



“Agricultural diversity, farmers’ definitions and uses: The case of Tasmanian farms”

Francesco Tacconi^{a,b,*}, Darcy Lefroy^{b,c}, Katharina Waha^{a,d}, Jonathan Jesus Ojeda^{e,f},
Peat Leith^{a,b}, Caroline Mohammed^b

^a Commonwealth Scientific and Industrial Research Organisation (CSIRO), St Lucia, Brisbane, Queensland, 4067, Australia

^b Tasmanian Institute of Agriculture - University of Tasmania, Sandy Bay Campus, Hobart, Tasmania, 7005, Australia

^c CSIRO, Battery Point, Hobart, Tasmania, 7004, Australia

^d University of Augsburg, Faculty of Applied Computer Sciences, Institute of Geography, Alter Postweg 118, 86159, Augsburg, Germany

^e Terradot, Stanford, CA, United States

^f Centre for Sustainable Agricultural Systems, University of Southern Queensland, Toowoomba, QLD, 4350 Australia

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ABSTRACT

Agricultural diversity can contribute to improving agriculture and food systems sustainability, but it is commonly associated with smallholdings and subsistence farming. The drivers and trade-offs around diversification strategies in high-income countries remain poorly understood. Tasmania, due to its diverse climate and geography, is among the most agro-diverse regions in Australia, which makes it an interesting case to study. This paper addresses three main research questions: (1) How do farmers define agricultural diversity and diversification? (2) How is diversification ‘used’ as a farming strategy? and (3) What incentives and barriers are currently structuring the adoption of these strategies? We conducted Computer-Assisted Telephone Interviews with 95 farmers across Tasmania and analyse them qualitatively using thematic analysis. Our findings show that attitudes and motivations towards agricultural diversity vary among farmers depending on personal experiences, values and farming backgrounds and context. These motivations may influence the role that agricultural diversity plays within farms. We could identify a net distinction between farmers using diversification strategies: (1) as integral components of their business to respond to different needs and purposes, (2) purely as additional business opportunities or (3) for motivations that go beyond the financial value. Nevertheless, other farmers prefer specialisation as they find it more profitable or consider that investing in additional activities is too demanding or financially risky. As only 14 farms in our sample specialised in a single product, our results suggest that agricultural diversification strategies can also represent viable options also in a high-income country. However, the variety of responses and perspectives among the participants of this study indicates that future research and policy interventions promoting agricultural diversity should aim to identify and address the specific challenges encountered by the different approaches to diversification employed by farmers.

1. Introduction

Agriculture has historically been a major feature of landscape transformation and simplification (Ramankutty et al., 2018; Folke et al., 2021). In high-income countries especially, agricultural systems have moved towards larger and specialised farms, and relatively homogeneous production at global scale, mostly driven by global markets and technological innovation (Khoury et al., 2014; Ramankutty et al., 2018; Abson 2019; Garrett et al., 2020). This has contributed to enhancing agricultural productivity, reducing labour costs and food prices, but has

also precipitated concerns about long-term sustainability (Benton and Bailey 2019; Garrett et al., 2020; Schut et al., 2021). The simplification and homogenisation of agricultural landscapes have implications for biodiversity (IPES-Food 2016; Lanz et al., 2018; Estrada-Carmona et al., 2022). The genetic erosion of domesticated crop and livestock species and the loss of wild species due to the decline of landscape complexity reduce ecosystem services such as pollination and natural pest control (Tschamtkte et al., 2012; FAO 2019; Dainese et al., 2019). Moreover, less diverse farms can be more vulnerable to climatic or market risks, and pests and diseases (Di Falco and Perrings 2005; Baumgärtner and Quaas

* Corresponding author. CSIRO, 306 Carmody Road, St Lucia, Queensland, 4067, Australia.

E-mail address: francesco.tacconi@csiro.au (F. Tacconi).

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2010; Dainese et al., 2019; Tamburini et al., 2020), hence they tend to depend more on external input use (Gaba et al., 2015; Spangler et al., 2020; Schut et al., 2021).

Diversified farming systems may be more sustainable. There is compelling evidence that a greater diversity of crop and livestock species enhance wild biodiversity and the provision of ecosystem services (Kremen and Miles 2012; Wood et al., 2015; Estrada-Carmona et al., 2022). Increasing agricultural diversity, through practices like intercropping, can enhance nutrient cycling and reduce soil erosion, then potentially allow the reduction of external inputs (Thrupp 2000; Gaba et al., 2015; Isbell et al., 2017). This can also increase the stability of crop yields and buffer climate and market risks, as farmers do not rely only on one product (Di Falco and Perrings 2005; Renard and Tilman 2019; Rosa-Schleich et al., 2019).

Studies focusing on global and national scale show that specialisation trends are prevalent in higher-income countries, where capital, inputs and technologies are more available, or in regions characterised by farms of larger dimension, like North America, Australia and South America (Herrero et al., 2017; Robinson 2018; Neuenfeldt et al., 2019; Giller et al., 2021). However, large-scale analyses may overlook underlying trends at regional, local and farm scale (Khoury et al., 2014; Martin et al., 2019; Renard and Tilman 2019; Aguiar et al., 2020). Analyses at smaller scales can also reveal drivers of change such as farmers' motivations and objectives which depend on contextual interactions between global and local socio-economic, political and environmental factors and drivers (Scoones 1998; Cayre et al., 2018; van Zonneveld et al., 2020).

While agricultural diversification strategies are most commonly associated with smallholdings and subsistence farming systems (Giller et al., 2021; Tacconi et al., 2022), the literature investigating its potential role and viability in high-income regions is increasing. However, the focus has predominantly been on European (Casagrande et al., 2017; Meynard et al., 2018; Cimino et al., 2021) and North American farming systems (Valliant et al., 2017; Roesch-McNally et al., 2018; Lancaster and Torres 2019), but less on Australia (Medhurst and Segrave 2007; Fielke and Bardsley 2013; Bardsley et al., 2019). Australian agriculture is among the least regulated and subsidised in the advanced economies (Greenville 2020). Thus, it offers a valuable case study to explore farmer perceptions of agricultural diversity and their motivation behind the adoption of diversification strategies, in a context where distortionary policies affecting farmer decision-making are less pervasive than in other OECD countries (Brown et al., 2021).

Tasmania, an island state of Australia, provides an appealing context of study to understand when and how agricultural diversity can (or not) play a crucial role also in a high-income country. Due to its unique climate and geography, Tasmania is among the most "agro-diverse" regions of Australia, both in terms of products and farm characteristics (Meinke et al., 2017; Leith et al., 2019). In this study, we focused on agricultural diversity at farm scale and conducted a qualitative analysis on a diverse sample of Tasmanian farmers from different regions of the state. Within our sample, we seek to address the following research questions: (1) How do farmers define agricultural diversity and diversification?; (2) how is diversification 'used' as a farming strategy?; (3) what incentives and barriers are currently structuring the adoption of these strategies? Through this analysis, we aim to identify potential diversification and specialisation pathways that may be more broadly relevant.

2. Background

2.1. Conceptualising agricultural diversity

In this study, we examine diversity at the farm scale based on the number of crops and livestock species produced (on-farm diversity). However, agricultural diversity is a wider "umbrella" covering different concepts and definitions in the literature, mostly depending on the scale,

discipline and goals of the analysis conducted (FAO 2019; Hufnagel et al., 2020). This multitude of definitions and approaches to agricultural diversity can involve either policy makers, researchers and farmers, creating confusion and potentially leading to missed opportunities regarding the potential benefits from the adoption of the optimal diversification strategy configuration (Hufnagel et al., 2020; Maas et al., 2021).

At the plot scale, diversity usually refers to the characteristics of the soil and its microbial richness (Kremen et al., 2012; Rosa-Schleich et al., 2019). On-farm diversity may also consider the genetic or variety diversity within the same species (Jarvis and Hodgkin 2008; Galluzzi et al., 2010), as well as a range of management practices including intercropping, the use of cover crops or hedgerows, agroforestry, organic farming, seasonal or annual rotation, and crop-livestock mixed systems (Lin 2011; Kremen et al., 2012; Gaba et al., 2015). Agricultural biodiversity is a more holistic concept that encompasses wild plants, animal species and insects interacting with the agricultural system and can refer to multiple scales from the farm to its surrounding landscape (FAO 2019; Bardsley et al., 2019). Some definitions of agricultural diversity embed also other livelihood activities in which farmers are involved in the context of analysis. Farmer livelihood diversification may consist of the use of processing facilities on the farm for product transformation and value-adding, the engagement in non-farm activities related to agricultural production, such as agritourism, or earning an additional income from off-farm activities (Barrett et al., 2001). Finally, a more comprehensive concept of agricultural diversity is defined by multifunctional farming, which expands the farm role beyond the intrinsic agrarian production to the provisioning of external environmental and sociocultural services, including recreational, educational, economic and ecosystem services (van der Ploeg et al., 2009; García-Arias et al., 2015).

Farmers' perceptions of what agricultural diversity is, its value and role are likely to vary from the above more formal concepts, and differ among individuals based on their farming experience, approaches, and personal values among other things (Medhurst and Segrave 2007; Cayre et al., 2018; Bardsley et al., 2019). These different concepts and perceptions are not necessarily mutually exclusive and can, to some extent, interact and influence each other (Hunt 2007; Fielke and Bardsley 2013; Estrada-Carmona et al., 2022). We posit here that further exploration of farmers' perceptions and definitions of agricultural diversity, may support the understanding of the adoption of diversification practices in different contexts and for different purposes. This, in turn, can enhance targeting local policy interventions and investments (Brown et al., 2021; Maas et al., 2021). Therefore, this study builds on prior research on farmers' definition of agricultural diversity, offering an in-depth analysis contextualised to the case of Tasmania.

2.2. Drivers and constraints of agricultural diversity

There is extensive literature exploring drivers and constraints of agricultural diversity. Previous studies suggest that farmer decisions and ability to diversify are often highly context-specific and depend on the combination of different factors (Gupta et al., 2022; Tacconi et al., 2022). These factors, considered for the design of this study, are highlighted in this section.

Economists posit that farmers decide among different farming strategies based on what they perceive as more beneficial to maximise their utility, which combines factors such as income, risk aversion, well-being and personal beliefs (Di Falco 2012; Bowman and Zilberman 2013; Isbell et al., 2021). Economies of scale and increased technical efficiency are among the main advantages of farm specialisation, especially in large-scale operations (de Roest et al., 2018; Abson 2019). Conversely, diversification can generate economies of scope and complementarity, that arise when the production of more than one product costs less than producing the same products separately (Bowman and Zilberman 2013; de Roest et al., 2018). An example is crop-livestock integrated systems

using manure as fertiliser for cropping or crop residue to feed livestock (Chavas and Di Falco 2012). Risk management is another common motivation for adopting diversification strategies, as risk-averse farmers are more inclined to diversify to buffer farming risks through a broader range of products (Baumgärtner and Quaas 2010; Pascual et al., 2011). Some studies also indicate that farmer worldviews strongly influenced by relational values, such as socio-ecological, cultural and aesthetic factors, can determine the decision to maintain and enhance on-farm diversity (Cayre et al., 2018; Chapman et al., 2019; Isbell et al., 2021). For instance, strong relational values can be often observed among farmers adopting organic and regenerative agriculture practices (Bardsley et al., 2019; Gosnell et al., 2019).

Farmers' ability to diversify depends on the combination of external factors (climate, political, institutional and socio-economic contexts) and farm internal assets and relationships, including human, physical, financial and social assets (Scoones 1998; Ellis 2000). Land characteristics and climate can, for instance, stimulate or hamper diversification, especially with exposure to variable conditions or extreme climatic events (Roesch-McNally et al., 2018). Regarding the political and socioeconomic context, an example are regions that have historically promoted specialisation in particular commodities, which can experience socio-technical lock-ins that hinder farmers to the dominant species. This emerged in studies such as Meynard et al. (2018) and Roesch-McNally et al. (2018), conducted in France and the Corn Belt region in the US, respectively. In these situations, access to updated information is critical, as farmers need specific knowledge, skills or technologies to adopt additional species (Medhurst and Segrave 2007; Bianchi et al., 2013; Brown et al., 2021). Farmer networks can enable diversification by fostering knowledge and practice exchange among farmers (Casagrande et al., 2017; Isbell et al., 2021). Drivers can also include access to alternative market options, such as local farmer markets (Fielke and Bardsley 2013; Lancaster and Torres 2019; Gupta et al., 2022), and financial capital to support farmer investments in additional productions and activities (Esquivel et al., 2021). Finally, labour availability is often relevant as diversified farms can be more labour-intensive and require a broader skillset than simplified farms (Casagrande et al., 2017). Diversification can also be an opportunity for family farms aiming to employ other family members by creating additional on-farm enterprises and income streams (Valliant et al., 2017; Leith et al., 2019; Cimino et al., 2021). This complex interplay between contextual factors suggests the value of case studies in offering nuanced insights regarding farmer decision-making processes, and the adoption of diversification strategies.

3. Materials and methods

3.1. Study area

Tasmania is an island state located 240 km off the Southeastern coast of the mainland of Australia. It has an area of 68,401 km² and a population of 557,500 people (ABS 2022a) and is characterised by diverse soils, environments and climates. Annual rainfall ranges from 300 mm in the Central Midlands to 3,600 mm on the West Coast, and annual average temperatures from 6 °C in the Central Highlands to 21 °C in the North East Coast (Ojeda et al., 2021).

While Tasmania's production of agricultural commodities is relatively small on a global scale and also in Australia, agriculture plays a significant role in the state's economy. Over the past decade, the sector has been thriving and transforming considerably, driven in particular by State and Federal government investments in the expansion of the irrigation infrastructure (Leith et al., 2019; DIPIPWE 2022). Fifteen new irrigation schemes were built since 2011 with more planned for the next years (Kumar et al., 2022). In 2019-20 Tasmania produced 5.5 times the food that is consumed locally and the gross farm gate value of production in 2019-20 exceeded for the first time 2 billion Australian Dollars (hereafter AU\$) (DIPIPWE 2021). Still, local government and industry

organisations are expecting further improvements by setting the target of reaching a farm gate value of \$10 billion by 2050 (DIPIPWE 2021).

There are about 2,544 farms across three regions (North, North-West and South), of which about half use irrigation (ABS 2022b). Despite pasture being the largest land use, due to favourable growing conditions, Tasmanian farms are highly diverse in terms of characteristics and products (Fig. 1). These include dairy, vegetables (potatoes, carrots, onion and others), livestock, fruits (mostly berries, cherries, apples and pears), viticulture, other field crops (seed crops, barley, wheat, canola, poppies and pyrethrum) and other niche and premium products (ABS 2021; DIPIPWE 2021). The highly diverse sector combined with the current process of intensification and growth contributes to making Tasmania an interesting case study to analyse agricultural diversity and potential diversification pathways.

3.2. Recruitment process

Recruitment and interviews were conducted between December 2021 and April 2022. The farmers interviewed were from different regions in Tasmania and involved in different agricultural production systems, from crops or livestock production to mixed systems, and other livelihood diversification activities, such as agritourism or processing. The rationale behind this choice was to create a diversified sample to provide a heterogeneous and more comprehensive representation of different perspectives on agricultural diversification strategies. The data collection and analysis protocol were assessed and approved by the University of Tasmania (UTAS) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) research ethics committees.

We used a database of contacts compiled by collating farmer lists from previous UTAS projects where participants had given consent to be re-contacted for future research. Additionally, we conducted online searches (i.e., Google and Facebook) and advertised the project in the newsletter of farmer organisations in Tasmania. Notably, UTAS frequently collaborates with the top 20% of producers, often referred to as early adopters. Many participants from previous UTAS lists, belong to this group. This was in part reflected in the sample characteristics (Section 4.1) and considered in the interpretation of the results.

Farmers were initially approached via email or phone, when available. We provided them with a Participant Information Sheet to inform them about the study protocol and objectives, the interview process, and terms of use of personal information. The farmers that provided consent to participate in the study were then contacted again to schedule the interview. The final sample included a total of 95 farmers from a total of 100 interviews, as five participants were no longer farming at the time of

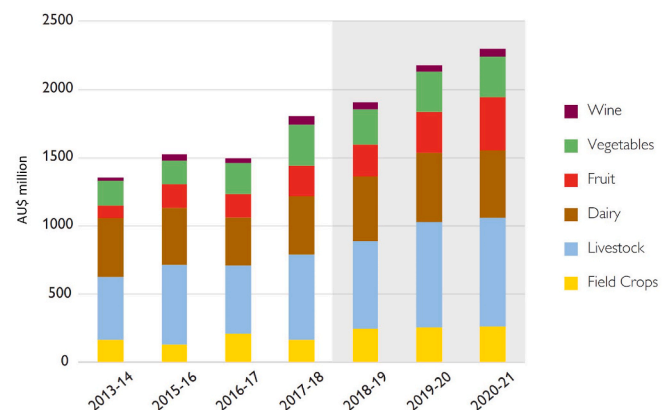


Fig. 1. Gross farm gate value of food and non-food agricultural production in Tasmania (in Australian dollars). The shaded background area indicates data sourced from both the Australian Bureau of Statistics and complementary industry sources. Image source: Tasmanian Agri-Food SCORECARD 2020–21 (DIPIPWE 2022).

the interview (e.g., retired, or moved to other farming-related business).

3.3. Survey design

We used a mixed-method questionnaire to collect quantitative and qualitative information that consisted of closed and open questions. The questionnaire was developed based on a previous literature review (Tacconi et al., 2022) and consisted of seven sections focusing on farmer characteristics, practices and perceptions about agricultural diversity (ANNEX I).

In the first section, we introduced the project to the participants and asked for the farm location. The second section was about farm characteristics, namely crop and livestock species produced, management practices adopted, farm size and farmer use of processing facilities for product transformation. The third section focused on farmer characteristics, such as the number of people working on the farm, including family members; if participants' parents were farmers as well; participants' age and level of education; if they had any children and their involvement in the farm; and membership with any farmer associations. In the fourth section, we asked about farm annual turnover (or sales receipts), where the products are currently sold, and if these had changed from previous years. Section five regarded eventual changes in farming activities in the past 5–10 years, which activities had changed and the main drivers for the decision to change or not to change. In the sixth section, we asked farmers about their future, if they were planning to increase or reduce the number of crop or livestock species in the future and to motivate the answer. The seventh and final section, focused on farmer's perceptions and contained four open questions to allow participants to expand and elaborate on their personal perspectives: "What are the major challenges you are trying to address on your farm?", "What does agricultural diversity mean to you?", "How does diversity fit into your farming objectives?" and "What would help you in increasing the diversity of your farm?".

Due to the travel restrictions and risks posed by the COVID-19 pandemic, the data were collected using Computer-Assisted Telephone Interviews (CATI) which allowed to reach a broader number of participants. The interviews generally lasted between 15 and 35 min, depending on the level of elaboration that each farmer provided during the open-ended questions, and were recorded using the software WebEx.

3.4. Data analysis

We used closed questions to identify the main characteristics of the participants and their farms and to understand the representativeness of our sample. This information is presented in the form of descriptive statistics in Section 4.1.

We conducted a thematic analysis of qualitative data from the four final open-ended questions with a focus on agricultural diversity, using NVIVO12 to code verbatim transcriptions (Braun and Clarke 2012). Coding was conducted using an exploratory approach and an iterative process to identify underlying patterns and themes among the participants (Liamputtong and Ezzy 2005). Initial thematic codes were created, informed by a previous literature review (Tacconi et al., 2022) and preliminary reflections of the investigators based on the direct experience of conducting the interviews. The codebook was updated after an initial round of open coding of the interviews, and a subsequent review with the team members (Liamputtong and Ezzy 2005). A following round of coding was conducted through all the interviews to group similar or connected codes. The lead author performed this task to ensure consistency of interpretation, and then the coding results were reviewed and discussed with the other team members to further refine and validate the coding process. The final codebook, including the count of times each code was mentioned by different participants, is available in ANNEX II. The thematic analysis of coded data was conducted by closely reading both full transcripts and data under the final codes and groups to address the research questions of the study. Therefore, the

results in the following sections focus on how the different participants defined agricultural diversity, described its role within their farm businesses, and the potential incentives and barriers to increasing its use.

4. Results

4.1. Sample characteristics

The sample included 95 farmers, 73 men (77%) and 22 (23%) women. Participants were well spread geographically across Tasmania's three regions, 38 (40%) from the North region, 20 (21%) from the North-West Region and 37 (39%) from the South (Fig. 2).

Farms were highly diverse in size, products, and farming strategies. The sample included large operations specialised in livestock, sheep and dual-purpose cropping and grazing (mostly potatoes or poppies) or irrigated and highly intensive mixed-vegetable cropping, but also small family farms producing fruit and berries, wineries or highly diverse microfarms and agritourisms. The average farm size was 1,256 ha, with a large spread across the sample (median = 350 ha, sd = 2,758), from the smallest being a microfarm of 2.5 ha to the largest one, a large operation of 19,500 ha (Table 1). Most of the farms were mixed crop-livestock systems, 65 in total. Only fourteen farms were specialised in single products, mainly beef, dairy cattle, sheep or wine grapes. The rest of the sample had at least two agricultural productions. Two of the microfarmers in the sample reported producing about 50 different vegetable species each year. In terms of the agricultural diversity indicators, participants grew 4 to 5 crop species on average, and 1 to 2 livestock species. The average total production diversity (crop and livestock) was 5.3. Also, other forms of livelihood diversification were very common in the sample with 32% of the farms having processing facilities, especially for cheese, jam or winemaking. More than two-thirds of the participants also had sources of off-farm income, while 14% of the farms provided agritourism services of different including farm stays, restaurants, workshop and sports facilities and farm tours.

Beef cattle and sheep were the most common livestock species being raised respectively in 52 and 51 farms, while poppies (n = 22) potatoes

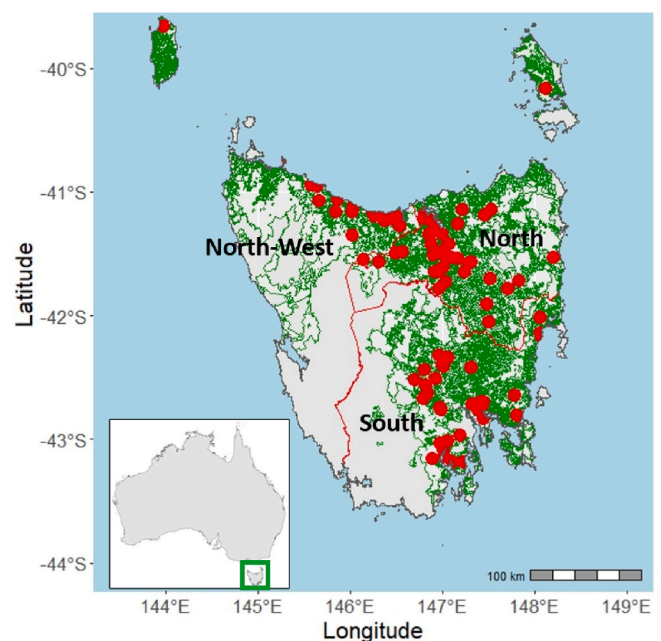


Fig. 2. Map of Tasmania divided by NRM regions (North, North-West and South). The green layer shows the area of land potentially suitable for agriculture (Land, 2016). The red dots show the sample distribution. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Summary of sample characteristics.

| Variable | Mean (SD) | Median | Min | Max |
|------------------------------|---|--------|-----|--------|
| Farm Size (ha) | 1,256 (2.8) | 350 | 2.5 | 19,500 |
| Agricultural Diversity | 5.3 (7.6) | 3 | 1 | 50 |
| Crop Diversity (n = 80) | 4.7 (7.8) | 2 | 1 | 50 |
| Livestock Diversity (n = 80) | 1.6 (0.8) | 1 | 1 | 5 |
| Age (years) | 51.8 (12.6) | 52 | 25 | 82 |
| Farm Experience (years) | 22 (13.3) | 20 | 2 | 65 |
| Sex | Male: 73 (77%) Female: 22 (23%) | | | |
| Region | North region: 38 (40%) North-West Region 20 (21%) South: 37 (39%) | | | |
| Off-farm activities (yes) | 62 (66%) | | | |
| Agritourism (yes) | 18 (14%) | | | |
| Farming background (yes) | 63 (66%) | | | |

(n = 20) and fodder crops (n = 14) were the most grown crops (Fig. 3). The average age of our participants was 52, ranging between 25 and 82, with an average of 22 years of farming experience. Among the participants, 63 grew up in families of farmers, 54 of them in Tasmania, while 32 came from families with non-farming backgrounds.

Thirty-one participants had completed a postgraduate degree, a disproportionately high level of education for the sample, which was considered while interpreting our results. Only twenty-six participants were not members of any farmer associations. Fifty percent of the farms declared an average annual turnover between \$200,000 and \$2 million over the past three years. This indicates that our sample leans towards farms with higher turnover compared to state-level data (Fig. 4). Eighty-three percent of the participants responded to having increased their annual turnover by more than 10% during the previous 5 years, in line with the growing trend of agricultural production value in Tasmania.

The ongoing changes in the agricultural sector in Tasmania could be observed within the farms participating in the study. Fifty-six percent of the participants declared to have applied some changes in their farming production and management strategies in the past 5 years (56%), with

28% that added at least one new crop or livestock species and 26% have removed at least one. The marketing options have also changed, with 43% of participants that have changed their distribution channels in the past 5 years, generally in response to the COVID-19 pandemic disruptions or changes depending on the global markets.

4.2. Farmers' definitions of agricultural diversity

The thematic analysis of participants' definitions of agricultural diversity revealed a distinction between those who identified diversity with the number or type of activities and enterprises (hereafter *practical*), and others who associated it with a set of values or outcomes (hereafter *conceptual*).

4.2.1. Practical definitions

The "practical" definitions were generally reflected in the activities on participants' farms. The most common related to the number of crops and livestock species as follows:

"It means having a range of crops and a range of enterprises, whether it be crops or livestock. Or intensive crops versus broad acre crops. It's just a bit of everything" (Medium mixed crop-livestock farm).

Another frequent practical definition centred on the number of income streams. In particular, some of the participants with processing facilities associated diversity to value-adding or the diversification of customers or markets, exemplified by direct sales or agritourism services, as explained by this participant operating a small berry farm:

"We grow, sell wholesale, retail and value-add. We've got a restaurant on site. Fortunately, we have quite a diverse operation of many different income streams."

Additionally, other participants mentioned the integration of on-farm activities with off-farm income streams, like leasing out part of the land, financial investments, or simply having another job alongside the farm.

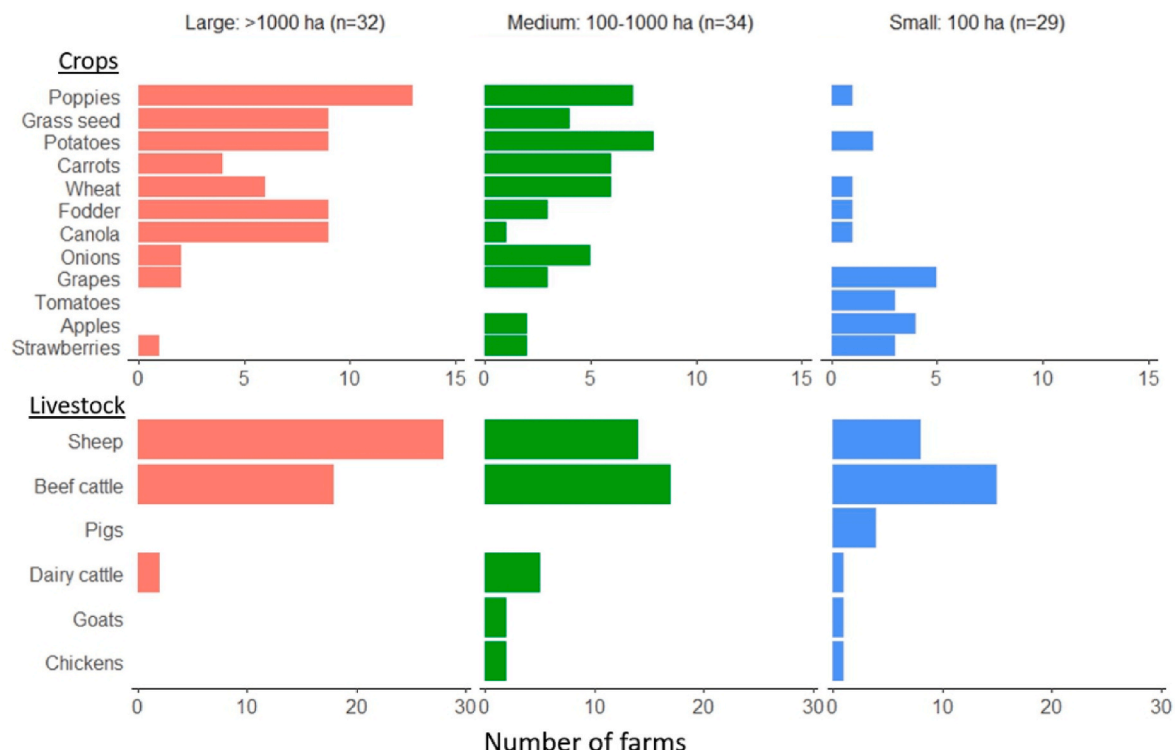


Fig. 3. Most common crop and livestock species by farm size group.

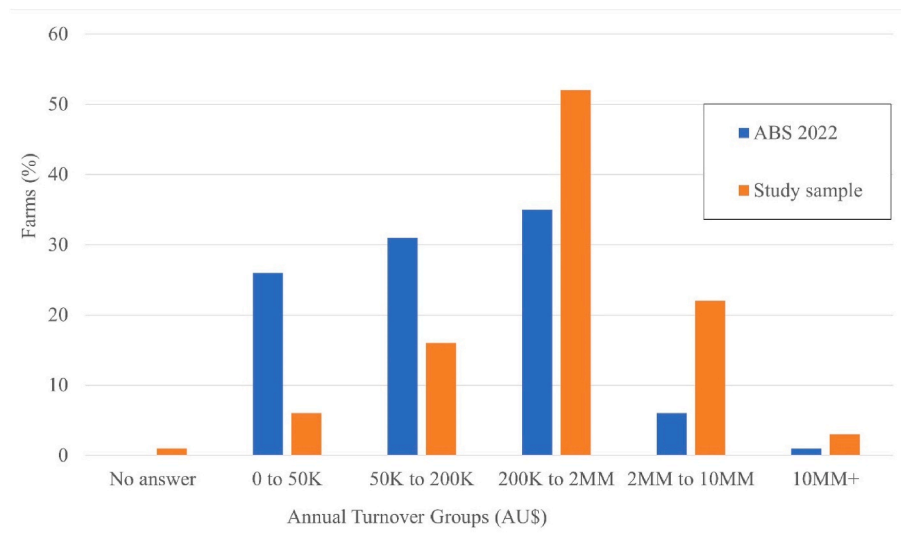


Fig. 4. Comparison of farm groups by annual turnover (AU\$) between the study sample and the official data at the state level in Tasmania. Source ABS (2022).

4.2.2. Conceptual definitions

Most of the participants who defined agricultural diversity as a set of values or outcomes associated it to a positive concept. The prevailing definition centred on risk management, with “*Not having all your eggs in your basket*” being the most cited quote during the interviews, mentioned by 14 participants. Also, several participants linked agricultural diversity to environmentally and socially sustainable farming. Some of them acknowledged the potential of diversification strategies to address all the components of the triple bottom line: financial, environmental and social sustainability (Hacker et al., 2009). As this small mixed-livestock farmer affirmed:

“Agricultural diversity doesn’t just mean a business model. So, agricultural diversity means diversity in the soil, living soil, diversity in the plants, in the insects, the birds, you know, the whole ecology, and then diversity in the people as well”.

For others, agricultural diversity also meant the ability to change and innovate farming practices. Some used expressions like “*thinking outside of the box*” or commented:

“I think diversity means, doing farming in different ways. Modifying your farming procedures based on findings in research and probably it’s around sustainability and as you get more knowledge and this sort of things” (Dairy farmer).

Only nine participants did not see diversity as a positive concept for their farms, mostly because they considered it unnecessary for their business or even financially risky. For instance, this beef cattle farmer focused on the skills, time and labour required:

“It can give you an alternative income, but it can also be a distraction and you might be working for something that does not give you a return. I guess that diversification, if you’ve got the tools, and not just tools but people and skills, it’s a good thing, without people, skills and the tools, it can be difficult. You do need to educate yourself before you go out and diversify [...]. It is not a fit for everyone”.

Another point was raised by an organic beef cattle farmer, who, despite acknowledging the benefits of maintaining a diverse ecosystem, warned that pushing on-farm diversification *a priori* can be detrimental to the environment when the land is not suitable for that:

“They get farmers in the midlands, which is dry country excellent for sheep production, to put irrigation and grow crops. Which is draining the river dry, it is not sustainable and requires massive capital investments

from farmers. This is just to push diversification. So, the focus shouldn’t be on diversification but on the practices”.

4.3. Role of agricultural diversity in the farm

We developed four themes around the role of agricultural diversity in participants’ farms, to describe whether and how diversification strategies fit into their activities (Fig. 5). Three themes involve the participants acknowledging that agricultural diversity fits within their farming activities ($n = 74$), although in different ways and for different purposes. These are the farmers considering and using diversification strategies (1) as integral components of their business (“integral to business”), (2) as additional business opportunities (“business opportunity”) or (3) for motivations that are beyond the financial value (“beyond financial value”). These themes are not necessarily mutually exclusive but represent three different approaches for adopting and utilising diversification strategies. The fourth theme (4) describes the motivations of participants who reported that diversity does not fit within their farming activities ($n = 21$). Below we present and explain these themes in detail with illustrative quotes from the participants.

4.3.1. Integral to business

The first theme encapsulates different motivations and needs by which participants considered agricultural diversity as integral to their farming activities. The prevalent motivations included spreading farming risks, adapting to the diverse land and climate characteristics, increasing income through value-adding enterprises and, in a few cases, creating employment opportunities for other family members.

Participants described the risks from climate, pests and diseases and market volatility as major challenges within their farming activities (ANNEX II). Spreading farming risk emerged as the most common reason by participants for adopting diversification strategies, with no particular difference between farms of different sizes and from different regions. For instance, one participant operating a small farm in the southern region explained that having diversified production on their farm saved them from being in a “*pretty rough position*” when their most important wholesaler changed strategy and decided to break the purchase contract on their main product. Another large mixed crop-livestock farm owner commented:

“It [agricultural diversity] is a big part of us. If one fails, we’re not just reliant on it. If we have a bad cropping year, the livestock can cover it. Yeah, and if stock prices are down, we can focus more on cropping”.

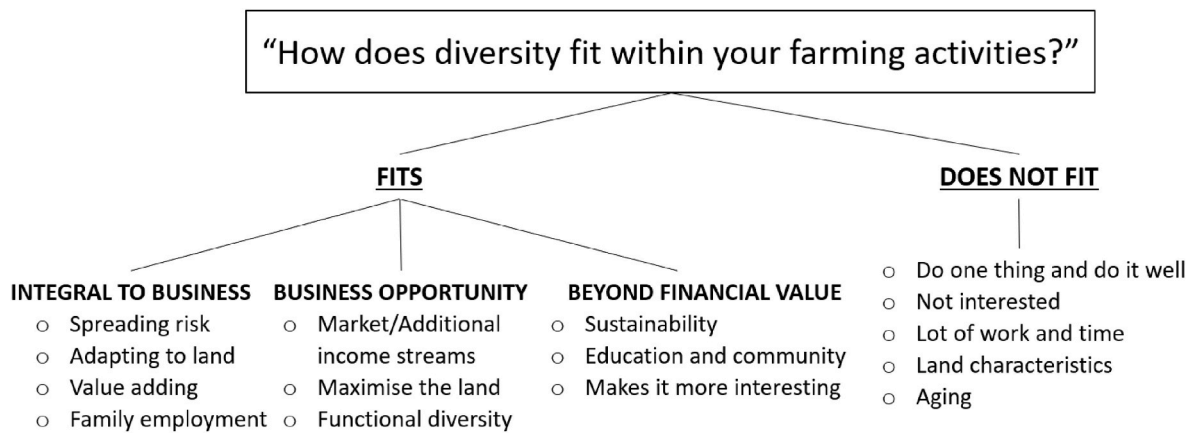


Fig. 5. Summary of agricultural diversity fit within participants' farming activities.

This was echoed in another interview with a potato and sheep farmer from northern Tasmania, who reinforced how especially important diversity was against market volatility:

“I think it's really naive for Australian farmers to only grow one thing and expect that everything is going to be fine. We need to produce different things to be safe from price shocks”.

Another frequent answer was that diversification was dictated by the heterogeneity of Tasmanian landscapes and climate, which constrains a large-scale focus on a single commodity. The right production system requires to be matched to the local land and climate characteristics. This necessity was well articulated by a small-holding farmer from the north that commented this way:

“I don't think there's any farm in Tasmania that isn't diverse. I mean, even if you looked at somebody that had 1000 ha down in the Midlands that's doing lamb and sheep grazing, they're still diversified and it could be that they're actually running private forestry as another crop or whatever. Every farm in Tasmania needs to be diversified to survive”.

Or another participant from a large mixed farm commented that they “would fit the operation to the land class and create diversification around that”. This implies that in these contexts, agricultural diversity is generally motivated by the need to adapt to the land and thus becomes deeply embedded in the farming activities:

“In Tasmania, with our microclimates, one variety might grow in one spot and might not grow in another. That's the real problem, you're going to find out what works in your area” (Small diversified farm).

Value-adding was another recurrent form of diversification largely driven by a necessity, in particular among farms of smaller dimensions. These farms described that their decision to diversify was mostly based on the necessity of value-adding from products that can be combined or transformed to provide additional income sources. In our sample, 21 farms out of 29 (72%) with a land size below 100 ha had processing facilities, making products like jams, cheese, wine and liquors, while 52% had agritourism activities. These numbers decreased respectively to 29% and 4% in farms of larger dimensions. According to a farmer producing berries jams and ice creams and running a small farm shop, the role of agricultural diversity meant “not just growing things, but it means processing, and the sale of the end product, value-adding, direct sale, not just wholesale”. Despite this form of diversification being more “vertical” and centred on processing and direct sales rather than crop and livestock diversification, it was often connected to a more diverse production. Farmers selling directly to local markets, or operating restaurants or agritourisms can be more motivated to produce a wider variety of crops or livestock. This approach allows them to offer a broader range of products to their direct customers and community. As

one participant managing a small and highly diversified farm mentioned: “We have one concern, which is getting people to come to the farm and eat food. But to support that, we are extremely diverse in terms of what we grow and rear, and we want to make it more”.

Succession was another challenge arising from the interviews. Few participants mentioned that diversification was their solution to create additional employment and income necessary to keep other family members on the farm after succession:

“There was another source of income for my sister and her family to be able to stay on the farm. Giving the chance to the new family generation to stay on the farm by creating new streams of work” or “It fits [...] also to provide stimulation through succession planning and sort of the start of involving the children in the business”.

Lastly, some participants, prevalently from small farms, to emphasize the importance of agricultural diversity, responded to consider it essential for their farms' survival:

“It [agricultural diversity] is essential. Because of the size of our farm and our philosophy, we can't be a monoculture. With our farm size, whatever we do, we can't create a commodity”.

In this regard, a participant from the southern region operating a mix livestock species farm wanted that the adoption of diversification strategies is crucial for small holdings:

“Particularly, important for small farms where you don't necessarily have the scale, and the ability to generate large amounts of money from the land. But, if you look at our neighbours who are really, very large, even though we're extremely small, we're still producing as much, if not more [...]. Diversification on-farm is particularly important for us to maintain economic viability”.

4.3.2. Business opportunity

Another theme identified regarded the participants seeing agricultural diversity as a strategy that can fit within their farm, but fundamentally only when “the right opportunity comes. In this context, participants do not diversify in response to a necessity or adapt to a particular situation, but rather to gain an additional income stream if they see a profitable market opportunity, to increase profits by maximising the use of their land or to improve farm performance by taking advantage of functional diversity benefits, using the interactions between different crops or livestock species. This was well-outlined by a mixed crop-livestock farmer from the northwest: “I guess it [diversity] is always there as an opportunity. If you see there is an opportunity you can pick up on that but also sometimes, you're better off just to focus on what you're doing and doing it well”.

Maximising the use of the different sections of the farm was a

common response:

“It fits in terms of maximising the use of our property, because different sections have different uses. That’s really the main driver of it” (Large mixed crop-livestock farmer).

This was particularly frequent among large, irrigated cropping and livestock farms. This use of diversity is different from adapting to the land and climate conditions. These participants explained to see diversification primarily as a business opportunity to create additional income streams where Tasmanian diverse landscapes allow for different production options:

“We can be fairly well diversified in our area [...]. Not being too diversified is probably the biggest issue because there are a lot of cropping opportunities available to us. And it’s trying to keep on top of that and making sure that you’re not just cropping for the sake of it” (Large mixed crop-livestock farmer).

Besides the land characteristics, the *right opportunity* can be also represented by market trends and farmer capacity to be informed and flexible enough to add new enterprises when convenient:

“It [diversity] is not a massive one [concern] but still important. We are always mindful of the potential of diversification. Looking for different ways we can produce and sell, find a niche that gives us a market edge that we can maximize”.

Farmers pursuing land use maximisation also considered other types of agricultural diversification than crop and livestock production. For example, by planting trees or setting aside land for the regeneration of native species to access carbon credit schemes, as brought up by this wine and sheep producer from the south:

“We’re trying to actually look at other alternatives. So, we’re probably now looking ... we might even consider carbon credits. We have some erosion areas on the property that we would probably even consider. Trying to put on carbon credit areas into them”.

Lastly, some participants acknowledged the advantage of utilising functional diversity benefits and complementarities between different species. These farmers use rotational cropping and synergies between crops and livestock to improve farm productivity and efficiency, like the control of weeds, pests and diseases or maintaining soil productivity. This was well-explained by two participants running large mixed crop-livestock farms:

“When you include livestock and a pasture phase is much easier, it’s much easier to control those resistant weeds and is much healthier for cropping. Putting trees around makes a lot of difference, instead of clearing all just to crop”.

“We used to have an area that was set up to cropping. And we would crop it and crop it and crop it, without a livestock period, without a lay period, and yields just kept going down and we were using more inputs to support the same yield. And when we moved away from that and went to minimizing cropping to 3 years out of 5 instead of 5 out of 5. We saw about a 20% increase in crop and a significant increase in profitability as a result”.

4.3.3. Beyond financial value

This theme includes participants adopting diversification strategies for motivations that go beyond the financial value, such as improving the environmental and social sustainability of their farms, and potentially of the surrounding landscape. These participants attributed an ethical value to agricultural diversity and recognized that diversification practices were crucial components of their approach to farming:

“Well, it underpins everything because from what we’ve learned, Mother Nature in those systems requires diversity. So, so, like, literally from the

soil microbiology to the livestock, that underpins absolutely everything in what we do”.

Increasing soil health, carbon sequestration and water retention, in particular, was a frequent topic, especially among the farmers explaining to adopt regenerative farming practices. A participant growing a mix of fruit and livestock species in the South said:

“Our objective is to create an enduring example of how sustainable regenerative farming is. Diversification allows us to be sustainable and helps us to be regenerative. It’s not that diversification is part of what we do, it is what we do”.

Few participants also mentioned the social role that diversity can play for the community in terms of education and well-being:

“It fits in a big way because of education, kids these days kids don’t know where their food comes from! [...] There needs to be more education in schools about agriculture and I do that on my farm. Diversity to me is doing something with your business that benefits the community”.

Finally, some discussed diversity as a stimulus to remain engaged and passionate about their work and daily activities, as noted by this farmer involved in mixed livestock production:

“It gets really, really boring doing the same thing every day. So, by diversifying you improve like ... your longevity in your work”.

Doing and learning new things can also improve the engagement with other people working on the farm, as pointed out by this participant running a mixed cropping farm:

“Diversity is a benefit to us, because it means we can, as I said before, sharelabour amongst a few different seasonal circles and different tasks and skills, which keeps people interested”.

4.3.4. Does not fit

The final theme involved those participants that responded that diversity did not fit in their farm objectives. There were different reasons for choosing to not use diversification strategies, often aligned with a negative perception of agricultural diversity. Prioritising focusing on one main business was prevalent:

“Not greatly. I’m not a huge ... I don’t think diversity for diversity’s sake is important. I think sometimes that doing one thing and doing it well, is actually better”.

For some of these participants with well-established specialised operations, diversification represented a riskier strategy than specialisation, requiring additional knowledge and skills, as commented by this participant specialised in dairy cattle:

“We’re running a fairly big business. We sort of think that we need to stay where our skill set is”.

Diversification was also considered highly demanding, hence the benefits from spreading the risks can be outbalanced by the investments and time effort required to manage mixed farms involved in several enterprises:

“Uh, it was interesting for a couple of years, but I got sick of all the work. We actually un-diversified at one stage. We were trying everything and then I just thought: ‘no, I can’t do all this’. So, diversification is a great thing as long as it pulls its weight and it’s worth all the extra effort”.

Some older participants explained that they used diversity in the past, but only as a transitory strategy to test different enterprising and find the right one to focus on. A mixed crop-livestock farmer explained that they were now looking to simplify the farming activities also due to aging:

“Twenty years ago, we went through a lot of diversifications and the emphasis now is on just knowing what we grow better, I’m not looking for silver bullets. We’ve been growing some very specialist crops”.

Finally, a few participants responded to have a specialised farm simply because of their land location and characteristics that are not suitable for a diverse production:

“We are in a high-altitude situation, a small property, very hilly, remote from marketing centres so crop production is not really a viable option for us, which limits diversification options” (Specialised cattle farmer).

4.4. Incentives and barriers to increase agricultural diversity

When we asked about the intention to enhance agricultural diversity in the future, twenty participants answered that they were planning to increase their farm diversity by introducing new crops or livestock species within the next five years. Instead, seventy-five expressed no current interest. Many of them were satisfied with their existing situations or focused on improving production efficiency through new technologies or scaling up current activities. We then discussed potential incentives to help participants in increasing agricultural diversity.

4.4.1. Potential incentives

Among the factors identified as potential incentives to enhance diversity, the most common answer was the availability of funding to use for diversification activities (26% of the participants). As previously mentioned, the financial investments for undertaking a new activity can be a risk that often farmers cannot or are reluctant to accept without the backing of government subsidies, as highlighted by a mixed crop-livestock farmer:

“We had access to a lot of that funding [local and federal], and it has caused us to diversify quite a bit. Like, we’ve locked up a lot of country by planting a lot of trees, farming more to land class now. [...] Yeah, the funding’s helped obviously speed that process up otherwise it’d just be: ‘Do a little bit each year’”.

Some participants argued to find it difficult to access government funding opportunities, mentioning tight requirements, or for instance that some programs mostly support specific farm types:

“It’s disappointing that every single state government funding program never seems to target people like us. It seems to target big businesses that want to get bigger. Not little businesses that just need to have to get that next little step. Who’s [already] got a good business strategy, [...] they’re putting their own money into their own pockets. It’s hard because we have to invest our money as we don’t have government funding”. (Small mixed fruit farmer).

The low availability of both skilled and unskilled labour emerged as another relevant limitation to diversification, discussed in around one-fifth of the interviews. Participants mentioned the lack of time to engage in new activities as a major constraint and the struggle in finding people to employ in Tasmania, either seasonal workers or skilled people to train and employ for longer periods. Because of its remote position, Tasmanian farms are highly reliant on seasonal workers from abroad, especially from the Pacific Island or backpackers on working holiday visas. The lack of labour was particularly emphasised during the period of the interviews due to the COVID-19-related travel restrictions and border closures in place in Australia between 2020 and 2022.

Some participants (19%) argued that they would consider diversifying more if they had access to more information, knowledge and skills required to undertake additional activities. They discussed networking opportunities to share experiences and innovative ideas as a potential stimulus for diversification. For instance, a large mixed crop-livestock farmer spoke about the importance of learning from other peer experiences:

“Innovation opportunities and education so that I don’t need to be a pioneer and risk to fail. I am happy to follow up if I see that it works otherwise, I am happy where I am”.

Access to alternative market options was also discussed as a

significant incentive (16%). For instance, some niche farmers, generally selling directly to consumers, mentioned that they would only increase diversification if they were certain to reach more customers. Similarly, other farmers affirmed that they would need to see clear and certain opportunities to gain an economic advantage:

“We wouldn’t change for the sake of change. We would change because there’s a reason to do it” (Dairy farmer).

Other factors that emerged during the interviews were access to irrigation (9%), additional land (9%), and broader access to planting materials and seeds (4%).

4.4.2. No incentives

Seventeen participants could not see any potential incentive to increase their level of diversity. Among them, the prevalent response was “Things are working as they are”, so they had no reason to change. Some diversified farms felt that they had already achieved an adequate diversity level based on their farm characteristics and opportunities. Others, considering their skills, time and labour availability, showed no interest towards further diversification. As per section 4.2.4, certain specialised farmers perceived diversification as a risky strategy and preferred focusing on the things that they were already good at: *“I look at diversity as having too many eggs in one basket”*. Finally, for some older farmers, age was a major reason for not diversify more, but rather to reduce and simplify the workload. One of them remarked: *“Time machine, I would [diversify] if I was younger”*.

5. Discussion

Through the interviews conducted in this research, we were able to collect and analyse a range of farmers’ perspectives about the meaning and role of agricultural diversity and diversification in Tasmania, as well as their main drivers and constraints. Exploring qualitatively the differences among farmers and their decisions provides a nuanced analysis of local dynamics that can serve to understand what and why on-farm diversification strategies are adopted and how they are used to address local issues, but also as a case study for comparison with other world regions (Medhurst and Segrave 2007; Roesch-McNally et al., 2018). Our findings show that most of the Tasmanian farmers interviewed make broad use of diversification strategies, although in different ways and for differing reasons. These differences were also influenced by values that farmers attributed to diversity, which were highly context-dependent.

Farmers in this study provided a variety of definitions of agricultural diversity, that could be summarised in two overarching ways. Firstly, “practical” definitions focused on the number of farming activities, including crop or livestock species produced, as well as more elaborate concepts that included processing, agritourism, and marketing. Secondly “conceptual” definitions centred on values and outcomes associated with diversity, such as buffering farming risks, creating additional income opportunities, and providing of multiple socio-ecological services. These findings corroborate previous studies conducted in other world regions showing that farmers’ considerations and awareness about the value of agricultural diversity can differ among individuals and are not limited to profit maximisation goals, but can also involve a more complex set of motivations, including, for instance, risk aversion, personal values, education, well-being or land stewardship orientation (Cayre et al., 2018; Bardsley et al., 2019; Isbell et al., 2021).

These divergent ways in which participants defined diversity and diversification are further reflected in the ‘uses’ or function of diversity on their farms. The four themes identified were summarised in the framework presented in Section 4.3 (Fig. 5). These themes may overlap in some circumstances, however, they provide a novel representation of four distinct roles and approaches to agricultural diversity. Firstly, for some farmers agricultural diversification emerged as a “business as usual” practice, integral to farming activities, despite being in response

to different needs and purposes. In Tasmania diversification is widely used to mitigate market or other production risks and to adapt the production to land and climate characteristics. As in other examples in the literature, it was also used to provide employment opportunities for other family members (Medhurst and Segrave 2007; Valliant et al., 2017; Leith et al., 2019). Secondly, the diversification for “business opportunity” represents more a profit-oriented approach (Cayre et al., 2018; Revoyron et al., 2022), involving farmers using diversification as one possible option, not a necessity, and only if justified by a clear advantage in terms of marketing, profits or efficiency. The third approach was described as “beyond the financial value”, indicating farmers valuing diversity as an essential characteristic of sustainable farming. This generally included farmers producing according to organic or regenerative principles. Within this group, non-commodity species, like cover crops or non-fruit bearing trees, were often used as functional species (Gaba et al., 2015; Brown et al., 2018) or for natural capital projects (Fleming et al., 2023; Bateman et al., 2023). These types of non-commodity diversification should be taken into account in studies measuring the environmental impact of the different diversification strategies (Lee and McCann 2019; Spangler et al., 2022). In this regard, some farmers argued that crop diversification does not always correspond to the most sustainable option, criticising the role of irrigation in promoting the adoption of intensive mixed-cropping, which risks instead increasing the agricultural impact on soil health and water resources (Kumar et al., 2022). The final approach includes farmers referring to diversification as an unnecessary overcomplication of their activities (Gupta et al., 2022). These farmers were generally satisfied with their current farm activities and had good performances, and usually consisted of large livestock operations or smaller farms with niche or high-value products, such as wine or berries.

Most of the participants expressed limited interest in increasing their current level of diversity. This was because many of them were already diversified and were satisfied with their current level of performance, and thus prioritized efficiency and scaling up production over further diversification. Regarding the incentives for increasing diversification, participants highlighted the importance of having access to funding opportunities. In line with previous research (Roesch-McNally et al., 2018; Gupta et al., 2022), this suggests that for, specialised farmers in particular, the transition towards more diversified agricultural systems can be perceived as a costly and potentially risky investment. Moreover, the idea of managing additional activities was often discouraged by limited labour availability and challenges in attracting and retaining skilled workers. This also aligns with previous research (Lee and McCann 2019; Spangler et al., 2022). However, it is particularly emphasised by the Tasmania’s geographical location, especially for smaller farms lacking the economic and technological capacity to streamline new activities and enterprises. We did not find any strong evidence of technological lock-ins into specialisation as a primary constraint to diversification, unlike other studies (Casagrande et al., 2017; Meynard et al., 2018; Roesch-McNally et al., 2018). This is probably because most of our participants were already involved in diversification practices, differently for instance from the large US monocultural systems studied by Roesch-McNally et al. (2018). On the other hand, in recent years technology adoption and access to irrigation have been major drivers of diversification opportunities in Tasmania, such as mixed vegetable cropping for instance (Leith et al., 2019). More than technologies, among less diversified farms, we could notice situations in which the lack of diversification-related knowledge and skills represented a potential barrier, hindering farmers from producing additional species. Further, we observed that our sample included some small and profitable farms displaying characteristics of multifunctional farming. In most of these cases, farmers not only engage in value-adding activities, through processing, but also offer tourism, cultural and education activities to their customers, such as restaurants, farm visits and workshops. These farmers often have a closer and more direct relationship with their customers, which motivates them to provide a

broader variety of products and contributes to higher on-farm diversity. This is consistent with previous research indicating that direct marketing channels may encourage on-farm diversification (Fielke and Bardsley 2013; Lancaster and Torres 2019). In these cases, achieving vertical diversification and multifunctionality, besides improving economic efficiency and profitability, seems to also stimulate agricultural diversity.

The farms in the sample were rather diverse, from land size to the type of production, and this allowed us to provide insights from farmers with different characteristics, reflecting in part the diversity in the Tasmanian agricultural system. Yet, in the interpretation of these results, it is important to consider that the sample should not be considered representative of all Tasmanian farms. The prevalence of high-performing farms in the sample, with some having previous collaborations with UTAS, was evidenced by the high average levels of education and annual turnover compared to the Tasmanian averages. Some of the farmers recruited through online searches, small and microfarms in particular, were surprised and enthusiastic about being involved in the research and having the chance to contribute with their personal and farming experiences about diversification. Using emails and CATI interviews may have limited participation from farmers less familiar with digital communication technologies, like email or social media. We believe that this limitation should be considered for future studies. Still, considering that the high use of diversification practices and on-farm diversity among participants, our findings further build on prior literature in showing that diversified farming systems can be a viable and profitable, alternative to specialisation (Rosa-Schleich et al., 2019; Spangler et al., 2022).

6. Conclusions

Within a sample of 95 farmers, we could identify a wide range of specific definitions, approaches, and uses of agricultural diversification strategies. The Tasmanian agricultural system has developed several forms and pathways of diversification over the years, mostly influenced by factors such as the remote location, heterogeneous geography, and the recent investments in new irrigation infrastructure. Our findings confirm that diversification strategies are widely adopted by the participants and represent a key feature of some of the surveyed farms.

The analysis of a diverse sample including farms of different dimensions, level of diversification of products and activities, technology adoption and market-orientation allowed us to provide a detailed picture of these different farming approaches. Farmers discussed a variety of definitions and motivations towards agricultural diversity, spanning from a more practical approach related to the number of activities and enterprises to a more conceptual definition referring to their personal experiences, values and farming backgrounds. When examining the role of agricultural diversity, it is essential to identify whether farmers consider it as an integral feature of their farming business, as an additional business opportunity or for motivations that go beyond the financial value. The participants operating in specialised farms expressed a contrasting view, not considering adding new activities as a priority, but potentially a financially risky investment that is more demanding in terms of management. The main incentives identified by farmers to increase their adoption of diversification strategies included economic factors such as access to funding opportunities and market availability; physical assets like land characteristics and irrigation; and human capital. The latter encompasses labour availability and, more importantly, the opportunity to access and share information, skills and knowledge required to manage multiple enterprises.

As farm diversity is increasingly promoted in the global debate as a potential strategy to enhance agricultural systems sustainability (FAO 2019; HLP 2019), exemplified among other OECD countries by initiatives like the latest European Union Common Agricultural Policy (Guyomard et al., 2023), our results are particularly relevant. Tasmania’s high diversity, despite the low government support of Australia’s agricultural sector, provides new evidence that, in the appropriate

context and through different configurations, diversification strategies may not necessarily stem from policy support, but also derive from adaptive needs, market dynamics, and farmers' relational values.

In conclusion, our findings suggest that agricultural diversity can be a viable and, in some cases, a key farming strategy even in a high-income country. Nonetheless, this study, by looking in detail at reasons that diversification may and may not be successful in a high-income country context, does not seek to provide generalised answers to where and why diversification does lead to benefit, but rather displays different pathways about how it can. Further place-based analyses would be needed to examine whether and why such patterns hold in other world regions, or whether they are context-specific to the unique features of Tasmania. Additionally, we suggest that in contexts like Tasmania, where diversification strategies are already widespread, future research and policy interventions should not aim at promoting agricultural diversity as a general goal. Instead, they should consider these different approaches and configurations, prioritising the identification and addressing of farmers' specific challenges.

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Ethics approval

This study was reviewed and approved by the University of Tasmania Human Research Ethics Committee (Ethics Approval n. H0026650) and the CSIRO's Social Science Human Research Ethics Committee (Ethics Clearance n. 088/22).

CRediT authorship contribution statement

Francesco Tacconi: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Visualization, Writing – original draft, Writing – review & editing. **Darcy Lefroy:** Data curation, Investigation. **Katharina Waha:** Conceptualization, Supervision, Writing – review & editing. **Jonathan Jesus Ojeda:** Conceptualization, Supervision, Writing – review & editing. **Peat Leith:** Conceptualization, Supervision, Visualization, Writing – review & editing. **Caroline Mohammed:** Supervision, Writing – review & editing.

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.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

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