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Contributions of alternative agricultures to food security, profitability and sustainability

A narrative review

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Católica Porto Business School
April 2023

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A narrative review

Master Final Work
submitted to Universidade Católica Portuguesa
for the obtainment of the Business Economics Master Degree

by

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under orientation of
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Católica Porto Business School
April 2023

Acknowledgements

I want to start by expressing my gratitude to Arlindo Cunha and Miguel Sottomayor, who acted as my supervisors, for their direction, encouragement, and support during the entire process. Their guidance and knowledge were really helpful to me as I developed my thoughts and shaped the course of this research. Working with two individuals who are so accomplished in the field of study was an honor.

I would also like to thank my family, for the motivation they provided and the excitement they showed towards my work. Throughout this thesis, I believe I learned as much from them as they have from me.

To my friends, who pushed me forward and reassured me when things didn’t go as planned, I am also extremely grateful.

Last but not least, I'd like to thank my Business Economics Master's program classmates as well. Their participation was crucial throughout the entire program as well as during this thesis. Without them, this journey wouldn’t have been possible, or nearly as enjoyable as it was.

Resumo

Vários autores defendem a agricultura convencional, argumentando que esta possibilitou alimentar uma população crescente e reduzir a fome mundial. No entanto, muitos criticam a sua dependência de recursos externos, designando-a como insustentável e afirmando que esta tem efeitos negativos no ambiente e na sociedade.

Os objetivos principais desta dissertação são determinar o estado atual da literatura no que toca a alternativas à agricultura convencional (a partir daqui serão designadas como "agriculturas alternativas"), mais especificamente em como estas se comparam à agricultura convencional no que toca a garantir segurança dos abastecimentos, lucro e sustentabilidade. A tese também procura guiar pesquisa futura, de forma a ser o mais útil possível para atingir o objetivo comum que é a agricultura sustentável.

Os resultados desta revisão de literatura, baseados na informação recolhida, sugerem que o desempenho das agriculturas alternativas nas três funções agrícolas exploradas (segurança dos abastecimentos, lucro e sustentabilidade) é altamente dependente do contexto em que estas se aplicam. Mas, em alguns contextos, as agriculturas alternativas podem fornecer um melhor desempenho numa ou mais das funções mencionadas.

Finalmente, várias publicações estimam transições mundiais para agriculturas alternativas; no entanto, estas apenas discutem o abastecimento alimentar global, e não consideram problemas existentes (por exemplo, problemas de logística e/ou distribuição de rendimentos) que são obstáculos para atingir a segurança dos abastecimentos.

Palavras-chave: agricultura convencional; agricultura alternativa; segurança dos abastecimentos; lucro; sustentabilidade

Abstract

Numerous authors support conventional agriculture, arguing that it has helped feed an expanding population and reduce hunger. However, many criticize its reliance on external resources, stating that it is unsustainable and has detrimental effects on the environment and society.

The main goals of this dissertation are to identify the current state of research on alternatives to conventional agriculture (from now on called "alternative agricultures"), specifically how these alternatives stack up against conventional agriculture in terms of achieving food security, farming profitability, and sustainability. Furthermore, an effort is also made to guide future research in order to be more helpful of reaching the socially shared objective of making agriculture sustainable.

The results of this literature review, based on the gathered information, suggest that the performance of alternative agricultures in the three researched agricultural functions (food security, profitability and sustainability) is heavily context dependent. However, under some contexts, alternative agricultures can either provide better performance in one or more of these functions.

Finally, several studies attempt to model worldwide transitions to alternative agricultures; however, these only discuss the global food supply, and fail to consider existing problems (such as logistic issues and/or income distribution) that are obstacles in achieving food security.

Keywords: conventional agriculture; alternative agriculture; food security; profitability; sustainability

Index

Word count: 10054

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List of Abbreviations

CF – Carbon Footprint

CO_2 – Carbon Dioxide

CO_2eq – Carbon Dioxide Equivalent

FAO – Food and Agriculture Organization of the United Nations

GHG – Greenhouse Gas

HLFE-FSN – High Level Panel of Experts on Food Security and Nutrition

IPM – Integrated Pest Management

LCA – Life Cycle Analysis

N_2O – Nitrous Oxide

WOS – Web of Science

Introduction

Before significant human intervention, Earth's capacity for regulation preserved the conditions that allowed for human development. Temperature, availability of freshwater, and biogeochemical flows all remained within a relatively small range. However, according to some authors, human activities have now reached a point where they may endanger Earth's natural systems, partly as a result of an exponentially rising reliance on industrialized types of agriculture (Rockstrom et al., 2009). On the other hand, other authors argue that modern agriculture has been able to boost nutrition, decrease hunger and increase the global per capita food supply, largely due to improved yields brought on by increasing use of inputs such as mineral fertilizers, water, pesticides, genetically modified organisms and other "Green Revolution" technologies (Borlaug, 2000; Burney et al., 2010; Godfray et al., 2010; Pretty, 2018; Tilman et al., 2002) despite the challenge of very high rates of world population growth all along the 20th century.

The world's population will, nevertheless, keep growing. According to projections, there will be 9.8 billion people on Earth in 2050 and 11.2 billion in 2100 (United Nations, 2017). Income growth is also expected to continue, and with rising wealth comes larger demand and consumption for processed foods, meat, dairy, and fish, all of which put pressure on the food supply system (Godfray et al., 2010). It is important to note that the amount of food produced, and, to a large extent, the state of the environment globally are both heavily influenced by agricultural technology. However, the negative environmental effects of agriculture are often hidden (unmeasured) costs as they have no direct or visible impact either on farming or farmers' decisions concerning production methods. Such hidden costs, exemplified below, cast doubt on the sustainability of current procedures (Tilman et al., 2002).

In 2001, Tilman forecasted that a billion hectares of natural habitats would need to be converted to agriculture by 2050, if historical dependencies between agricultural impacts on the environment and human population and consumption hold true. Eutrophication of terrestrial, freshwater, and near-shore marine ecosystems, for example, caused by nitrogen and phosphorus (agricultural inputs), would increase by 2.4 to 2.7 times along with corresponding increases in pesticide use. Eutrophication and habitat loss would result in unparalleled ecological damage, loss of ecosystem services, and extinctions of various species (Pretty, 2018; Tilman et al., 2001). Some authors argue that agriculture-related activities are one of the main contributors to habitat loss, and present evidence that in 2003 they already affected 70% of the threatened species of birds, 49% of the threatened species of plants and 13% of the threatened species of mammals (Dirzo & Raven, 2003). Meanwhile, other authors argue that 25% of the world's greenhouse gas emissions in 2005 were attributable to agricultural production and land use changes like clearing land for agriculture and extracting forest products (Burney et al., 2010). As a result of the so called ”Green Revolution”, agriculture reduced ecosystems’ goods and services supply, for example through groundwater pollution and beneficial insect losses. Ideas on how agricultural systems may be more efficient at producing food and simultaneously reducing environmental harm changed because of concerns over these sorts of negative effects. Many calls for more sustainable agriculture are reflective of the desire for agriculture to produce more food without harming the environment or even being beneficial to natural and social capital (Pretty, 2018). This concern has made its way into literature, as a considerable number of authors are consistent in stressing the significance of providing environmental protection considering the global effort to change paradigms of agricultural systems (Constantin et al., 2022).

Having this in mind, this literature review therefore attempts to identify the current state of research regarding alternatives to conventional agriculture, namely, to what extent these alternatives compare to each other and to conventional agriculture under the following three functions of agriculture: achieving food security, farming profitability and sustainability. Furthermore, we also attempt to help direct future research, in order to be more instrumental for achieving the common goal of sustainable agriculture.

The remaining of the dissertation will be divided in the following way: first, in chapter 1, the methodology of the present review will be explained; secondly, in chapter 2, this dissertation attempts to gather the variety of viewpoints in the literature on what constitutes "alternative agriculture," which can then be more extensively explored under each of the three study strands chosen for this work (food security, sustainability and profitability); in chapter 3, the contribution of the aforementioned alternatives to food security is discussed; the impact of the aforementioned alternatives on profitability is explored in chapter 4; the effects of these alternatives on sustainability is then explored in chapter 5; finally, chapter 6 will contain the concluding words of the dissertation, in which the current state of the art and the research gaps are summarized and identified.

Chapter 1
Methodology

The present dissertation will follow the structure of a narrative literature review. A narrative or traditional literature review is a thorough, crucial and objective analysis of the most recent research on a subject. They are a crucial component of the research process and aid in creating a theoretical framework, focus, or context for the study. This kind of literature review assists in the discovery of patterns and trends in the literature, allowing for the identification of any gaps or contradictions in a body of knowledge (Charles Sturt University, 2023b). In comparison to systematic reviews, narrative reviews adopt a less formal methodology because they are not required to present the stricter elements of a systematic review, such as reporting methodology, search terms, databases used, and inclusion and exclusion criteria (Jahan et al., 2016). However, in order to decrease the risk of bias and increase the methodological detail of the dissertation, we will discuss the search terms and databases used, and screening techniques (Charles Sturt University, 2023a).

To assess how different alternatives to conventional agriculture contribute to food security, profitability and sustainability, the following search queries were applied in the Scopus and Web of Science (WOS) databases:

(1) (TITLE-ABS-KEY ("conventional agriculture") AND TITLE-ABS-KEY ("food security")) in Scopus / TS=("conventional agriculture) AND TS=("food security") in WOS. This resulted in 93 documents in the Scopus database and 82 in the WOS database.

(2) (TITLE-ABS-KEY ("conventional agriculture") AND TITLE-ABS-KEY (profit*)) in Scopus / TS=("conventional agriculture) AND TS=(profit*) in

WOS. This resulted in 52 documents in the Scopus database and 67 in the WOS database.

(3) (TITLE-ABS-KEY (“conventional agriculture”) AND TITLE-ABS-KEY (sustainability)) in Scopus / TS=(“conventional agriculture) AND TS=(sustainability) in WOS. This resulted in 97 results in the Scopus database and 234 in the WOS database.

It may seem contradicting to use the term “conventional agriculture” when looking to assess the contributions of its alternatives. However, there are 3 ways in which the term is used. The first is “to refer to a counterpoise, comparator or control treatment against which alternatives agricultures or practices can be tested, compared and contrasted”. Secondly, it is used when making the argument for alternative approaches. Finally, some advocates of alternate agricultures use the term in an effort to characterize and validate diverse or new agricultural methods and/or systems (Sumberg & Giller, 2022). Therefore, considering how the phrase “conventional agriculture” is used to present and/or compare various agricultural methods, utilizing it in the previous search queries is optimal.

After the identification of scientific publications based on the aforementioned research queries, the resulting literature was filtered. This was done firstly by title and abstracts, and, in some cases, after a full reading. The number of publications retrieved from the previously mentioned search was 132. It's interesting to observe that the terms "conventional agriculture" and "sustainable" were combined to produce the majority of the material found (65%). “Conventional agriculture” and “food security” were coupled to obtain 23% of the content, and “conventional agriculture” and “profit*” matched to provide the remaining 12% of the results. The references of the resulting scientific papers were then probed in order to identify important articles relevant to the topic of interest which are the source of the remaining literature.

Chapter 2
Defining "alternative agriculture"

A type of agriculture may or may not be mentioned in the reviewed bibliography as an alternative to "conventional agriculture." In this respect, different views are found in the literature. This helps to understand the range of views in the literature on what is an "alternative agriculture" ,which subsequently can be more thoroughly examined under each of the three research strands selected for this work (food security, profitability and sustainability). However, an alternative will only be revised in this dissertation if it is mentioned in more than one article. Additionally, a single article can discuss more than a single alternative. Therefore, it is possible that the amount of times that alternatives are mentioned is higher than the number of articles.

1. Alternative agricultures found using search term "Food Security"

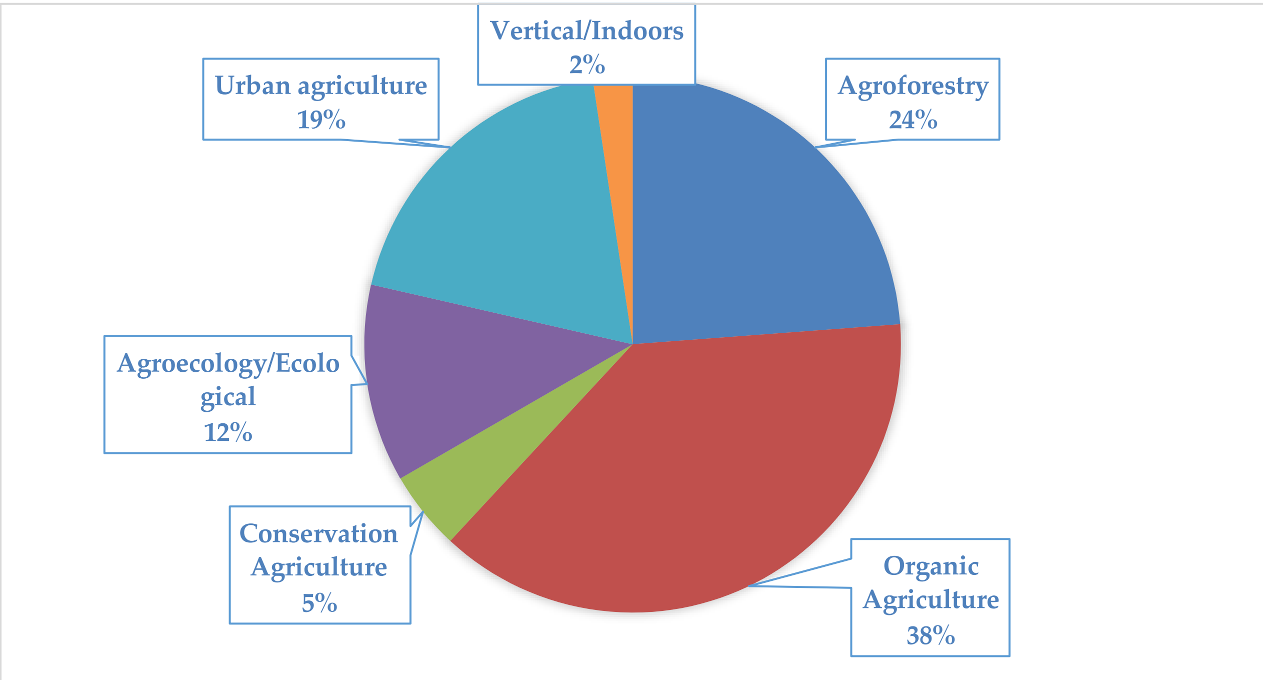

Figure 1: Alternative agricultures found using search term "food security". Source: own elaboration

Organic agriculture is the most extensively studied alternative to conventional agriculture in the research considering the term "food security," accounting for 38% of all mentions of an alternative agriculture. It is by far the most discussed alternative, with agroforestry coming in second place with only 24% of the total references. The two remaining options that account for more than 10% of mentions in the literature are urban agriculture and agroecology/ecological agriculture, which make up 19% and 12% of all mentions, respectively. Just 5% of all references are related to conservation agriculture. The last choice is vertical/indoor agriculture, which receives barely 2% of mentions in the literature on food security. The publications under consideration that address "food security" mention an alternative to conventional agriculture 42 times in total.

2. Alternative agricultures found using search term “profit*”

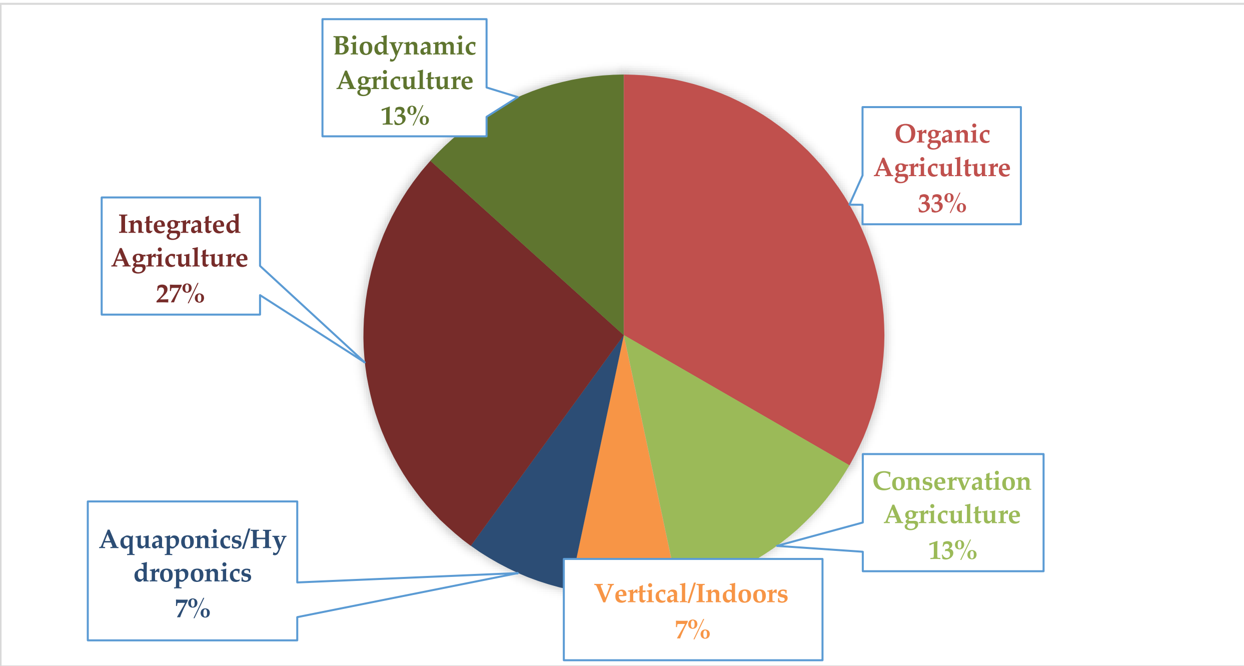

Figure 2: Alternative agricultures found using search term “profit*”. Source: own elaboration

When the search phrase "profit*" is taken into account, an alternative to conventional agriculture is mentioned in an article 15 times total. Then again, organic farming is the alternative that is most frequently mentioned, accounting for 33% of all mentions of an alternative agriculture in terms of profitability. Nonetheless, integrated agriculture, which is reported 27% of the time an alternative is recognized, is the second most frequent alternative in this strand. It's interesting that not a single article about food security discussed this alternative. The following most frequently cited types of agriculture are biodynamic and conservation agriculture, both receiving 13% of all references. In terms of profitability, vertical/indoor agriculture and aquaponics/hydroponics are the least discussed (7% of references each).

3. Alternative agricultures using search term “sustainability”

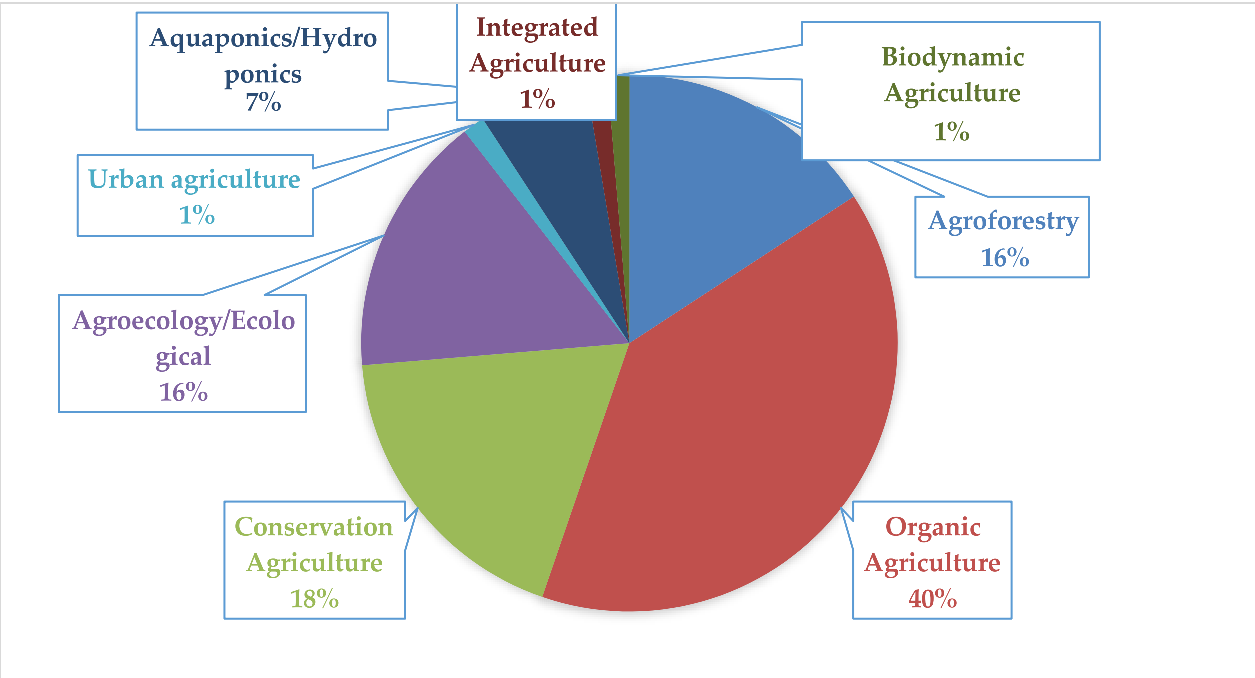

Figure 3: Alternative agricultures found using search term “sustainability”. Source: own elaboration

A substitute for conventional agriculture is mentioned 76 times in total in the publications under review that consider the term "sustainability".

Once more, organic farming is the alternative that is most frequently mentioned (30 times). Conservation agriculture, in contrast to the other two scenarios, earned 18% of all mentions of alternatives, placing it as the second most often mentioned option. Following closely after, agroforestry and agroecology/ecological agriculture made up 16% of the times an alternative was stated (both were mentioned 12 times). The remaining 8% of references belong mostly to aquaponics/hydroponics (7% of mentions), while the remaining 1% of references belong to biodynamic agriculture.

4. Alternatives found using search terms "food security", "profit*" and "sustainability"

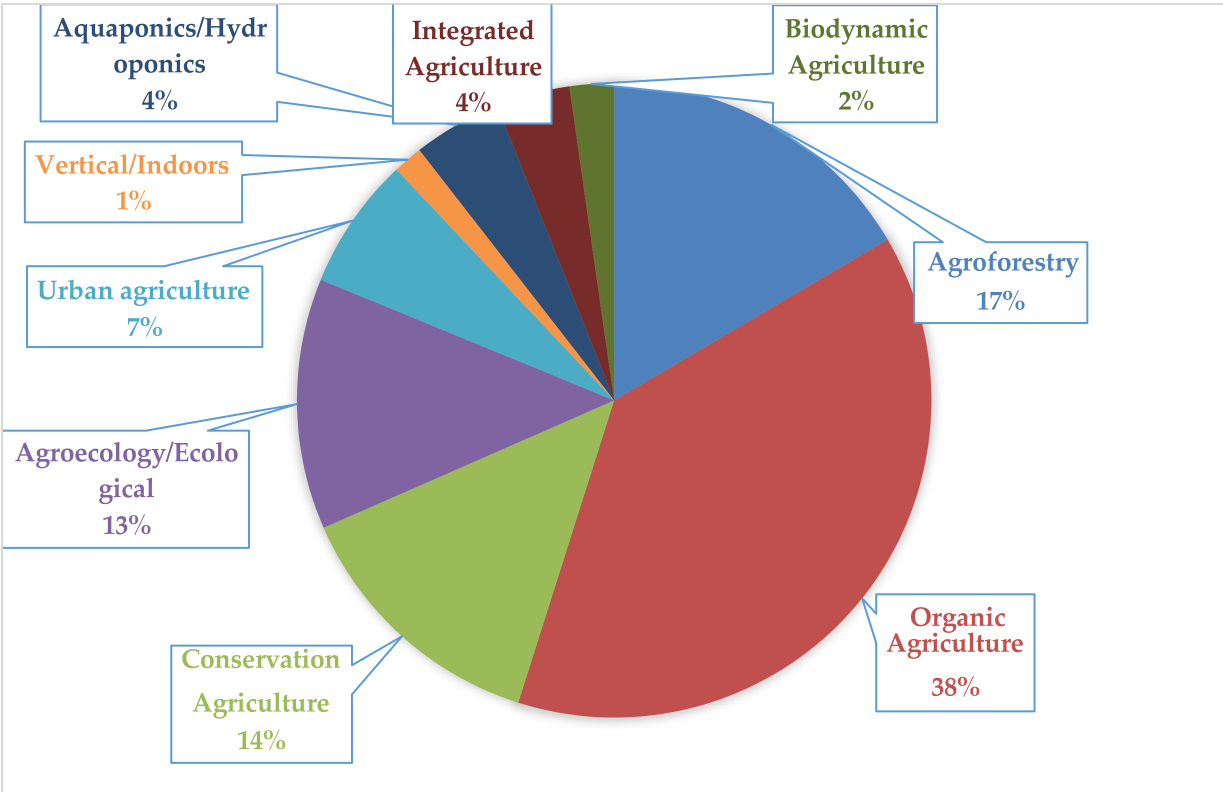

Figure 4: Alternatives found using search terms "food security", "profit*" and "sustainability". Source: own elaboration

Combining all three search terms, an alternative form of agriculture was mentioned a total of 133 times. With 51 references, organic agriculture was undoubtedly the alternative agriculture practice that was most frequently discussed. Agroforestry, which accounted for 17% of all references and was therefore mentioned 22 times, was the next most frequently mentioned alternative to traditional agriculture. This illustrates how heavily organic farming is discussed in literature that discusses alternatives. Agroforestry was followed closely by references to conservation agriculture and agroecology/ecological agriculture, which made up 14% and 13% of all mentions, respectively. None of the remaining options received more than 10 references in the literature review. With nine mentions, urban agriculture came quite close to crossing this threshold. Six references to aquaponics/hydroponics were found, five of which were in works on sustainability. Five references to integrated agriculture were found, with four of those resulting from the search word "profit*". Biodynamic agriculture was only mentioned 3 times, which is still once more than Vertical/indoors agriculture. The latter was barely considered as an alternative in this work, viewing as it only was mentioned 2 times in total.

Chapter 3
Contributions to food security

To understand how alternatives to conventional agriculture can contribute to food security, this thesis will utilize the definition of FAO: "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2006). Since this thesis focuses on the supply side (producers of food), the discussion needs to consider the capacity of production (can the alternative form of agriculture under study yield enough food or not when compared to conventional agriculture). However, yield isn't the sole food security factor to be considered. Other than the physical availability of food, there are other three dimensions of food security: 1) economic and physical access to food; 2) food use; 3) the stability of the other three dimensions over time (FAO, 2008). All four dimensions are necessary to achieve the common goal.

This is an important discussion since some argue that the capitalized, high external input food systems are susceptible to disturbances that operate outside of the system's own control boundaries, such as unexpected or non-linear climate variability or unforeseen ecological consequences of continuing external inputs use (Brzezina et al., 2016). Therefore, even though it currently achieves the goal of food security, its future success is uncertain, meaning that the fourth dimension of food security – Stability of the other three dimensions over time – is at stake (FAO, 2008).

1. Organic agriculture

As stated by the FAO, organic agriculture has many definitions, but they all acknowledge that it is a system that relies on ecosystem management rather than outside agricultural inputs. By avoiding synthetic inputs like chemical fertilizers, pesticides, veterinary drugs, genetically modified seeds and breeds, preservatives, additives, and irradiation, the system starts to take into account potential environmental and social effects (FAO, 2023).

Producing organic food has the potential to solve the vulnerability brought on by the deteriorating state of natural resources. Producers are specifically able to identify the two balancing loops identified by Brzezina et al.(2016) - natural resource degradation and regeneration - and put practices in place that strengthen both of them. As a result, and according to the same authors, the system builds up an important stock of natural resources and becomes more resistant to disturbances like climate change (Brzezina et al., 2016). According to some authors, organic agriculture has shown to be far more profitable for small-scale farmers in rural areas when compared to agriculture dependent on external inputs (Qiao et al., 2018), which is extremely important since, counter-intuitively, most people on the planet who are food insecure are small farmers (HLPE-FSN, 2013).

Organic agriculture is heavily criticized when it comes to its contribution to food security, as many see it as a less productive alternative and believe there is an insufficient amount of organic fertilizers. However, a study by Badgley et al. (2007) based on 2001 data, modelled a worldwide conversion to organic agriculture and concluded that, in the same amount of land as conventional agriculture, this agricultural alternative could produce more than enough calories considering the nutritional requirements of the world population. A more pessimistic approach resulted in less calories available for each person, but still above the requirement for an adult, and a more optimistic approach yielded 57% more than conventional agriculture. Nevertheless, these results were achieved considering a yield ratio of organic/non-organic of 0.92 in the developed world and 1.80 in the developing countries, whereas studies regarding the yield gap between conventional and organic agriculture have found less promising results, such as yield ratios of 0.8 and 0.75 (De Ponti et al., 2012; Seufert et al., 2012). This large difference can maybe be explained by the fact that Badgley et al. considered organic to refer to "farming practices that may be called agroecological, sustainable, or ecological", not being limited by any certification criteria. Therefore, this may have included cases in which practices that diminish the yield gap were used, such as multi-cropping and/or crop rotations, or even no-till soil preparation (Ponisio et al., 2015; Redlich et al., 2021). More recent estimations (Joshi & Piya, 2021) considering lower yield ratios than the ones used by Badgley et al., (e.g., 0.84 for North America and 1.05 for least developed countries) still showed that a full transition to organic agriculture is feasible. The same authors found that this transition would increase food and nutrient supply in the developing world, and the decrease in developed countries would result in less calories, protein and fat per person, but still far higher than the minimal level (Joshi & Piya, 2021). Several other studies have shown that organic farming tends to achieve higher yields than conventional agriculture in the least developed countries, and this trend is shown in other literature reviews. A review of the available research examined the variations between organic and conventional farming in the tropics and subtropics and found that yields from organic agriculture were 15% lower in the developed world, 16% higher in medium developed countries and 116% higher in the least developed countries (Te Pas & Rees, 2014).

The higher yield variability or organic systems may prove to be an obstacle in achieving food security, as it generates uncertainty in food supply and in farmers' incomes (O. M. Smith et al., 2019). This higher uncertainty has been proven using data from developed countries, in which food security is the highest, therefore similar analysis should be done using data from developing countries. Another obstacle may be the price premiums that organic systems need to be profitable. A meta-analysis comparing organic and conventional agriculture concluded that when organic premiums were not used, organic farming had significantly lower benefit/cost ratios and net present values than conventional farming. However, when actual premiums were used, organic farming was much more profitable than conventional farming (22–35%) and had higher benefit/cost ratios (20–24%). Despite premiums being between 29 and 32 percent, the breakeven premium required for organic profits to equal conventional profits was only 5 to 7 percent (Crowder & Reganold, 2015). Nonetheless, the fact that organic agriculture yields more expensive products than its conventional counterparts may impact the second dimension of food security negatively – economic and physical access to food (FAO, 2008).

2. Agroforestry

One of the mentioned alternatives in the literature is agroforestry. Agroforestry is a type of intercropping where annual herbaceous crops are interplanted with permanent trees or shrubs (Pretty & Bharucha, 2014). Based on the idea that natural systems are ecoefficient, a strategy to face the constraints to agriculture discussed in the introduction is to develop farming systems that closely resemble the composition and operation of natural ecosystems. This concept of ecological design is the foundation of a system of land use which blends the growth of trees and shrubs with the production of crops and/or cattle. According to a key tenet of agroforestry, complementarity in resource capture explains why production can even be higher in agroforestry systems than it is in monocropping systems (J. Smith et al., 2013). For example, over two cropping seasons, the introduction of Gliricidia sepium in enhanced fallows increased sorghum output by 55% (Hall et al., 2006), and according to estimates, the use of agroforestry systems has increased food production by 500 000 tonnes annually (Reij et al., 2009). Even though some studies already indicate beneficial effects on yield, some authors argue that if more investment focused on less-established strategies like agroforestry, production could rise significantly, greatly narrowing or even eliminating any current yield gap with conventional agriculture and altering trade-off calculations (Waldron et al., 2017). These systems are increasingly seen as a component of a multifunctional working landscape that offers ecological services, environmental advantages, and commercial goods. Diversity is built into traditional agroforestry systems, as opposed to modern mainstream agriculture, which focuses on a narrow range of crops (Jose, 2009). Environmental benefits from this alternative have been proven, such as higher carbon sequestration and conservation, proving its importance in the process of creating management plans to reduce atmospheric CO_2 over the long term (Baah-Acheamfour et al., 2014; Dixon et al., 1994), and increased soil quality and drought resistance of agroforestry systems (Rivest et al., 2013; Udawatta et al., 2014). Therefore, as it contributes to climate change mitigation and is better suited to deal with environmental shocks, agroforestry can positively contribute to food security in the nearing future.

3. Urban Agriculture

Urban agriculture has recently been promoted as a prominent countermovement that attempts to lessen conventional agriculture's negative environmental effects, increase food security, and strengthen social cohesion in urban areas (Buehler & Junge, 2016). A large majority of urban farmers are located in the developing world and use agriculture as a way to achieve extra income and subsistence (Smit et al., 2001). Therefore, it is mainly operated by people who are at the higher risk of food insecurity.

Urban agriculture can even be more productive than commercial horticulture, depending on the practices used by urban farmers, considering its potential yields (Tomkins, 2006), and it does not compromise soil quality measures that are favorably connected with controlling and maintaining ecosystem services. There is evidence that typical urban soils are much higher quality than agricultural soils and equivalent to semi-natural environment, and this is maintained despite its agricultural use (Edmondson et al., 2014). If the correct practices are used in order to achieve high yields and maintain soil health, urban agriculture seems to be able to positively contribute to food security in the future, especially in cities of developing countries (Smit et al., 2001). However, it is reasonable to consider that the contribution of urban agriculture to food security is minimal, considering that agricultural soil in urban areas represents a very small proportion of the whole agricultural soil resources.

4. Agroecology/Ecological agriculture

Ecological agriculture is a diversified system that places an emphasis on integrating natural resources into the production process, better utilizes local resources, and conserves and manages resources by using external inputs in a responsible manner in an attempt to make agriculture both environmentally and economically sustainable (Rasul & Thapa, 2003).

Based on empirical data, a report analyzed the sustainability of an ecological and conventional system in terms of their social acceptability, economic viability, and environmental soundness. Crop diversification, soil fertility management, pest and disease management, and agrochemical use were all shown to be significantly different between the two systems (Rasul & Thapa, 2004). The same authors found that other variables, such as land-use patterns, crop production and stability, risk and uncertainty, and food security, did not, however, show any appreciable differences. Therefore, the research suggests that ecological agriculture has a propensity to be more environmentally, economically, and socially responsible than conventional agriculture because it uses significantly fewer agrochemicals, enriches the soil with more organic matter, improves the quality of food, and requires more local inputs without noticeably reducing output or financial rewards (Rasul & Thapa, 2004). A review of the literature on the competitiveness and effectiveness of ecological agricultural systems revealed that while the widespread use of this environmentally friendly form of agriculture has many positive effects on the environment, more research is needed to identify ways to reduce costs while maximizing yields and farmers' income (Constantin et al., 2022). Therefore, it seems like agroecology/ecological agriculture can contribute to the fourth dimension of food security, by granting stability due to positive environmental effects. However, more research needs to be done in order to improve its contribution to FAO’s first dimension of food security – yield (FAO, 2008).

5. Conservation agriculture

Conservation agriculture encourages minimizing mechanical soil disturbance (no/zero tillage), maintaining a permanent soil cover, and diversifying plant types. It improves biodiversity and natural biological processes above and below the ground, which helps to boost the efficiency with which water and nutrients are used and to improve and sustain crop output (FAO, 2022).

Research indicates that when contrasting the stability of conventional and conservation agriculture, the more ecologically responsible choice does not appear to reduce the yield stability of agricultural operations (Knapp & van der Heijden, 2018). However, conservation agriculture practices are identified as a way to conserve and sequester carbon, achieving up to 10 times the carbon sequestration rates as compared to less environmentally friendly land-use practices (Dixon et al., 1994). Therefore, considering that its yield stability is comparable to conventional agriculture yield stability, but with lower environmental impacts, it seems that conservation agriculture can contribute positively to the fourth dimension of food security (FAO, 2008).

Chapter 4
Contributions to profitability

Authors differ on their choice of indicators to analyze profitability of farming systems. Therefore, indicators used can be benefit-cost ratios (Jamil et al., 2021), gross margins (Te Pas & Rees, 2014), gross revenue and/or net returns (Olgun et al., 2006), gross profits (Kılıç et al., 2020), Net Present Values (Mafongoya et al., 2016) or simpler alternatives such as cost comparisons (Meisner et al., 2007) or examining farmers annual accounts in the cases they don't keep financial records (Reganold et al., 1993).

1. Organic agriculture

Organic agriculture does not only tend to increase yield in least developed countries, according to the reviewed authors, but it has also apparently shown, on average, very high gross margins. In the tropics and subtropics, the gross margin of organic agriculture is, on average, 51% higher, due to higher prices of organic products (17,6% higher) and the 6% lower costs of organic methods (Te Pas & Rees, 2014). Using information from earlier meta-analyses that provided means and standard deviations for matched organic and conventional systems, Smith et al., 2019 concluded that organic farms had similar costs and higher profits than their conventional counterparts, despite their higher yield variability and lower yields (O. M. Smith et al., 2019). A prior study used a worldwide dataset consisting of 55 crops cultivated on five continents to conduct a meta-analysis to compare the financial performance of organic and conventional agriculture. When organic price premiums were not used, organic farming had significantly lower benefit/cost ratios (8 to 7%) and net present values (27 to 23%) than conventional farming. However, when actual premiums were used, organic farming was much more profitable than conventional farming (22–35%) and had higher benefit/cost ratios (20–24%). Although organic produce price premiums ranged from 29 to 32 percent, the breakeven premium required for organic profits to equal conventional profits was just 5 to 7 percent. This provides evidence that organic agriculture is currently more profitable, but also that it will remain profitable if price premiums are lowered significantly (Crowder & Reganold, 2015). In the Pacific Northwest region of the USA, a study on organic forage, quinoa and grain crop rotations led to similar results. The authors found that although the yields from organic systems were lower than the county's conventional norms, their economic performance was on par with or even higher (Wieme et al., 2020).

2. Integrated Agriculture

Multi-enterprise agricultural systems that interact in time and/or space and transfer resources in a synergistic way are known as integrated agricultural production systems (Hendrickson et al., 2008). Conceptually speaking, integrated agriculture resembles organic farming because its primary goal is the sustainable use of resources. But when it comes to the agricultural methods they advocate, integrated agriculture falls short of organic agriculture. The focus is on using fewer resources to generate economic savings and environmental benefits rather than completely eliminating chemicals (Morris & Winter, 1999).

A study executed in Scotland compared the profitability of a conventional and an integrated low carbon farming system, otherwise identical. The conventional farm system performed more successfully economically than the low-carbon integrated farm system on the assumption that GHG emissions were not costed. When the costs of emissions from both farm systems are considered, the difference is less noticeable but is still present. The relative economics of both farm systems are similar when anticipated price premiums within the range of reported price premiums for integrated system produce are considered (Abdul-Salam et al., 2019). In the Netherlands, a comparison between an integrated and conventional system growing the same crops shows that the integrated system not only had higher total returns, but also lower costs. Therefore, the integrated system provided a better gross margin, and was more profitable than the conventional one (Vereijken, 1986).

3. Biodynamic agriculture

Both biodynamic and organic farming focus on the environment and avoid using chemical pesticides and fertilizers. The primary distinction is that biodynamic farmers prepare their soils, crops, and composts with 8 precise amendments. Growing interest has been shown in biodynamic farming methods and systems recently since they can mitigate some of the negative consequences of conventional agriculture's reliance on chemicals. Most, if not all, certified biodynamic goods would satisfy the requirements for being labeled as organic, while certified organic goods would not satisfy the biodynamic standards, mostly because organic farming does not use biodynamic preparations (Reganold, 1995).

Therefore, some studies have compared biodynamic and conventional farms profitability. In New Zealand, total gross margins on the biodynamic farms are lower than those of their conventional neighbors. However, most of the time, compared to conventional farms, the biodynamic farms' gross margins varied less year over year, showing more economic stability (Reganold et al., 1993). In The Netherlands, an experimental farm allowed the study of biodynamic and conventional systems. Due to significantly higher pricing and lower costs, the biodynamic system generated better gross margins. However, profitability from the conventional system was higher when own labor costs were included (Vereijken, 1986).

4. Conservation Agriculture

According to a meta-analysis, conservation agriculture in Zimbabwe produces more maize than traditional agriculture. However, farmers experience losses when they transition from a conventional system to conservation agriculture because of the increased labor requirement necessary to combat weed pressure. Nonetheless, if labor demand is decreased, conservation agriculture could become lucrative (Mafongoya et al., 2016). The importance of climate resilient agriculture has been discussed by the Food and Agriculture Organization of the United Nations. Any sustainable land & water management technique that boosts climate change resistance, enhances resource use effectiveness, sustainably boosts yield, and lowers greenhouse gas emissions, such as conservation agriculture, is known as climate resilient agriculture (Food and Agriculture Organization of the United Nations, 2013). Climatic variations pose a significant threat to conventional agricultural production. In some countries such as Pakistan, the effects of climate change have led to an increase in droughts and temperatures, floods, the depletion of land resources, desertification, yield losses, and unpredictable rainfall. A comparison of cotton producers that adopt conservation agriculture practices and those who don’t in Pakistan shows that the adoption of sustainable land & water management strategies not only lead to more productive systems, but also to lower total input costs. As a result, adopters' net returns were around twice as high as those of non-adopters (Jamil et al., 2021).

Chapter 5
Contributions to sustainability

The usefulness of the concept of agricultural sustainability has been discussed in the literature. There are currently two major interpretations of agricultural sustainability, each with a distinct set of objectives (Hansen, 1996). Sustainability can be seen as a quality of agriculture developed in response to concerns about threats to agriculture (such as climate change and a continuously growing population), with the goal of using it as a criterion for guiding agriculture as it responds to change. Sustainability can also be viewed as an approach to agriculture developed in response to concerns about impacts of agriculture on society as a whole and on the environment in particular, with motivating adherence to sustainable ideologies and practices as its goal. The concept of sustainability as an approach has been effective for spurring change, but not for directing it, as it is constrained by a mistaken perception of traditional agriculture, circular reasoning, and a lack of generality in the prescribed methodologies. So, it makes more sense to view sustainability as a systemic approach to agricultural production (Hansen, 1996). The concept of sustainability is now more discussed than ever, as claims link a wide range of problems to agriculture, including obesity, hunger, and poverty. Many think that industrial farming, an excessive reliance on chemical pesticides and fertilizers, poor food quality, biodiversity loss, exploitative labor practices, and animal welfare, as well as corporate control and a lack of resilience, are to blame (Giller et al., 2021). These assertions are compatible with "conventional agriculture" being used as a counterpoint, comparator, or "control treatment" to test, compare, and contrast alternative agricultures or practices in scientific literature (Sumberg & Giller, 2022), such as its use in our thesis. Although many environmental, economic, and social factors are included in definitions of sustainability, the majority place a relatively narrow emphasis on the environment, resource conservation, productivity, and farm and company profitability. Therefore, this thesis will be guided by the definition of sustainability provided by Allen et al.: "A sustainable agriculture is one that equitably balances concerns of environmental soundness, economic viability, and social justice among all sectors of society" (Allen et al., 1991).

1. Organic agriculture

Comparing organic and conventional farming methods, there is evidence that the latter emit less nitrogen. In comparison to conventionally farmed soils, organically farmed soils show higher potential denitrification rates, denitrification efficiency, organic matter levels, and microbial activity. In comparison to organic plots, annual nitrate leaching was 4.4–5.6 times higher in conventional plots (Kramer et al., 2006). Additionally, species diversity is frequently greater on organic farms than on conventional ones. Many of these variations relate to species known to have seen decreases in range and/or abundance because of historical agricultural intensification, many of which are currently the focus of direct conservation legislation (Hole et al., 2005). There are fewer traces of agrochemicals in the soil and water from organically managed fields compared to conventionally managed fields, according to a comparison of soil and water parameters in organic and conventional farming systems in England. Additionally, it was demonstrated that organically managed grassland soils had much higher infiltration rates than conventionally managed grassland with lower stocking rates. These higher rates will prove to be useful, for example, in the case of flooding. However, it is necessary to understand if these higher rates are caused by organic management or other factors (Hathaway-Jenkins et al., 2011). A study conducted on an experimental station near Versailles, France, compared the long-term effects of organic and conventional agriculture on major soil organisms. The study concluded that, compared to a conventional system, organic alternative farming methods increased the abundance and/or biomass of soil biota. All soil organisms except one had an increase in population and biomass thanks to organic systems (Henneron et al., 2015).

Organic farmers depend more on alternatives such as cover crops for improving soil organic matter and nitrogen fixation, while conventional farmers tend to rely on external inputs. This explains why they value the ecosystem services provided by such practices much more than conventional farmers (Wayman et al., 2017). This trend is also existent in pest management practices, as organic farmers focus on preventative rather than curative measures and the long-term objective to increase agroecological system resilience through the development of on-farm management approaches rather than the purchase of external products, a practice preferred by conventional farmers (Lammerts Van Bueren & Myers, 2012). Mainstream agriculture dependence on external inputs may explain why Italian olive farms register a higher Technical Efficiency under organic management of approximately 10% (Raimondo et al., 2021), as, given a certain amount of input, the Technical Efficiency measure enables comparison of the observed output to the best production output (Farrell, 1957).

A good way to compare the sustainability of organic farming systems with conventional systems is through Life Cycle Analysis (LCA), as the use of LCA to compare the environmental effects of organic vs. conventional products adequately captures the effects of those various production methods. However, it is important to notice that results may vary depending on the choice to calculate environmental impact by area or by product (Meier et al., 2015). Therefore, using different LCA analyses considering various crops seems suitable for comparing the environmental impact of the aforementioned production methods. A study comparing an organic field pepper cultivation with a conventionally managed counterpart in Northern Greece concluded that both systems have comparable overall environmental effects. Contrary to conventional farming, which scores better in the damage categories of "resources" and "human health", organic farming receives a slightly lower score for damage to "ecosystems" category, when results are expressed as a function of product. Due to its higher crop output and the use of Greece's fossil fuel-dependent energy mix during the irrigation stage, conventional farming overall displays a somewhat better environmental performance. However, when results are expressed as a function of area, organic pepper cultivation has overall environmental effects on "resources", "ecosystems", and "human health" damage that are around 35% less severe (Chatzisymeon et al., 2017). In the same region, LCA was also conducted comparing an organic and conventional system, both used for lettuce cultivation. When sustainability was evaluated per growing area, it was discovered that organic lettuce farming had lower environmental footprint and CO_2 emissions than conventional lettuce cultivation by 11% and 15%, respectively. Contrarily, when the quantity of lettuce produced is utilized as the functional unit of calculations, conventional lettuce farming outperformed organic by 51% and 53% in terms of CO_2 emissions and overall environmental impacts, respectively. This is explained by the fact that the organic system needs a much larger cultivation area to produce the same amount of crops as its conventional equivalent because of its lower crop yields (Foteinis & Chatzisymeon, 2016). From the region of Rumbeke-Beitem in Belgium, data was used to conduct LCA analyses on leek production, again comparing an organic and conventional system. When the comparison was made according to the amount produced (per kilogram of leek), the authors came to the conclusion that conventional farming is preferred for some effect categories because the overall yields are often lower in conventional than in organic systems. Comparing the effects, conventional leek production has a 3 percent lower impact on eutrophication and a 23% lower impact on the generation of photo-oxidants, 15% lower impact on ozone depletion, and 11% less impact on abiotic resource depletion. However, conventional production exhibits a far higher impact on global warming, human toxicity, and land ecotoxicity (2, 4, and 100 times higher, respectively). Organic farming has a 15% reduced influence on acidification potential. However, when the comparison is performed by area, taking into account all pertinent effect categories, one square meter of organically grown leek has a lesser impact than its conventional equivalent. The effect categories of human toxicity and terrestrial ecotoxicity are significantly impacted by the usage of pesticides in conventional agriculture systems (de Backer et al., 2009). A study that took place in central Italy analyzed, using the LCA approach, the carbon footprint of a locally produced organic wholemeal bread and a conventional wholemeal bread manufactured in the same bakery enterprise. The authors discovered that 1 kg of conventional wholemeal bread had a carbon footprint of 1,18 kg CO2eq, which was 24% less than the same amount of organic bread. Contrarily, if the measure is evaluated per cultivated area (hectare), organic wheat agriculture outperformed conventional cultivation in terms of greenhouse gas emissions by 60%. The lower yield per unit of area cultivated with organic farming and the resulting attribution to a smaller amount of products of the greenhouse gas emissions created in the field phase of the life cycle (the study considered the whole life cycle, from farm to consumer) are the causes of the higher carbon footprint per unit of organic output. However, when conventional methods are used, the CF per hectare is greater since more raw materials are used in comparison to the same organic system (Chiriacò et al., 2017). A previous publication focused on 39 studies that applied LCA in agricultural products, calculated toxicity and mentioned fungicides, in order to calculate expected benefits to human health and ecosystem quality of organic agriculture. The study concluded that the elimination of fungicides in the production of fruits and vegetables in Europe will result in an enhancement in life quality for European inhabitants if existing conventional agriculture techniques are converted to organic ones. As a result of the absence of fungicides from fruit and vegetable cultivation, advantages related to species loss of up to 90 species per year are also anticipated (Tsalidis, 2022).

Nonetheless, assessments of sustainability aren't solely done by LCA. Another approach can be seen in a study focusing on the production of wild rocket in conventional, organic and biodynamic systems, on the province of Udine, Italy. The authors attempted to employ a multi-criteria method and ranked the 3 aforementioned options in a purely ecological scenario, a purely economic scenario, and any point in between. Regarding the organic farm, the study's findings supported the notion that this form of farming is crucial for achieving favorable economic outcomes while also protecting the environment and generating advantages for the entire community. The article specifically demonstrates how this farming system is capable of striking a balance and achieving equilibrium across all aspects of sustainability, viewing as it's a close second to the conventional system in the purely economic scenario, and even closer to second in the purely ecological scenario, beaten by the biodynamic system (Troiano et al., 2019). A previous literature review focused on energy efficiency and savings and CO2 and GHGs abatements of organic agriculture, and concluded that when it comes to energy efficiency, organic agriculture outperforms conventional agriculture significantly. Further, it also is a significant option for providing a carbon sink and reducing GHGs (Gomiero et al., 2008).

2. Agroforestry

Building a healthy soil and environment to raise food crop output and household income while boosting the farm enterprise's resilience to various threats is the key measure of the effectiveness of agroforestry systems. They are designed to produce longer growing seasons, higher output, more effective water use, and drought resistance (Garrity et al., 2010).

It has been demonstrated that agroforestry adaptation in Southern Malawi increases soil organic carbon, soil fertility, and reduces reliance on inorganic fertilizers (Makumba et al., 2006), while also improving water filtration, therefore increasing drought resistance (Chirwa et al., 2007). Comparing 30 highland agroforestry systems and 30 conventional agriculture systems, a study in Ecuador used a combination of biophysical and socioeconomic data based on household interviews. The goal was to identify which system offers the best conditions to support sustainable livelihoods for smallholder farmers. The findings show that compared to conventional systems, agroforestry systems have higher levels of agrobiodiversity, more varied livelihoods, better land tenure security and household income, more varied sources of irrigation, and a lower reliance on rainfall (Córdova et al., 2018). Ecological services like disease prevention, soil structuring, and nutrient cycling are provided through promoting biodiversity in agrosystems. Agroforestry is one example of a cultural practice that might improve biodiversity (Lichtfouse et al., 2009). In order to address low yields and low income in the tropics, diversification with nitrogen-fixing trees and the cultivation of native tree species that offer nourishing and marketable goods can be used to restore the soil fertility, the agroecosystem functions, and the source of income. Evidence from agroforestry suggests that in this approach, productive and environmentally friendly farming systems can be established in harmony with wildlife while also ensuring food and nutritional security and reducing poverty. These systems' higher levels of biodiversity create habitat for natural predators, which in turn lowers the population of herbivores and pathogens. Therefore, incorporating trees in tropical agrosystems helps reduce reliance on outside inputs (Leakey, 2014). Other authors evaluated the potential of agroforestry in tropical countries and found that these systems offer a potentially beneficial conservation method that can be helpful for easing land-use pressure. The burden on conservation areas' ability to utilize resources can be reduced by the presence of valuable tree species and other non-timber forest products in agroforests. It is possible to sustain and create habitats in human-dominated landscapes that can help retain a significant amount of biodiversity, as evidenced by the ability of many tree-covered but highly exploited landscapes to support native species (Bhagwat et al., 2008). In a study comparing agroforestry systems to solo crop production, it was discovered that the energy usage efficiency of various neem-based agroforestry systems under a rainfed ecosystem was higher than that of the control (Doddabasawa et al., 2020). A review of evidence considering agroforestry systems in the tropics found that compared to the alternative (such as mineral fertilizers), legume-based agroforestry is unlikely to pose an additional harm to the rise in atmospheric N2O concentrations. Furthermore, legume-based tree systems can influence methane exchanges as well as sequester and accumulate carbon (Rosenstock et al., 2014). Agroforestry practices improved smallholder farmers' resilience to climate changes and climate variability, particularly by improving farm production (food, fodder, timber, fuel wood, and manure) and ecosystem services (soil improvement, climate amelioration, wind break, erosion control, and disease and pest control) , according to a study conducted in the Mwanga District of Kilimanjaro, Tanzania (Munishi et al., 2013). Research at the University of Guelph in Ontario, Canada, compared an agroforestry system to a conventional one and discovered that the intercropped area had higher soil organic carbon content and greater bird and insect diversity. Closer to the tree rows, earthworm abundance and dispersion were higher, indicating increased soil health. In comparison to conventional agricultural fields in the area, the Carbon sequestration capacity in fast-growing tree-based intercropping systems was four times higher. The tree-intercropping systems may also result in a decrease in nitrous oxide emissions from agricultural areas due to less fertilizer use and more effective nitrogen cycling (Thevathasan & Gordon, 2004).

3. Conservation Agriculture

By attempting to eliminate the conventional agriculture system's unsustainable components (tillage, residue clearance, and monocropping), conservation agriculture hopes to address the majority of the problems preventing output improvements. High water losses from agricultural lands through surface run-off are dealt with by factors that increase infiltration and decrease water evaporation (minimal soil disturbance and maintenance of soil cover), while soil fertility decline is dealt with by factors that increase soil carbon by using organic materials as soil cover and increase fertilizer use efficiency through precise application. The soil is additionally fertilized by interactions and rotations of plants from agroforestry and legumes (Marongwe et al., 2011).

At a 14-year-old experimental site of La Cage, close to Versailles, France, soil samples were taken from a conventional, organic and conservation agricultural system. Compared to organic farming, conservation agriculture demonstrated an even greater overall improvement on soil life (Henneron et al., 2015). Study findings in southern Africa demonstrate that conservation agriculture typically boosts infiltration and lessens erosion. Additionally, compared to plots that were normally ploughed, those utilizing this approach had considerably higher carbon (Thierfelder et al., 2012). A study comparing conventional and conservation agricultural techniques in India came to the conclusion that conservation agriculture enhanced soil physical, chemical, and biological indicators of soil health, such as soil organic carbon and accessible nutrients. In most cases, these improvements could be measured by the 6th year of implementation (Bhattacharya et al., 2020). In Lesotho, conservation agriculture is referred to as "likoti". Data from surveys conducted in this nation demonstrates that conservation agriculture increased environmental sustainability because it improved soil structure and fertility (Silici et al., 2011). Farmers that practiced conservation agriculture in Northern Tarzania reported better soil conservation and water management (Owenya et al., 2011). With the use of technology that promote water infiltration and decrease moisture evaporation from the soil, Zimbabwe is addressing the effects of climate change, including rising temperatures and irregular rainfall patterns, which explains why more people are embracing conservation agriculture (Marongwe et al., 2011).

4. Agroecology/Ecological agriculture

Establishing ecological agriculture is essentially the process of changing present, conventional agricultural techniques as needed. The long-term viability of agricultural production has already been jeopardized by the rapid exploitation of natural resources and the environment, which surpasses their potential for self-renewal and overstresses their inherent resilience. Ecological agriculture will progressively compete with, if not completely replace, conventional agriculture to the extent that it is viewed as a potential solution to the latter's' weaknesses (Shi, 2002). According to research, if all paddy rice production in northeast China used agroecological techniques, the rice planting area could be increased by 30 to 40% without increasing the total amount of irrigation water needed. As a result, rice output in northeast China might rise by around a million metric tons, and the effectiveness of irrigation water use could rise by 30 to 50 percent (Wen & Pimentel, 1992). Also in China, it was discovered that the plant diversity in ecological agriculture was significantly higher than in conventional agriculture in a study site in a rural area of the Heishuitan River, a tributary of the Jialing River in the Beibei District of Chongqing. This suggests that greater stability of the paddy ecosystem is expected in ecological agriculture, which supports the sustainability of agriculture development (Shao et al., 2019). In a different Asian country, two agricultural systems were chosen from the Delduar subdistrict of Tangail district in Bangladesh, one with a conventional agricultural system and the other with an ecological agricultural system. The use of inorganic fertilizers and insecticides, which are the main contributors to air, water, and land pollution, shows a significant difference between the conventional and ecological systems. Even while inorganic fertilizers are still used by the majority of ecological farmers, their use is much less than that of conventional farmers. The authors claim that the project's most notable accomplishment in the ecological farming system is the reduction in the number of farmers using insecticides on crops. Most ecological farmers employ various techniques, including the use of herbal insecticides, to control insects using their local knowledge. Due to these characteristics, the authors considered the ecological system more environmentally sustainable than the traditional system. It was also concluded that the ecological system has had positive environmental impacts by lowering the usage of inorganic fertilizers and by storing carbon in the soil. (Rasul & Thapa, 2003).

5. Aquaponics/Hydroponics

Hydroponics is a crop production technology that has been utilized effectively for the cultivation of vegetables and flowers. It employs a fertilizer solution and largely regulated environmental conditions, making it more energy intensive but more productive than traditional agriculture (Cifuentes-Torres et al., 2021). The yield per area of the hydroponic system system was found to be 11 times higher while using 13 times less water in a study comparing a conventional and a hydroponic system both utilized for lettuce cultivation in Arizona. Nonetheless, the hydroponic system's energy requirement was much greater than that of the traditional system. This may be a setback to the hydroponics system sustainability, depending on the energy source (Barbosa et al., 2015). Reclaimed water (rainwater or treated wastewater) can be a source of water for hydroponic systems because of its high nutrient content, according to research that examines water savings using hydroponic systems (Cifuentes-Torres et al., 2021). The same authors concluded that it is possible to obtain safe agricultural produce and purify reclaimed water further before releasing it into the environment with special care. Hydroponic systems offer a substitute for preventing water pollution and water scarcity due to their high rates of nutrient removal from wastewater. Some argue that using recycled water as a nutrient supply in hydroponic systems has produced positive results, and its viability as a substitute for traditional crop production is increasing (Cifuentes-Torres et al., 2021). Authors have also looked into the potential of aquaponics systems, which combine hydroponics for soilless plant growth with recirculating aquaculture systems for fish production to recycle dissolved nutrients from fish metabolism. They discovered that this technique produced crops of a comparable yield and quality to those grown in traditional hydroponic systems, but it also significantly decreased greenhouse gas emissions by reducing the use of inorganic fertilizer, when it comes to lettuce production. According to a study, compared to the control hydroponic system, using aquaponic fish water resulted in a 62.8% reduction in the need for mineral fertilizer and a full substitution of the necessary water for the nutrient solution. Also, by adopting decoupled aquaponics to minimize the demand for fertilizer, an annual lettuce production site's per-hectare greenhouse gas emissions might be cut by 72%. This is because less energy would be used to produce fertilizer (Monsees et al., 2019).

Chapter 6
Conclusions

The following color coded table sums up the results of the research of this dissertation, which will be discussed below:

	Food Security	Profitability	Sustainability
Organic agriculture	[Gray]	[Green]	[Green]
Agroforestry	[Green]		[Green]
Conservation agriculture	[Green]		[Green]
Agroecology/Ecological agriculture	[Gray]		[Green]
Urban agriculture	[Green]		
Aquaponics/Hydroponics			[Green]
Integrated agriculture		[Green]	
Biodynamic agriculture		[Gray]	
Vertical/Indoors agriculture			

Table 1: Main results. **Green** – positive contribution; Gray – neutral contribution; **Red** – negative contribution; Blank spaces – further research needed. Source: own elaboration.

As we can see from the table, the popularity of organic agriculture in the literature seems to be justified by (or be due to) the results found in this literature review. Organic agriculture seems to be able to contribute positively to food security, whether it is by higher yields in the developing world (Badgley et al., 2007; Joshi & Piya, 2021; Te Pas & Rees, 2014) or by diminishing natural resources degradation and improving their regeneration (Brzezina et al., 2016), while increasing profitability (Crowder & Reganold, 2015; O. M. Smith et al., 2019; Te Pas & Rees, 2014; Wieme et al., 2020). However, the price premiums necessary for this alternative to be competitive may counteract its positive contribution to food security, and also explain its higher profitability (Crowder & Reganold, 2015). Therefore, this alternatives contribution to food security is considered neutral, and its positive contribution to profitability is most likely due to these price premiums. Furthermore, organic agriculture positively contributes to sustainability, whether it is by decreasing the environmental impact of agriculture (Hathaway-Jenkins et al., 2011; Henneron et al., 2015; Hole et al., 2005; Kramer et al., 2006) or decreasing the use of external farm inputs (Lammerts Van Bueren & Myers, 2012; Wayman et al., 2017), which is examined by several Life Cycle Analyses (Chatzisymeon et al., 2017; Chiriacò et al., 2017; de Backer et al., 2009; Foteinis & Chatzisymeon, 2016; Tsalidis, 2022) and other approaches (Gomiero et al., 2008; Troiano et al., 2019).

Agroforestry is the second most mentioned alternative in the reviewed literature. It has been found to contribute positively to food security by increasing production (Hall et al., 2006; Reij et al., 2009; J. Smith et al., 2013; Waldron et al., 2017) and/or increasing the stability of farming systems (Baah-Acheamfour et al., 2014; Dixon et al., 1994; Rivest et al., 2013; Udawatta et al., 2014). The reviewed literature also points to its positive contribution to sustainability (Bhagwat et al., 2008; Chirwa et al., 2007; Córdova et al., 2018; Doddabasawa et al., 2020; Leakey, 2014; Lichtfouse et al., 2009; Makumba et al., 2006; Munishi et al., 2013; Rosenstock et al., 2014; Thevathasan & Gordon, 2004). However, there is a lack of literature regarding the profitability of this alternative. The closest this review considers is a single article that concluded Agroforestry as a positive contributor to land tenure security and household income (Córdova et al., 2018). Therefore, it seems that agroforestry contributes positively to food security and sustainability, but its contribution to profitability still needs to be further researched.

Conservation agriculture is found to increase production of agricultural systems (Mafongoya et al., 2016), and maintain the stability of production (Knapp & van der Heijden, 2018; Marongwe et al., 2011), which makes the alternative seem suitable to guarantee food security. The sustainability of conservation agriculture systems is also higher than its conventional counterparts (Bhattacharya et al., 2020; Henneron et al., 2015; Marongwe et al., 2011; Owenya et al., 2011; Silici et al., 2011; Thierfelder et al., 2012). However, this study can't conclude about this alternatives contribution to profitability, as in some cases it contributes to a higher profitability (Jamil et al., 2021), and in some, the opposite (Mafongoya et al., 2016). Therefore, just as it is the case with agroforestry, conservation agriculture contribution to profitability must be studied further.

Agroecology/ecological agriculture isn't as promising to food security as the previously mentioned alternatives because the production achieved by this alternative is lower than the one achieved by conventional agriculture (Constantin et al., 2022), which can be somehow counteracted by the stability provided by this alternative (Rasul & Thapa, 2004). Furthermore, its profitability still needs to be studied, which is both proven by the lack of literature found and other authors experience (Constantin et al., 2022). However, positive contribution to sustainability of this alternative is widely recognized (Rasul & Thapa, 2003, 2004; Shao et al., 2019; Wen & Pimentel, 1992).

Several authors points to urban agriculture as a way to increase food security (Buehler & Junge, 2016; Smit et al., 2001), while some view it as a possible way to increase productivity (Smit et al., 2001; Tomkins, 2006), and increase stability of production (Edmondson et al., 2014; Smit et al., 2001), by increasing agricultural sustainability. However, as in other cases, its contributions to profitability need to be further researched, such as its contributions to sustainability.

Aquaponics/hydroponics is only shown by the literature to possess a positive contribution to sustainability, lacking research in the strands of food security and profitability.

Meanwhile, integrated agriculture's positive contribution to profitability is discussed, but its contribution to food security and sustainability needs to be further researched.

Biodynamic agriculture is shown to not have an impact on profitability, but to understand its effects on food security and sustainability more research is needed.

Lastly, even though Vertical/Indoors agriculture was identified as an alternative, the reviewed articles did not allow to reach any conclusion on the contribution of this alternative to any of the three agriculture functions.

A key takeaway from this work is the context dependent performance of alternative agriculture. Some studies already consider this factor (e.g., Seufert & Ramankutty, 2017), but this thesis further proves it. Organic agriculture is a good example of an alternative with a context dependent performance. Global yield ratios of organic agriculture are shown to be below one, identifying it as less productive than conventional agriculture (De Ponti et al., 2012; Seufert et al., 2012). However, studies that split organic agriculture yield ratio into developed and developing countries tend to find that yield ratios of organic agriculture in the developing world are higher than one, therefore this alternative is more productive than conventional agriculture in the developing world (Badgley et al., 2007; Joshi & Piya, 2021; Te Pas & Rees, 2014). Therefore, in order to achieve food security worldwide, it seems obvious to conclude that the adaptations to agriculture must consider the performance of each alternative according to each region's social, economic and geographic factors.

Furthermore, the importance of farmer groups/cooperatives cannot be understated while discussing alternative agriculture. Their success in increasing information, farmers income and bargaining power and adoption of alternative agriculture, especially when it comes to small/medium scale farmers is well documented in the literature (Owenya et al., 2011; Qiao et al., 2018). The information provided by groups or cooperatives is extremely valuable, as in some cases, the farmers tend to rely on the information provided by agrochemical companies, making it less likely that these farmers attempt to use less of these chemicals (Chalak et al., 2017).

Finally, achieving food security relies on much more than producing enough food to feed the population of the world. Several other factors may be an obstacle to achieve the four dimensions of food security (FAO, 2008), such as logistic issues and/or income distribution. Therefore, even though several studies (e.g. Badgley et al., 2007; Joshi & Piya, 2021) discuss the contribution of alternative agricultures to the global food supply, this is only one of the many factors needed to achieve the common goal of food security.

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