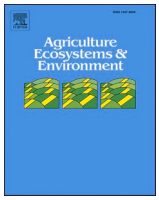
Agriculture, Ecosystems and Environment 385 (2025) 109547

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee



Agricultural diversification across spatial levels – A contribution to resilience and sustainability?

Marie Arndt [a,b,*], Katharina Helming [a,c]

[a] Research Area 3 "Agricultural Landscape Systems", Leibniz-Centre for Agricultural Landscape Research (ZALF) e.V., Eberswalder Str. 84, Müncheberg 15374, Germany
[b] Agricultural and Food Policy Group, Thaer Institute of Agricultural and Horticultural Sciences, Humboldt-Universität zu Berlin, Germany
[c] Faculty of Landscape Management and Nature Conservation, University for Sustainable Development (HNEE), Schickler Straße 5, Eberswalde 16225, Germany

ARTICLE INFO

Keywords:
Robustness
Adaptation
Transformation
Field level
Farm level
Landscape level

ABSTRACT

Decades of efficiency-oriented agricultural intensification have raised sustainability and resilience concerns. Diversification aims to address these issues but varies across time, space and system levels, which hinders an assessment of success of diversification and makes transfer to other regions difficult. We classified diversification measures from field to landscape through a systematic review of 142 papers on intensive agricultural systems in temperate climates. Most measures were at field and farm levels, with fewer at landscape level. Since biodiversity requires provision and maintenance at the landscape level rather than just at the field or farm level, the limited emphasis on landscape-level diversification measures highlights a significant knowledge gap. We further analyzed the impact of diversification on sustainability (integration of environmental, economic, social targets) and resilience capacities (robustness, adaptation, transformation). We show that specific diversification levels were linked to specific sustainability targets and resilience capacities. Environmental aspects are mainly addressed at the field level, economic aspects at the farm level, and social aspects, which are less frequently addressed, are also primarily tackled at the farm level. Resilience is often equated with robustness towards economic (farm) stability. Adaptation relates to climate change and economic instability, while transformation, though rarely addressed directly, emphasizes societal change. Our findings suggest that the concepts of resilience and sustainability are interconnected: resilience can be understood as a property of a system, while sustainability is the overarching target. In literature, transformation relates to societal changes for better integrating social, economic and environmental targets. In contrast, robustness and adaptation address environmental or economic aspects with less linkage to integration of sustainability as a whole. While agricultural diversification is often associated with improved resilience and sustainability, most studies on diversification remain vague about the causal linkage to those concepts. Literature on diversification often focuses only on individual aspects of sustainability or resilience, which undermines both concepts, as it is the holistic consideration of all aspects together that makes a system sustainable or resilient. Our research highlights that diversification at all spatial levels is necessary to achieve resilient and sustainable systems, as each level of diversification addresses distinct sustainability goals or resilience capacities.

1. Introduction

Productivity-focused intensive agricultural systems resulted in structurally simplified landscapes (Clough et al., 2020; García et al., 2020; Hermanns et al., 2017; Burkhard et al., 2016), soil degradation (Rust et al., 2022; Alam, 2014) and transgressing planetary boundaries (Campbell et al., 2017). In addition, intensive agricultural systems lead to simplification of landscape structures which in turn contributes to a loss of biosphere integrity and diversity (Clough et al., 2020; Benton et al., 2003). These environmental changes create a negative feedback loop to agricultural systems. Additional to environmental challenges, agricultural systems are exposed to economic, social and institutional challenges (Meuwissen et al., 2020). Hence, agricultural systems are facing pressure from multiple drivers to which they mostly cannot react

* Corresponding author at: Research Area 3 "Agricultural Landscape Systems", Leibniz-Centre for Agricultural Landscape Research (ZALF) e.V., Eberswalder Str. 84, Müncheberg 15374, Germany.
E-mail address: marie.arndt@zalf.de (M. Arndt).

https://doi.org/10.1016/j.agee.2025.109547
Received 23 August 2024; Received in revised form 22 January 2025; Accepted 9 February 2025
Available online 21 February 2025

adequately, i.e. todays' agricultural systems are neither long-lasting, e.g. sustainable (Agovino et al., 2019), nor responsive to pressures, e.g. resilient (Meuwissen et al., 2020). Nowadays, a trend toward diversification of agricultural production is emerging to overcome the challenges associated with simplified, intensive systems and to transform existing vulnerable agricultural systems into sustainable (Shah et al., 2021; Kremen, 2020; Tamburini et al., 2020) and resilient systems (Szymczak et al., 2020; Roesch-McNally et al., 2018). We distinguish between resilience and sustainability: resilience can be understood as the inherent property of a system, while sustainability is the overarching target of a system. For example, it is consensus nowadays that a truly sustainable food system requires a transformation towards plant-based diets. In this sense, transformation is only the means, while sustainability is the target. The more a system transforms towards sustainability, the more the systems becomes resilient (Reidsma et al., 2023; García-Arias et al., 2015; Bennett et al., 2014; Wilson, 2013). While diversification in agriculture is understood to improve resilience (Reckling et al., 2023; Bowles et al., 2020; Szymczak et al., 2020; Liebman and Schulte, 2015) and sustainability (Reckling et al., 2023; Baldwin-Kordick et al., 2022; Shah et al., 2021), little knowledge on the specific mechanism exists. Also, an overview of available diversification measures and their specific purposes is lacking, as most authors focus on single aspects rather than on an overview. Such missing systematic information hinders an assessment of the success of such measures and makes transfer to other regions difficult.

Diversification takes place at different spatial levels and aims at various goals (Reckling et al., 2023). For example, diversification of cropping systems at the field level leads to enhanced ecosystem services, biodiversity, pollination, pest control and nutrient cycling. This could be shown in a review of Tamburini et al. (2020) and in a meta-analysis on crop diversification by Beillouin et al. (2021). However, diversification could also be conducted on a higher system level such as the farm or the landscape level (Scherr and McNeely, 2008). Benton (2012) for example suggests to manage ecological systems at the landscape level, which strongly influences the ecosystem on the farm and the field level. Moreover, the effect of a single farmer's implementation of diversification practices is less strong than the effect of multiple farmers cooperating to implement those practices (Sutherland et al., 2012). Consequently, spatial and system levels are interlinked when it comes to diversification of agriculture, and there is a connection from plant to field to landscape and finally even to global level (Reckling et al., 2023; Thomson et al., 2019) which justifies the necessity of cross-level research to analyze synergies and trade-offs of diversification measures and their effect on resilience and the sustainability of agriculture.

The objectives of this paper are to

(i) identify possible agricultural diversification measures of intensive agricultural systems in temperate climates,
(ii) develop a classification of these diversification measures across spatial levels and
(iii) analyze the targets of the diversification measures at different spatial levels in regard to the concepts of resilience and sustainability.

We addressed these objectives through a literature review that first defined diversification measures at different spatial levels and subcategories within these levels, and second analyzed how they relate to the concepts of resilience and sustainability.

2. Conceptual framework and definitions

2.1. Conceptual framework

To analyze and classify diversification measures in agriculture, we developed a conceptual framework that combines spatial levels of diversification with resilience and sustainability (Fig. 1). Taking a deductive approach, we took the spatial levels of field, farm and landscape as a starting point of our analysis. We understand field level as a spatial unit characterized by uniform or complementary arable management strategies that are physically implemented within the field, like crops that grow on the same field and are managed by a uniform ploughing scheme or fertilizer dose. The farm level is a structural and economic entity, characterized and steered by decisions of a farm manager and spatially delineated by the managed area. Marketing of products, agritourism, agri-photovoltaics are examples of this level. We perceive the landscape level as an intertwined geo-biophysical and socioeconomic unit, characterized by the interplay between land use and geo-biophysical reactions and often exhibiting a distinct socio-cultural identity. That includes measures beyond the single farm level, e.g. nature protection in nature conservation areas, watershed management, but also cooperations of multiple farmers on marketing.

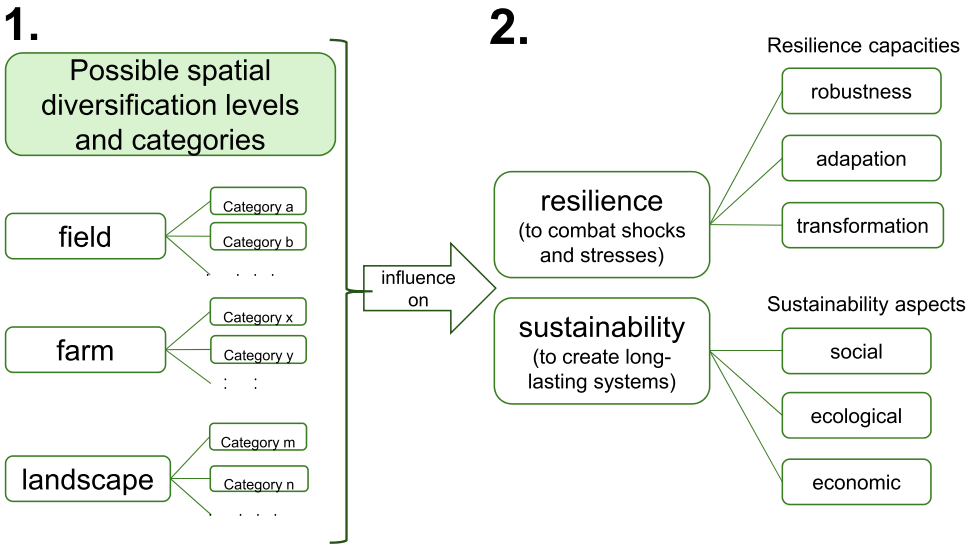


Fig. 1. Conceptual framework on how diversification at different spatial levels might influence resilience and sustainability. In a first step, we identified diversification measures and assigned them to different spatial levels. Within each spatial level, the diversification measures could be grouped into different categories. In a second step, we analyzed how diversification measures at different spatial levels referred to resilience and sustainability.

2.2. Sustainability definition

The understanding of the term "sustainability" changed throughout time, so that an overall valid definition is missing. Evolved from a predominantly natural science concept (von Carlowitz, 1713) nowadays, many authors relate to the political definition of either the Brundtland report (WCED, 1987) or to the framework of the triple bottom line with economic, environmental and social pillars that was coined by Elkington (1997). In any case, sustainability is a normative concept being highly context-dependent (Tillmanns, 2020; Binder et al., 2010; Amsler, 2009). In regard to sustainable agriculture, there are more than 70 political and scientific definitions (Streimikis and Baležentis, 2020) and many underlying concepts on sustainable agriculture change over space and time (Velten et al., 2015). The triple bottom line is one of the most common concepts when sustainability is to be discussed (Zaharia and Zaharia, 2021; Correia, 2019). In line with that, we define sustainability as an overarching target, where social, economic and environmental aspects are treated equally important and trade-offs between them are minimized.

2.3. Resilience definition

While the use of the term resilience is expanding, the concept of resilience is under constant development (Darnhofer et al., 2016).

Resilience was firstly used in the context of ecological systems to describe the handling of these systems with instability (Holling, 1973). By being exposed to internal or external instability, a system often passes through the four different phases of exploitation, conservation, release and re-organization described as the adaptive cycle (Gunderson and Holling, 2002). At that time, Holling (1973) stated that an ecological system needs two characteristics to persist: stability (defined as "*the ability of a system to return to an equilibrium state after a temporary disturbance*" (Holling, 1973, p. 17)) and resilience (defined as "*the ability of (…) systems to absorb changes of state variables, driving variables, and parameters, and still persist*" (Holling, 1973, p. 17)).

Later, the concept of resilience was also applied to socio-ecological systems (Folke, 2006; Carpenter et al., 2001). The Resilience Alliance (2024), a research organization that focuses on resilience in socio-ecological systems, defines resilience as "*the capacity of a social-ecological system to absorb or withstand perturbations and other stressors such that the system remains within the same regime, essentially maintaining its structure and functions. It describes the degree to which the system is capable of self-organization, learning and adaptation (…)*".

To assess the resilience of farms (Darnhofer et al., 2016; Darnhofer, 2014) and of farming systems (Meuwissen et al., 2019), the concept was adapted to the agricultural sector. In this paper, we define resilience as a property of a system and as described by Meuwissen et al. (2019) as the ability of a system to ensure the provision of the main system functions in the face of shocks and stresses, through the three resilience capacities of robustness, adaptability and transformability.

2.4. Interrelations between sustainability and resilience

The two concepts of resilience and sustainability complement each other (Reidsma et al., 2023; Meuwissen et al., 2020). Kelly et al. (2015) assert that sustainable development is an outcome of a resilient community. Resilience can thus be seen as a precondition for sustainability. In this logic, we understand resilience as a system's property characterized by the ability to deal with perturbations, while we understand sustainability as an outcome of the system in terms of successfully balancing multiple social, economic and environmental targets (Meuwissen et al., 2020). In line with that, Bennett et al. (2014) suggest to move the focus away from creating sustainable agricultural systems that aim to improve the social, economic or environmental aspects of agriculture, towards a focus on agriculture that can react to external changes. As a general trend in literature, we observed that both terms are often used without clear definitions.

3. Methodology - Literature review and analysis

The data collection was conducted in three parts: i.) the identification of relevant literature, ii.) a systematic inductive review of the literature regarding diversification measures and iii.) the identification of linkages between diversification measures and the three sustainability pillars (environmental, economic and social aspects) and the three resilience capacities (robustness, adaptation, transformation).

3.1. Identification of relevant literature

The collection of relevant scientific literature was based on a keyword database search on 10.05.2022 in Web of Science Core Collection and Scopus with Boolean operators:

Topic (abstract, keywords, title): agri* OR "value chain" NOT tropic* NOT "development studies" NOT "developing countr* "

AND

Title: diversification NOT income

With these keywords we wanted to include all papers that relate to agricultural diversification including marketing diversification but exclude papers that focus mainly on income diversification (pluriactivity) or that address high yield-gap systems or subsistence agriculture such as in the tropics in so-called developing economies. Only peer-reviewed articles published in English between 2012 and 2022 were considered, and journals not related to the topic were excluded (Fig. 2). The search resulted in 609 articles in Scopus and 330 articles in Web of Science (WoS) which were extracted in two databases. These two databases were then combined, and duplicates were removed, resulting in 730 papers. After a quick screening of title, keywords and abstract and the removal of not relevant publications (e.g. anthologies, systems that are not low yield-gap systems in temperate climates, not agricultural related articles), a full-text analysis of the remaining 142 papers was conducted.

3.2. Qualitative full-text analysis

The systematic literature review derives from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (Page et al., 2021) to provide valid, reliable and replicable results. The first phase of the qualitative analysis was conducted with MAXQDA. Agricultural diversification measures mentioned in the literature were assigned to spatial levels based on the conceptual framework in Fig. 1. Within each spatial level, different categories were developed exploratively. In the second phase, the mentioned diversification measures were related to the diversification objectives of the analyzed literature, using the concepts of sustainability – characterized by environmental, economic, and social targets – and resilience – characterized by robustness, adaptability, and transformability. In this step, we analyzed the line of argumentation used in the selected papers. Even if neither sustainability nor resilience was explicitly mentioned, papers were assigned to categories within these two concepts based on their narrative by exploratively developed inductive keywords. E.g. if ecosystem services were mentioned, we assigned the paper to the environmental pillar of sustainability, if productivity or income was mentioned, we assigned it to the economic pillar and if food security or rural development was mentioned, we assigned it to the social pillar. Although the review process was based on defined keywords, it cannot be separated from the personal interpretation of the authors. If a paper mentioned several diversification categories or if it was referring to not only one of the resilience capacities or sustainability pillars, we listed and counted it several times. The papers that could not be assigned to sustainability (9) or resilience (26) were excluded from this part of the

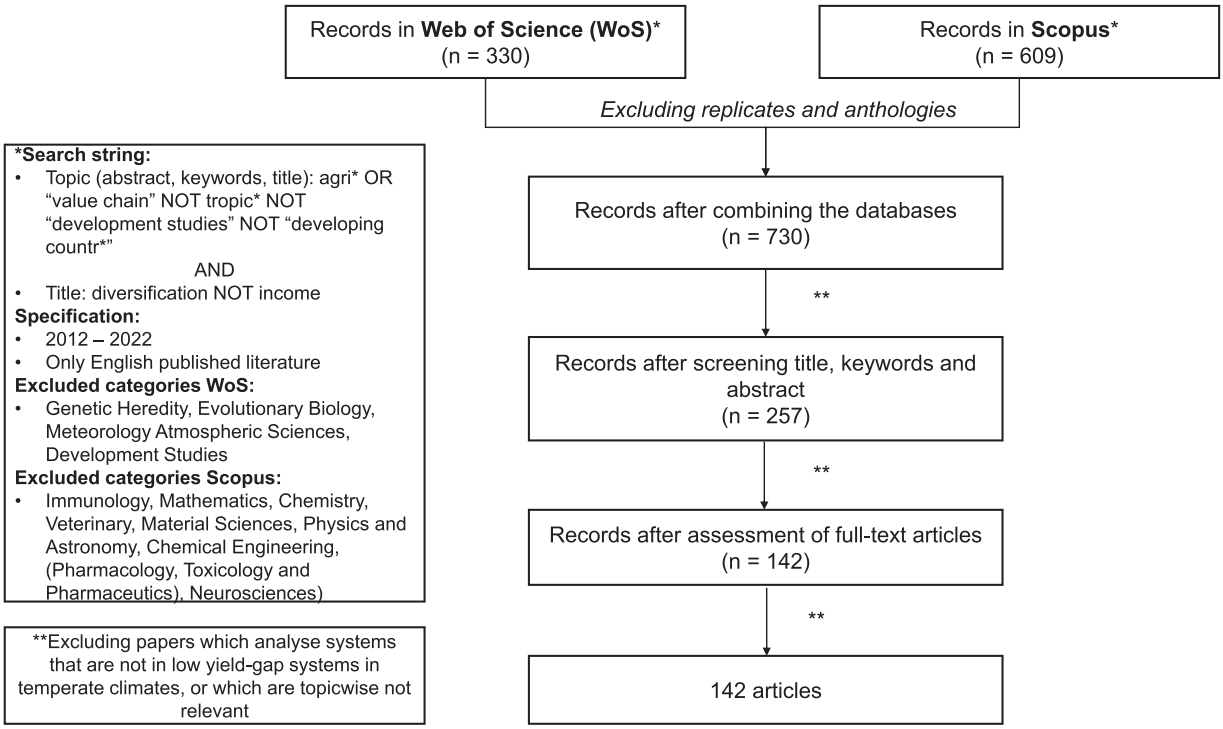


Fig. 2. Literature search and selection flow.

analysis.

4. Results

4.1. Identification and classification of agricultural diversification measures

We identified multiple measures that were framed as agricultural diversification and could mostly categorize them into the three spatial levels of field, farm and landscape. Within each of the three levels, we could further identify several sub-categories of diversification measures (Fig. 3).

Few authors analyzed diversification measures at more than one spatial scale or even used a cross-level approach: Josefsson et al. (2017) for example state that crop diversification impacts on farmland bird community. They conclude that at landscape level, structural diversity is more important than species diversity. Lemaire et al. (2015) state that ecological intensification of agriculture can function only if sufficient diversity is maintained at all levels of organization: the field, the farm, the landscape, and the region.

4.1.1. Field level

74 of the 142 the analyzed papers mention agricultural diversification measures that take place at the field level. These measures can be further categorized into crop diversification and management diversification, each with several sub-categories (Fig. 3).

4.1.1.1. Crop diversification. Crop diversification measures can further be categorized by a system developed by Hufnagel et al. (2020) into the sub-categories

(i) temporal diversification and
(ii) spatial diversification
to which we added the third category
(iii) species diversification.

Spatial agricultural diversification relates to all measures that take place at the same time on a field. Examples are

- intercropping, including multiple cropping (Viguier et al., 2021; Francaviglia et al., 2020),
- relay cropping (Renwick et al., 2021; Rodriguez et al., 2021) and
- strip cropping (Puliga et al., 2021; Sharma et al., 2021; Morel et al., 2020; Hatt et al., 2018).

Temporal agricultural diversification refers to crop rotation, which equals a crop type sequence on a field over time (Chapman et al., 2022; Beillouin et al., 2021, 2019; Martínez-Mena et al., 2021; Puliga et al., 2021; Renwick et al., 2021; Rodriguez et al., 2021; Sharma et al., 2021; Viguier et al., 2021; Alcon et al., 2020; Bowles et al., 2020; Francaviglia et al., 2020; Iocola et al., 2020; Paut et al., 2020; Feliciano, 2019; Ciaian et al., 2018; Leandro et al., 2018; Nunes et al., 2018; Osterholz et al., 2018; Roesch-McNally et al., 2018; Mcdaniel et al., 2016; Lemaire et al., 2015; Smith et al., 2015; Sanderson et al., 2013).

Species diversification, which covers the diversification of crop types or crop varieties at the same time and at the same location, includes mechanisms like

- the introduction of associated plant species (Francaviglia et al., 2020; Beillouin et al., 2019) that are sown in addition to the main crops, like high value crops (Cohen et al., 2020; Feliciano, 2019), underutilized crops (Jahanshiri et al., 2020), legume crops (Cusworth et al., 2021; Osterholz et al., 2018), cultivation of major and minor crops (Meynard et al., 2018), cash crops (Rodriguez et al., 2021; Zimmerer and Vanek, 2016) and cover crops (Chapman et al., 2022; Beillouin et al., 2021; Rodriguez et al., 2021; Sharma et al., 2021; Viguier et al., 2021; Alcon et al., 2020; Kremen, 2020; Nunes et al., 2018; Zarina et al., 2015; Sanderson et al., 2013),
- grassland diversification measures (Kirmer et al., 2018) including fodder diversity on pastures (Sanderson et al., 2013).
- cultivar diversification through breeding, gene selection, landraces and different crop genotypes (Beillouin et al., 2021, 2019; Villegas-Fernández et al., 2021; Jahanshiri et al., 2020; Feliciano, 2019; Villa et al., 2019; Chen et al., 2017; Runck et al., 2014)

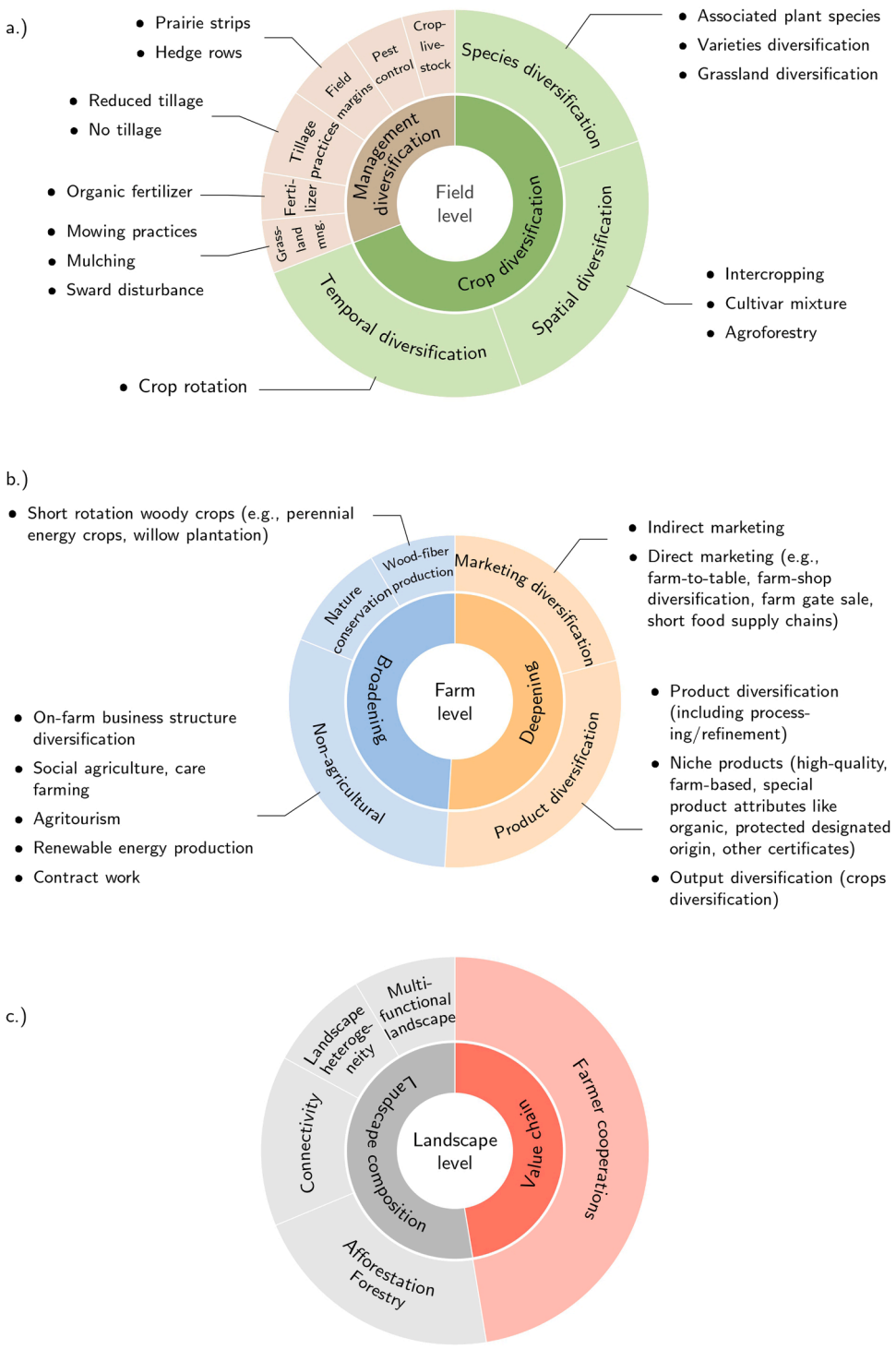


Fig. 3. Classification of agricultural diversification measures across different spatial levels. While there were 73 authors relating to the field level diversification measures (a.), 97 related to farm level diversification options (b.) and 17 to landscape level diversification (c.). The size of the different segments is in relation to the number of papers that referred to these measures.

- agroforestry (Beillouin et al., 2021, 2019; Ben Fradj et al., 2020; Kremen, 2020; Feliciano, 2019; Ferguson and Lovell, 2019; Lakner et al., 2018; Roese et al., 2018; Brandes et al., 2016).

We added agroforestry to this sub-category, as it is conducted at the field, although it is more a measure that influences the landscape. But as Beillouin et al. (2019), Kremen (2020) and Feliciano (2019) mention agroforestry among other crop diversification measures to improve ecosystem services or eliminate poverty, we decided to add it to field level diversification measures.

4.1.1.2. Management diversification. Management diversification measures include all management practices that deviate from the standard practices of conventional farming, such as the use of organic fertilizer (Morugán-Coronado et al., 2022; Francaviglia et al., 2020), mulching (Kirmer et al., 2018), different tillage practices (Chapman et al., 2022; Morugán-Coronado et al., 2022; Renwick et al., 2021; Francaviglia et al., 2020; Kirmer et al., 2018; Nunes et al., 2018), sowing and sward

management mechanisms, (Kirmer et al., 2018), changes in the mowing regime (Hatt et al., 2018; Kirmer et al., 2018), different possibilities for pest control (Vialatte et al., 2022; Puliga et al., 2021; Kremen, 2020; Hatt et al., 2018) and the management of field margins with prairie strips or hedge rows (Chapman et al., 2022; Kremen, 2020; Kirmer et al., 2018; Sardiñas and Kremen, 2015). Within the analyzed literature, a focus was clearly on arable diversification measures. A transition from arable cropping systems to mixed crop-livestock-systems was rarely mentioned as a diversification measure at field level (Roese et al., 2018; Lemaire et al., 2015; Sanderson et al., 2013).

4.1.2. Farm level

Diversification at the farm level (on-farm diversification) comprises any resource or activity related to agriculture, that goes beyond classical farming-activities and that provides goods or services based on existing farm resources. It mostly aims to improve the economy of the farm (Dias et al., 2022; Jack et al., 2021a; Kiryluk-Dryjska and Wieckowska, 2020; Augere-Granier, 2016; Lange et al., 2013) by reallocation and recombination of farming resources away from the classical farming activities towards new activities (Kiryluk-Dryjska and Wieckowska, 2020; Meraner et al., 2015; Lange et al., 2013; Ilbery, 1991). A second diversification measure is off-farm diversification (pluriactivity), involving activities that are not related to farming or the farm itself (Dias et al., 2022; Augere-Granier, 2016). The distinction between those two measures is crucial, as only the on-farm diversification can receive farm subsidies such as the Common Agricultural Policies (CAP) subsidies. While pluriactivity is related to the farmer him/herself, on-farm diversification is taking place at the farm level and can be implemented by other people than the farmer (Kiryluk-Dryjska and Wieckowska, 2020; Augere-Granier, 2016).

We decided to use the sub-categories of deepening (agricultural focus) and broadening (rural development focus) for on-farm diversification (Fig. 3), based on a classification developed by van der Ploeg and Roep (2003) which goes back to Ilbery (1991). We excluded off-farm diversification (regrounding/pluriactivity) from our analysis, as it is not related to agricultural activities.

The farm level diversification measures identified in literature mostly relate to the farm as a business unit, and only indirectly relate to physically diversifying elements at the landscape or at the field level. This business-driven approach becomes even more obvious by the terminology used by some of the authors, such as economies of scale (changing the volume of the production) or economies of scope (changing the amount of outputs/products), which aligns with product diversification (Benedek et al., 2021; Garcia-Cornejo et al., 2020; Alem et al., 2019; Ferguson and Lovell, 2019; Lancaster and Torres, 2019; Ciaian et al., 2018; Roest et al., 2018; Eretová and Jančák, 2017; Salvioni and Agovino, 2015; Amanor-Boadu, 2013).

4.1.2.1. Broadening. Broadening or horizontal diversification covers measures that create additional income through complementary activities connected to agriculture, often with an influence on the rural surroundings (Mazzocchi et al., 2020; Meraner et al., 2015), but which are not directly related to agriculture (Kiryluk-Dryjska and Wieckowska, 2020; Mazzocchi et al., 2020; van der Ploeg and Roep, 2003). Sometimes broadening activities are referred to as structural diversification (Pitrova et al., 2020; Vroege et al., 2020).

A qualitative analysis of the text documents led to three main measures with several specifications that are

(i) wood/fiber production through short rotation woody crops (Ben Fradj et al., 2020; Hauk et al., 2017),
(ii) nature conservation services (Khanal, 2020; Lakner et al., 2018; García-Arias et al., 2015; Meraner et al., 2015; Runck et al., 2014),
(iii) and non-agricultural services as on-farm business structure diversification:

- renting out of building, rural assets and land space (Kristensen et al., 2019; Lakner et al., 2018),
- social agriculture/care farming (Dias et al., 2022; Jack et al., 2021a; Vroege et al., 2020; Eretová and Jančák, 2017; Pölling and Mergenthaler, 2017; Meraner et al., 2015; Heggem, 2014),
- agritourism (Dias et al., 2022; Aronica et al., 2021; Hochuli et al., 2021; Jack et al., 2021b, 2021a; Canovi and Lyon, 2020; Khanal et al., 2020; Khanal, 2020; Mazzocchi et al., 2020; Pitrova et al., 2020; Rytkönen and Tunón, 2020; Salvioni et al., 2020; Stotten, 2020; Vroege et al., 2020; Yoshida et al., 2020; Arru et al., 2019; Canovi, 2019; Alvarez et al., 2018; Boncinelli et al., 2018; Lakner et al., 2018; Meraner et al., 2018, 2015; Roest et al., 2018; Eretová and Jančák, 2017; Pölling and Mergenthaler, 2017; García-Arias et al., 2015; Zasada and Piorr, 2015; Bartolini et al., 2014; Heggem, 2014; Amanor-Boadu, 2013; Lange et al., 2013; Lukić 2013; Di Domenico and Miller, 2012)
- energy production through agriphotovoltaic (Cuppari et al., 2021) and biogas (Heggem, 2014; Chodkowska-Miszczuk and Szymańska, 2013) and
- contract work (Némethová, 2020; Salvioni et al., 2020; Barnes et al., 2015; Salvioni and Agovino, 2015; Bartolini et al., 2014; Lange et al., 2013).

4.1.2.2. Deepening. Deepening or vertical diversification describes agricultural activities that take place at the farm level and are linked to agricultural products. Deepening activities lead to an increase of the output value and can be classified according to Dias et al. (2022) into

(i) product diversification and
(ii) marketing diversification (Mazzocchi et al., 2020; Meraner et al., 2015).

Product diversification measures can be grouped into

- processing (Jack et al., 2021b, 2021a; Garcia-Cornejo et al., 2020; Khanal, 2020; Némethová, 2020; Salvioni et al., 2020; Vroege et al., 2020; Yoshida et al., 2020; Alvarez et al., 2018; Boncinelli et al., 2018; Meraner et al., 2018; Eretová and Jančák, 2017; Barnes et al., 2015; Meraner et al., 2015; Chang and Iseppi, 2012),
- output diversification (Benedek et al., 2021; Bartolini et al., 2014) and
- niche or high quality product diversification like organic farming (Benedek et al., 2021; Garcia-Cornejo et al., 2020; Alvarez et al., 2018; Sutherland et al., 2016), protected designated origin (PDO) (Benedek et al., 2021; Garcia-Cornejo et al., 2020; Alvarez et al., 2018) and insect farming (Tomberlin et al., 2022).

Marketing diversification measures can be classified into

- indirect marketing measures with diversifying the marketing channels (Dias et al., 2022; Roest et al., 2018) and
- direct marketing measures with farm shops (including a café) (Lokier et al., 2021) and farm gate sale measures (Benedek et al., 2021; Jack et al., 2021a; Lokier et al., 2021; Lange et al., 2013).

4.1.3. Landscape level

Diversification at the landscape level includes measures that take place either at the socioeconomic or the geo-biophysical component of a landscape and take place at a higher spatial level than the farm. Those diversification measures were mentioned only in few documents and often the descriptions were vague. Within the landscape level, we could identify two sub-categories (Fig. 3)

(i) landscape complexity and
(ii) value chain diversification.

Landscape complexity can be further subdivided into subsections such as

- creating multifunctional landscapes (Kremen, 2020),
- creating structural diversity and landscape heterogeneity (Beillouin et al., 2019; Hatt et al., 2018; Josefsson et al., 2017),
- habitat connectivity (Kremen, 2020; Burchfield et al., 2019) and
- afforestation and forestry (Sallustio et al., 2018; Hopkins et al., 2017; Sutherland et al., 2016).

We assigned the category of value chain diversification to measures that increase synergies between regional producers (Eretová and Jančák, 2017) and that address a co-existence of value chains in co-operatives (Herde et al., 2020).

4.2. *Diversification measures in combination with resilience capacities and sustainability aspects*

The objective of implementing diversification measures differs throughout the analyzed literature from e.g. improving the economy of the farm or the rural area, to an improvement of energy supply toward an adaptation to climate change. Although diversification is commonly seen as a measure to improve resilience and sustainability (Reckling et al., 2023), we could not draw this general conclusion from our literature analysis. While diversification does not hamper sustainability or resilience, it most often only addresses single aspects of resilience or sustainability and does not address the possible trade-offs.

4.2.1. *Sustainability and diversification*

We assigned diversification measures at different spatial levels to the social, environmental and economic sustainability targets they aim for (Fig. 4, SM1) and also indicated, whether a diversification measure targets more than one dimension (Table 1).

Diversification measures at field level that target the environmental pillar refer to:

- Ecosystem services (ES): improvement or maintenance of ES including pollinator services, biodiversity and soil health
- Environmental impacts: reduction of negative environmental impacts of land use, stabilization of the ecosystem, increase of the environmental sustainability and the heterogeneity of habitat mosaics, improvement of resource use efficiency and conservation of resources, provision of ecological services and establishment of agroecology, protection of biodiversity
- Climate change: increase of the robustness to climate-change-related threads, reduction of greenhouse gases, buffer against weather extremes associated with climate change, increase of drought resistance
- Weed/diseases: combatting weed interference, reduction of diseases, improved weed management, disease risk and pest control, suppression of insects, weed, and disease pressures
- Society-related: development of sustainable agri-food systems.

Diversification measures at the farm level that aim for environmental aspects address:

- Ecosystem services (ES): enhancement of ES, including soil health
- Environmental impacts: reduction of environmental impacts and burdens, improvement of the environmental performance, reduction of emissions, use of agro-environmental schemes
- Climate change: adaptation and mitigation of climate change, buffering of climate change-related risks.

Landscape level diversification measures that target environmental aspects relate to:

- Environmental impact and biodiversity: stabilization of the ecosystem, maintenance of ecosystem functionality and resilience, increased biodiversity
- Ecosystem services (ES): improvement of ES including pollination, soil conservation and nutrient cycling
- Diseases: landscape scale disease dynamics.

Measures at field level that relate to economic aspects address:

- Income: increase of the income and the economic situation

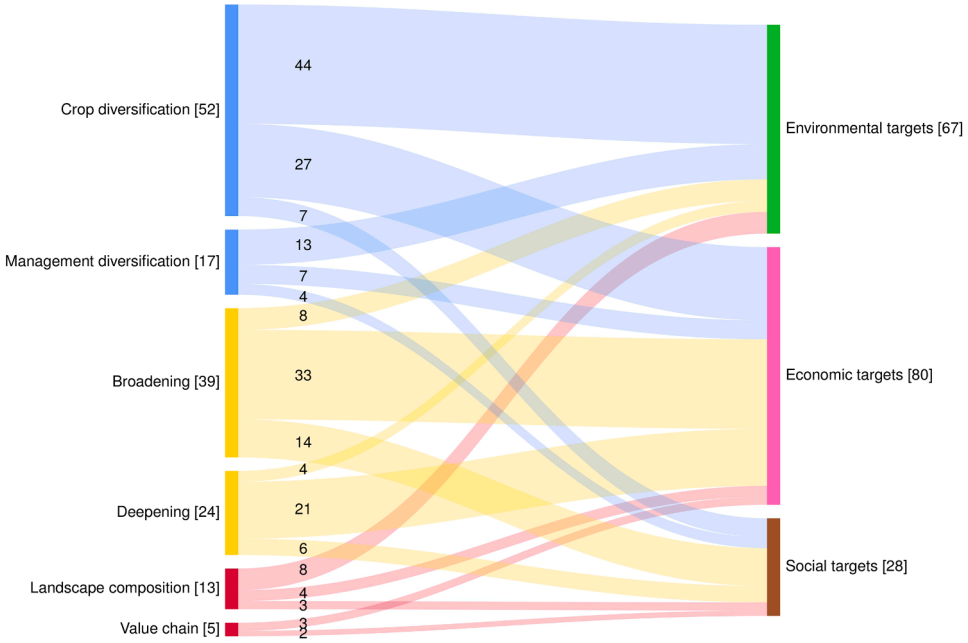


Fig. 4. Diversification measures at different spatial levels (blue = field level, yellow = farm level, red = landscape level) linked to the three sustainability pillars.

Table 1
Diversification measures linked to the sustainability targets. The numbers indicate how many papers at each diversification level refer to either a single sustainability target or to multiple sustainability targets. Landsc. = landscape, env. = environmental targets, eco. = economic targets, soc. = social target, ∑ = the number of papers that we could assign to the specific diversification level.

		∑	env.	eco.	soc.	env. & eco.	env. & soc.	eco. & soc.	env. & eco. & soc.
field	Crop diversification	50	22	8	1	16	3	0	3
	Management diversification	17	9	3	0	1	1	1	2
farm	Broadening	39	2	19	6	4	1	7	0
	Deepening	24	1	15	2	2	0	3	1
Landsc.	Landscape composition	13	6	3	2	1	1	0	0
	Value chain	5	0	3	2	0	0	0	0

- Productivity: increase of agricultural and labor productivity, profitability and yield, maintenance of crop productivity and yield, combatting weed interference as one of the main constraints on productivity
- Efficiency and profitability: improvement of economic efficiency, profitability and efficiency, coping with the contemporary market, creation of economic values
- Risks & Shocks: decrease of the impact of labor-shocks, mitigation and reduction of (business) risks, environmental-dependent risks and income insecurities, reduction of yield gaps, and yield losses and yield failure.

Farm level-related diversification measures that address economic aspects refer to:

- Income: creation of additional income, stabilization or increase of income, reduction of income volatility, broadening and enhancement of income
- Risks and stresses: reduction of climate-related financial risks, overcoming of price competition and price pressures, increase of the profitability at farm level, reduction of energy costs, managing economic instability, shrinking income and seasonality, relief from disturbances and declining revenues through additional income, buffering of economic insecurities due to Covid, Brexit, subsidies etc.
- Financial performance: improvement of financial performance and viability, the economic farm output, the economic resilience and sustainability and the economic impact on the holding and the region
- Productivity and efficiency: increase of agricultural productivity, profitability and cost efficiency at farm scale, improvement of the viability and the technical efficiency, reduction of costs through economies of scale and scope.

Measures at landscape level that relate to economic aspects address:

- Yield: increase of yield
- Risks and stresses: minimization of the economic risks of farming, reduction of financial insecurities, increase of economic and productive resilience
- Income: livelihood diversification in a rural context.

Social aspects that are aimed at by field level diversification measures address:

- Food security: meeting food security goals, improvement and provision of food security, production of a sufficient amount of food, support of self-sufficiency
- Society-related: societal benefits due to increased autonomy.

Diversification measures at the farm level address the following aspects that are related to the social pillar:

- Rural development: sustainable rural development and economic opportunities, increase of employment and job creation in rural areas,
- Pressure: response to policy pressures, combatting social, financial and policy pressure
- Farm functions: encouraging multifunctionality and transformation of the agricultural sector.

Landscape level diversification measures that aim on the social pillar address:

- Land use: relation between land use and landscape diversification and rural development
- food security: increase of product diversification and food security, establishment food self-sufficiency.

While the main aspects addressed at each level are within each sustainability pillar very similar, a difference in the quantity of connections can be seen. While field level diversification measures mainly focus on environmental aspects such as repressing diseases, improving soil health, mitigating climate change, farm level measures mostly relate to economic aspects of sustainability such as creating a stable or higher income or increasing productivity. The few landscape diversification measures mostly relate to environmental aspects. Only few papers combined multiple sustainability pillars. Sanderson et al. (2013) e.g. argues that crop diversification leads to improved ecosystem services, which in turn improves the productivity at the farm and the yield and therefore the income and also relates crop productivity to food security. They relate to all spatial levels and to all three sustainability pillars.

For some of the papers we could not draw a connection to the sustainability pillars. Those either focused only the socio-economic conditions of farmers who diversify (Canovi and Lyon, 2020; Hopkins et al., 2017; Rivaroli et al., 2017; Mc Fadden and Gorman, 2016; García-Arias et al., 2015; Hyytiä 2014), on the effectiveness of policy measurements (Hopkins et al., 2017; Hyytiä 2014), on location factors for certain diversification measure (Pölling and Mergenthaler, 2017) and insect agriculture (Tomberlin et al., 2022).

The numbers indicate the amount of referring papers. If a paper referred to two different diversification categories, it was counted multiple times.

4.2.2. *Resilience and diversification*

We could also assign diversification measures to the three resilience capacities robustness, adaptation and transformation (Fig. 5, SM2) and could also indicate, whether a diversification measure targets more than one resilience capacity (Table 2).

Diversification measures at field level that target robustness refer to:

- Stabilization of income, ecosystem, ecosystem services, finances and yield
- Increase of the robustness of soils, ecosystems, cropping systems and (agro-)ecosystems, and robustness against climate change threats
- Maintenance and sustaining of ecosystem services, productivity, profitability and food production.

At the farm level, robustness was addressed as:

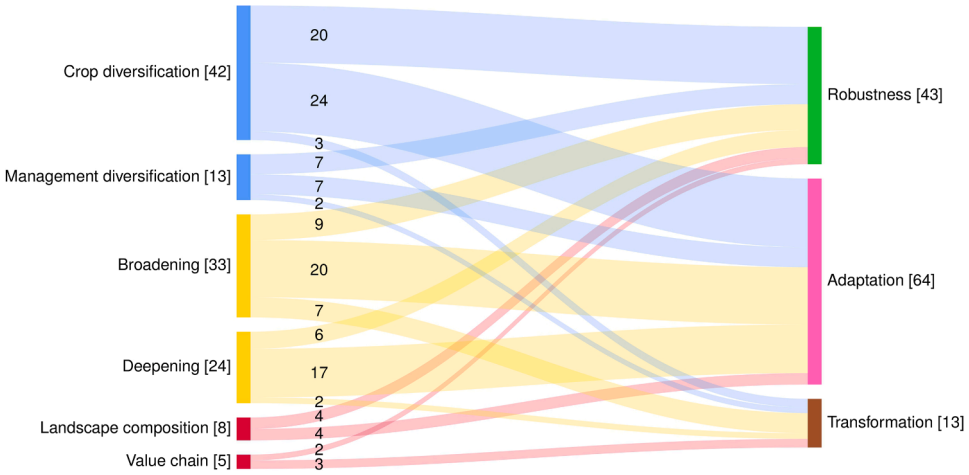


Fig. 5. Diversification measures at different spatial levels (blue = field level, yellow = farm level, red = landscape level) linked to the three resilience capacities.

Table 2
Diversification measures linked to the resilience capacities The numbers indicate how many papers at each diversification level refer to either a single resilience capacity or to multiple resilience capacities. Landsc. = landscape, rob. = robustness, adap. = adaptation, trans. = transformation, ∑ = the amount of papers that we could assign to the specific diversification level.

		∑	rob.	adap.	trans.	rob. & adap.	rob & trans.	adap. & trans.	rob. & adap. & trans.
field	Crop diversification	42	15	19	3	5	0	0	0
	Management diversification	13	5	5	1	1	0	0	1
farm	Broadening	33	6	16	7	4	0	0	0
	Deepening	24	5	15	2	2	0	0	0
Landsc.	Landscape composition	8	4	4	0	0	0	0	0
	Value chain	5	2	0	3	0	0	0	0

- Increase of the robustness to external shocks

- Stabilization of prices, the economic situation and income.

The contributions to robustness of diversification measures at landscape level are

- Stabilization of the ecosystem, economic situation and productivity
- Resolution of environmental challenges
- Resistance against diseases.

Measures at field level that relate to adaptation capacities address:

- Improvement or increase of soil- and ecosystem resilience, food security, farm adaptability and resilience capacities of food growers
- Resolution of adverse effects on pollinator abundance, weed interference, and trade-offs between environmental aspects and food-production
- Reversion of negative effects of intensification and simplification and biodiversity decline,
- Reduction of risks: revenue risk, business risks, economic risk, environmental dependent risks, climate change risks, crop failure risk
- Buffering of shocks: labor shocks, climate change, diseases
- Adaptation of crops to new environments and to climate change.

Farm level diversification measures addressed adaptation capacity as:

- Adaptation of new mechanisms, adaptation to (economic) changes, development of the agricultural sector
- Overcoming challenges and managing risks
- Improvement of profitability, and economic, environmental and social resilience
- Reduction of environmental impacts, energy costs and profitability and the buffering of stagnation
- General creation of more resilient farming systems.

At the landscape level, diversification measures that we assigned to adaptation address:

- Decrease of farm risks.

Transformation was the capacity to which we could relate the least diversification measures. The narrative of those papers aims mostly at a transformation of the existing system. At the filed level that means:

- Creation of new pathways, establishment of agroecology and agro-biodiversity at field level

At farm level, measures that address transformation aim to a:

- Complete change towards a post-productive and multifunctional system
- Transition from a fruit producing farm towards a vegetable producing farm
- Establishment of agritourism or the transformation of the agricultural sector that goes along with urbanization.

Transformation-related aims of diversification at landscape level mention a

- Regionalization of food production as well as a
- Systemic transformation like the establishment of agri-tourism in an area.

Again, the identified objectives differentiate between the three resilience capacities but remain consistent across spatial levels. However, differences in the quantity of established connections can be seen. Field and farm diversification measures mainly relate to adaptation and

to robustness. For the few landscape diversification measures, there is no clear trend towards one resilience capacity, but they relate equally to all three capacities.

As in relation to sustainability, there were papers that could not be assigned to any of the resilience capacities or to the resilience concept in general (Chapman et al., 2022; Dias et al., 2022; Strobl, 2022; Tomberlin et al., 2022; Esquivel et al., 2021; Martínez-Mena et al., 2021; Canovi and Lyon, 2020; Khanal, 2020; Némethová, 2020; Podawca and Dabkowski, 2020; Ang et al., 2018; Hopkins et al., 2017; Mc Fadden and Gorman, 2016; Mcdaniel et al., 2016; Nowak et al., 2016; Bartolini et al., 2014; Hyytiä 2014; Lukić 2013).

In contrast to that, there were papers where the diversification measure refers to multiple spatial levels and which target different resilience capacities. E.g. crop diversification and increasing agro-biodiversity on a higher spatial level are important pathways towards more sustainable and resilient landscapes (Spangler et al., 2022).

The numbers indicate the amount of referring papers. If a paper referred to two different diversification categories, it was counted multiple times.

5. Discussion

5.1. Classification of diversification measures

We could see that the term "diversification" is used for very different measures in agriculture, which calls for a specification and classification. Most of the analyzed agricultural diversification measures could clearly be assigned to one spatial level and within this spatial level to a category. The classification facilitates the comparative analysis of the applicability and effectiveness of measures in different locations and agricultural contexts, which is an important prerequisite for the development of policy support measures.

For some of the identified diversification measures, it can be debated whether they constitute diversification or merely represent management changes. Examples are the use of organic fertilizer, direct marketing, or the production of niche products such as PDOs or organic certified products. However, we included them in our categorization because they were cited as diversification measures. Direct marketing is often an additional income option additional to existing strategies, and PDOs or organic products offer different marketing chains. Moreover, adopting organic agriculture requires systemic change and involves various management techniques that naturally diversify the system.

There are diversification measures that are impossible to be assigned to only one of the levels and often, the levels are interrelated (Bellingrath-Kimura et al., 2021). Examples of cross-level approaches are agroforestry, afforestation, product diversification and rural development. Agroforestry and afforestation take place at the field level, but as new landscape elements are added, they influence the landscape (Sallustio et al., 2018) and the output might be used for wood/-fiber/energy production (Sutherland et al., 2016) which are diversification measures assigned to the broadening category at farm level. Therefore, Hopkins et al. (2017) and Sutherland et al. (2016) for example analyze the decision for afforestation/forestry at farm level. Product diversification which is assigned to the deepening category at the farm level, has an influence on the field level, as it might requires the cultivation of new crops and also influences the landscape level if the supply chain has to be adapted (Arru et al., 2019). Rural development targets the landscape level, but the tangible measures can be conducted at the farm level (Aronica et al., 2021), e.g. through the provision of recreational services, which creates jobs in the area and it also influences infrastructure and public goods of the area (Arru et al., 2019). We have allocated these cross-scale measures to the level at which they are implemented or at which they have the greatest impact. However, these very obvious cross-scale diversification measures highlight the need for a cross-scale approach.

Also, the understanding of terms sometimes differs. While a majority of authors understand crop diversification by either spatial or temporal diverse patterns of certain crops, few authors understand by it genetic variability within a variety (Chen et al., 2017; Runck et al., 2014). Although we decided to integrate genetic variability of crops to the field level diversification measures into the category of species diversification, one could argue to add an additional level below the field level.

The number of papers mentioning diversification measures at landscape level is limited. In many cases, these diversification measures were mentioned as a by-product of diversification measures at other levels. There are three possible reasons for the limited occurrence of landscape level diversification measures: (i) conceptual: the definition of landscape is not clear, (ii) methodological: the search string for the selected papers did not include landscape-level literature and (iii) thematic: there is not enough focus on the landscape level in literature.

(i) Conceptual: there exist several understandings for landscape ranging from merely socio-economic to merely geophysical characterization which makes it subject to the conceptual methodology (Simensen et al., 2018). For example, agricultural landscapes take a farming perspective while rural landscapes address a knowledge-action area (Latimer et al., 2020).

(ii) Methodological: our search string included agri* and "value chain" connected to diversification but did not explicitly mention landscape, farm and field. The fact that only few landscape level diversification measures were mentioned, shows that agricultural diversification is obviously not often linked to the landscape level and that sustainability-based value chains are not related to agricultural diversification. The decision for diversification is taken at the farm level, the area affected is either the field level or the farm level, although these in turn affect the landscape (Bellingrath-Kimura et al., 2021). Therefore, a *landscape approach* is crucial, where all stakeholders in an area balance the competing social, environmental and economic objectives (Dudley and Alexander, 2017; Chatterton et al., 2016).

(iii) Thematic: although there is literature that focus on landscape level approaches (Burchfield et al., 2019; Dudley and Alexander, 2017; Chatterton et al., 2016), our research output shows that the majority of the literature focusing on agricultural diversification does not focus on the landscape level. Since biodiversity and many ecosystem services require a landscape rather than a field or farm to be provided and maintained (Batáry et al., 2020), the low focus on landscape level diversification measures represents a severe knowledge gap.

5.2. Analysis of the relation between spatial levels of diversification and resilience and sustainability

The analysis of the targets of agricultural diversification measures shows that measures address different targets, and thus impact different sustainability dimensions and resilience capacities. Often, authors relate to targets that might be seen as impacting resilience or sustainability without explicitly using those concepts. Consequently, categorizing these papers' targets into resilience capacities or sustainability categories is based on the interpretation of this paper's authors. When papers focused not on the specific targets of diversification but rather on the decision-making process itself (García-Arias et al., 2015; Meraner et al., 2015), it was difficult to assign them to the sustainability categories or to the resilience capacities. In this case, if the narrative was clear, they could still be integrated. Otherwise, the papers were either excluded from this part of the analysis, or the narrative.

5.2.1. Sustainability and diversification

The foci of sustainability related papers strongly differ. While there is always a positive relation between diversification and sustainability targets, often only single sustainability aspects are analyzed and most research on diversification is not directly linked to sustainability, as it is

not mentioned. If researcher refer to it, they often refer to sustainable development in general, or further specify by relating to the Sustainable Development Goals (Feliciano, 2019), to sustainable intensification (Paut et al., 2020; Runck et al., 2014), sustainable cropping systems (Rodriguez et al., 2021) or sustainability of family farms (Jack et al., 2021a). This wide range of interpretation of the term makes a closer look and a categorization necessary to actually understand similarities and differences of papers. We are aware that the triple bottom approach for sustainability is only one option among many to assess sustainability. However, since the normative nature of the sustainability concept precludes a generally applicable definition, the triple bottom approach was the best for our analysis to combine all the different targets into one framework.

The strong link between diversification measures at field level and environmental targets is obvious, as we define the field level as a spatial unit where arable measures are taking place. Those arable measures have - even if they are implemented due to economic reasons - an environmental impact such as supporting ecosystem services, generally reducing the environmental impact of agriculture, dealing with climate change or managing weeds and diseases. The diversification measures at the field level also influence economic targets such as increasing income or productivity, which both result from more stable or just an increased yield. Therefore, economic and environmental targets are complementing each other. Those targets then lead to increased food security and an improved social rural system, which we assigned to the social pillar of sustainability, but here the link is indirect.

Given that the farm level is defined as a structural and economic entity, it is unsurprising that the primary focus of diversification measures at this spatial level is on economic aspects. However, the economic targets are quite similar to the ones that are mentioned at the field level. They range from an increase or a stabilization of income to increasing productivity or efficiency. Only the measure through which those targets shall be reached differs from those at field level, but the aims are the same. A strong link is also between mostly broadening activities to the social pillar, as e.g. agritourism has an influence on the rural area and the development of the rural area including the employment (Stotten, 2020; Zasada and Piorr, 2015), which we assigned to the social pillar. Additionally, farm level diversification measures aim to improve environmental sustainability by reducing the environmental impact of farming or by increasing the ecosystem services.

Diversification measures at the landscape level, which we defined as encompassing geo-biophysical and socioeconomic aspects, aim to either improve the environment through ecosystem-enhancing measures, or to improve rural areas through rural development.

The most striking result was that only few papers address more than one sustainability pillar (Table 1). Some connections exist, e.g. by combining product diversification with crop diversification as a measure to deal with climate change that leads to economic challenges (Valliant et al., 2021). Or broadening activities such as agritourism, social farming or renewable energy production that improve the farm level income, but that also improve the wider rural economies (Aronica et al., 2021; Jack et al., 2021b; Morris and Bowen, 2020; Zasada and Piorr, 2015), preserve natural resources and local traditions and can limit a rural exodus (Aronica et al., 2021). However, the lack of most papers to address all three sustainability pillars together can be seen as a distortion of the sustainability concept, which aims at an integrated consideration of all three dimensions that should not be set against each other. But also positive, unexpected synergies can be overlooked if the pillars are analyzed in isolation. This is a clear knowledge gap, and future research should aim to assess the three sustainability targets together. Policy regulations, such as agri-environmental measures designed to enhance agricultural sustainability, often focus solely on the field or the farm level, but broader levels are rarely considered, as it would require governance (Westerink et al., 2017; Westerink et al., 2015). However, achieving broader sustainability goals requires policy measures that address multiple spatial levels or adopt cross-level approaches. To explore synergies and cross-level effects, research must emphasize all three dimensions of sustainability while evaluating the impacts of diversification across different spatial levels.

5.2.2. *Resilience and diversification*

Only few authors address resilience as a concept of a system that is able to deal with shocks and stresses (Cusworth et al., 2021; Stotten, 2020; García-Arias et al., 2015). Often, authors use specified resilience instead of general resilience, such as agroecosystem resilience (Roesch-McNally et al., 2018), resilient crop varieties (Cortinovis et al., 2020), yield resilience (Bowles et al., 2020) and drought resilience (Renwick et al., 2021). Some authors use resilience as a synonym for robustness, e.g. if they mention resilience against diseases (Villegas-Fernández et al., 2021; Smith et al., 2015) or if they mention resilience and adaptability of cropping systems to climate change (Hufnagel et al., 2020) or increase of economic resilience (Kiryluk-Dryjska and Wieckowska, 2020; Alvarez et al., 2018).

A majority of the analyzed papers links diversification measures either to robustness or to adaptability.

Interestingly, the shocks or disturbances mentioned for both categories are similar. For the field level, systems need to become robust or adapt to climate change or general environmental pressure. Mitigating or adapting to economic risks or income fluctuations is mentioned less frequently but also plays a role in both capacities. Sometimes these arguments are interlinked. For example, field level diversification can help to deal with climate change related risks and uncertainties what would be counted as adaptation, whereas the aim is to stabilize the income, which we linked to robustness. (Kurdyś-Kujawska et al., 2021). At the farm level, the shocks and stresses against which a system needs to be resilient, are very similar for robustness and adaptability again. The focus here is on economic aspects such as buffering income volatility (adaptation) or stabilization of income (robustness), or buffer economic insecurities in general. Stresses that were mentioned solely in the adaptation capacities are policy pressures (Morris et al., 2017; Mc Fadden, 2014) or overcoming the crisis of agriculture that is continually increasing the yields (Meraner et al., 2015). As the landscape level is the vaguest among the spatial levels, it is not surprising that also the mentioned shocks and stresses against which a system can be resilient are rather vague. Challenges at robustness capacities refer to general environmental challenges, large scale resistance or disease control, whereas adaptation capacities mention land fragmentation, and production risks due to climate change.

The transformation capacity differs from the other two capacities, as already evidenced by the number of linkages. At the field level, challenges relate to path dependencies and agroecological transformation. The farm level relates to challenges such as post-productivist systems, and system transformation, due to cost-profit pressures. We also included the farm-wide changing from fruit to vegetable production, as the authors themselves call it a transformation (Gupta et al., 2022). Landscape level diversification measures associated with transformation are regionalization of food chains (Vicente-Vicente et al., 2021), the necessity of rural development (Zasada and Piorr, 2015), or the transformation of the whole agricultural sector after the end of the soviet union (Žakevičiūtė 2019). Hence, the assignment of papers to the transformation capacity is due to certain management practices that can be or have already been implemented, and not due to pressures and targets as it was the case with robustness and adaptability.

The assignment of the different diversification measures to resilience capacities is not always straightforward. Product diversification illustrates this difficulty: While Hamlin et al. (2016) defines the establishment of a niche market as adaptation, Gupta et al. (2022) considers the shift from fruit to vegetable production as transformation. Another challenge is that resilience is not always well defined, so it is sometimes equivocal which definition is meant. In some cases, resilience is not used to describe the agricultural system, but it is relating to the farmer himself and his personal resilience (Mc Fadden and Gorman, 2016). We

focused a lot on the resilience definition of Meuwissen et al. (2019) including the three resilience capacities. However, this definition cannot claim it's solely correctness and is also under constant development, as later, a fourth resilience capacity, *anticipation*, was added (Feindt et al., 2022) to which we did not relate the analysis. Different understandings of resilience exist that all include the reaction of a system to external pressure (Döring et al., 2015), but some focus more on the conserving ability of a system to withstand those stresses (called "equilibrium resilience" by Soubry and Sherren 2022) and others focus more on the transformative aspect of resilience (called "evolutionary resilience"). While Meuwissen et al. (2019) combine in their definition those two approaches, we found it difficult to define the transformation capacity and to draw a clear line between transformation as a resilience capacity and a transformation that leads to a completely new system with new functions, hence, something beyond resilience. An example for that could be farm abandonment. It could be seen as an extreme form of transition, and although some basic functions (the provision of public goods like ecosystem services) are still provided, private goods such as agricultural products are no longer produced, so it goes even beyond the resilience capacity of transformation (Stotten, 2020; Lange et al., 2013). Therefore, one could argue whether farm abandonment could be assigned to the category of regrounding and off-farm business diversification.

The lack of a common understanding of resilience leads to difficulties to effectively target it (Soubry and Sherren, 2022). Furthermore, focusing on individual resilience capacities is insufficient due to their interrelated nature. Our analysis demonstrates that research predominantly addresses robustness and adaptability, while largely neglecting transformation (Table 2). Similarly, European strategies have primarily focused on robustness, with limited attention given to adaptability or transformability (Reidsma et al., 2023). This narrow focus undermines the core concept of resilience, as a system can only be resilient if all three capacities are considered in an integrated manner.

Based on our analysis, we can draw a link between resilience capacities and sustainability pillars:

Transformation capacity often emphasizes societal changes, which refer to environmental, economic and social targets. Therefore, transformation can be linked to the integration and (re-)balancing of the three sustainability pillars. In contrast, robustness and adaptation target mostly on environmental or economic aspects and can be linked to the corresponding isolated sustainability pillars. As a general trend in literature, we observed that both terms are often used without clear definitions and often, resilience was related to economic robustness whereas sustainability was related to environmental sustainability. Additionally, our research outcome confirms our categorization of sustainability as a systems' target as measures addressing sustainability address static targets, and resilience as a systems' property, as it is addressed as an ongoing process or a systems' property.

A notable finding is that literature on agricultural resilience and sustainability frequently highlights agricultural diversification as an important measure (Darnhofer, 2014). Conversely, we could show that literature on agricultural diversification tends to focus on single sustainability targets or resilience capacities, rather than on comprehensively addressing sustainability and resilience. But since every level of diversification seems to focus on specific sustainability targets or resilience capacities, it is crucial to promote diversification across all spatial levels for creating systems that are both sustainable and resilient.

6. Conclusions

We developed a classification of diversification measures across different spatial levels, linking them to the concepts of resilience and sustainability. Diversification measures at the landscape level were considerably less frequently addressed than the measures at farm or field level.

While diversification is often associated with enhancing resilience and sustainability, only few studies explicitly define these concepts or detail the mechanisms through which diversification contributes to them. Our findings reveal that measures at field and farm levels often emphasize environmental or economic aspects, with social dimensions rarely addressed. Regarding resilience, the diversification measures at field and farm level predominantly focus on robustness and adaptability, while transformation capacities are only marginally considered. This suggests that transformation in agriculture is not well understood and that distinguishing transformation from a complete systemic shift to new activities remains challenging. Notably, transformation and the social pillar are closely connected, as both aim to facilitate societal change. In contrast, robustness and adaptability are more aligned with environmental and economic aspects, linking them to their respective sustainability dimensions.

Our analysis highlights that the three sustainability dimensions and resilience capacities are addressed differently across spatial levels, underscoring the need for a cross-level approach to foster resilient and sustainable agriculture. A more nuanced, theory-based, and empirical analysis of how different diversification methods contribute to resilience and sustainability remains necessary. This requires examining resilience capacities and sustainability targets holistically, considering potential synergies and trade-offs.

Funding

This work was supported by the Integrated Priority Project 2022 "CrossDiv - Co-designing smart, resilient, sustainable agricultural landscapes with cross-scale diversification" of ZALF. Open Access funding is enabled and organized by Projekt DEAL

CRediT authorship contribution statement

Helming Katharina: Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Arndt Marie:** Writing – review & editing, Writing – original draft, Visualization, Resources, Methodology, Investigation, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to thank the IPP "CrossDiv" team for insightful discussions, Peter Feindt for valuable remarks, Shaswati Chowdhury for inspiring ideas and Laura Zara for the support with the visualizations.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.agee.2025.109547.

Data Availability

Data will be made available on request.

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