Rockström et al. (2017)
Embodying transparent, accountable, and inclusive governance mechanisms	Pretty et al. (2011), Pretty et al. (2018)
Supporting producers during food and agricultural re-design processes	Pretty (2008), Pretty et al. (2011), Rockström et al. (2017), Pretty et al. (2018)
Granting equitable access to land	Pretty et al. (2011)
Branding of agroecological produce	Pretty (1997)
Circular and solidarity economy	
(Re-)connecting producers and consumers	Pretty et al. (2018), Pretty (2018)
Encouraging recycling, shorter food circuits	Pretty et al. (2018), Pretty (2018)
Prioritising local markets and economic development	Pretty (2008), Pretty et al. (2011), Pretty (2018)
Strengthening the resilience of the local fabric	Pretty (1997), Pretty et al. (2011)
Encouraging fair prices for consumers	

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