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Faculty of Tropical AgriSciences

# Potential of agroforestry as a climate change adaptation and mitigation strategy in the lowlands of Azerbaijan

MASTER'S THESIS

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# Declaration

I hereby declare that I have done this thesis entitled **Potential of agroforestry as a climate change adaptation and mitigation strategy in the lowlands of Azerbaijan** independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the Faculty of Tropical Agrisciences (FTZ).

In Prague, 22nd April 2023

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Eva Baldassarre Švecová

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**Abstract**

Azerbaijan faces severe climate change (CC) impacts, aggravating land degradation caused by wind erosion and inappropriate agricultural practices. This is particularly the case in the lowlands, where most agricultural production occurs and is carried out by smallholder farmers. Farming practices like agroforestry would enable CC adaptation and mitigation, but the adoption has so far remained limited. The thesis analysed the potential of agroforestry in the lowlands of Azerbaijan with the following objectives: (i) to review the non-financial and financial benefits and costs of agroforestry; (ii) to estimate the profitability of agroforestry and wheat monoculture, including changes in the prices of inputs and outputs, through cost-benefit and sensitivity analyses; (iii) to determine farmers' awareness of CC effects and agroforestry practices and their perceived feasibility through a quantitative questionnaire survey; (iv) to identify the strengths, weaknesses, opportunities and threats of agroforestry through a weighted SWOT analysis. Agroforestry practices (pomegranate orchard, pomegranate orchard intercropped with wheat, windbreaks with wheat) were more profitable than wheat monoculture. They had a greater capacity to deliver various environmental and social benefits, but they were more sensitive to changes in input and output prices (product selling prices, labour cost, subsidies, cost of agrochemicals). The Azeri farmers perceived CC severity and the importance of climate-smart strategies. However, farmers were rather sceptical about implementing fruit orchards and windbreaks, although the strengths and opportunities outweighed the weaknesses and threats in the SWOT analysis. The major strengths identified were improved livelihoods and knowledge. Investment costs and lack of access to technology and innovation were the main weaknesses. Key opportunities were infrastructure development and improved food security. The threats were limited knowledge and awareness of CC risks and adaptation solutions, insufficient institutional coordination and community capacity, and deteriorating infrastructure. It can be concluded that agroforestry is a valuable alternative to traditional monoculture, but its adoption would be feasible only with institutional support for the investment costs and for addressing the identified threats.
**Keywords**: cost-benefit analysis, profitability, sensitivity analysis, SWOT analysis, fruit orchards, windbreaks

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**List of the abbreviations used in the thesis**

| | |
|---|---|
| ADB | Asian Development Bank |
| AFOLU | Agriculture, Forestry and Other Land Use |
| BCR | Benefit-Cost Ratio |
| CBA | Cost-Benefit analysis |
| CCA | Caucasus and Central Asia |
| CGIAR | Consultative Group on International Agricultural Research |
| CZU | Czech University of Life Sciences Prague |
| DALGA | Dalga Environmental and Nature Protection Public Union |
| EASAC | European Academies' Science Advisory Council |
| FAO | Food and Agriculture Organisation |
| FTZ | Faculty of Tropical AgriSciences |
| GCF | Green Climate Fund |
| GHG | Greenhouse gas |
| ICARDA | International Center for Agricultural Research in the Dry Areas |
| IPBES | Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services |
| IPPC | Intergovernmental Panel on Climate Change |
| IRR | Internal Rate of Return |
| LULUCF | Agriculture and Land Use, Land-Use Change and Forestry |
| NPV | Net Present Value |
| OECD | Organisation for Economic Co-operation and Development |
| OMAFRA | Ontario Ministry of Agriculture, Food and Rural Affairs |
| RCP | Representative Concentration Pathway |
| SPSS | Statistical Package for the Social Sciences |
| SRAZ | Strategic Vision and Roadmap for Azerbaijan Agriculture |
| TNA | Technology Needs Assessment Report |
| UN | United Nations |
| UNFCCC | United Nations Framework Convention on Climate Change |
| WB | World Bank |

# 1. Introduction

Climate change (CC) has become a key global concern, affecting all aspects of human society and life on Earth. It is characterised by long-term changes in temperature and weather patterns (UN 2022) that the Earth has been experiencing since the 19th century (IPCC 2023). This is mainly due to fossil fuel burning, which produces greenhouse gas (GHG) emissions trapping the sun's heat. GHG emissions result from the use of petrol, deforestation, and landfill, with energy, industry, transport, buildings and agriculture being the main emitters (UN 2022).

Most countries have recognised that a concerted effort is needed to mitigate and adapt to the threat of CC. International initiatives such as the United Nations Framework Convention on CC (UNFCCC 1992), the Kyoto Protocol (1997), the Paris Agreement (2015) and various national policies have been put in place to offset the negative impacts of CC by limiting GHG emissions. Nevertheless, not all countries have adequate material, technological and intellectual resources to manage complex CC adaptation and mitigation strategies. The implementation of climate-smart strategies requires a national approach tailored to local conditions. Hence, developing countries with limited resources, such as Azerbaijan, need support from developed countries and international organisations to achieve common CC-related goals.

In Azerbaijan, the most important areas for agricultural production are located in the semi-arid zone. Thus, the country's agricultural production is seriously threatened as the effects of CC are more severe in arid and semi-arid areas due to increased temperature extremes and water scarcity. In some areas, the temperature increase on the hottest days is projected to be two times the rate of global warming (IPCC 2021). Moreover, semi-arid regions are more vulnerable to land degradation leading to desertification and related socio-economic problems such as food insecurity, poverty risk, and migration. Agriculture is also one of the main sources of GHG emissions in Azerbaijan (Ministry of Ecology and Natural Resources 2015). Effective climate action is therefore urgently needed to maintain and increase agricultural productivity while protecting and conserving agroecosystems (UNDP 2021a).

In 2016, Azerbaijan committed to reducing GHG emissions under the Paris Agreement. As a result, the country addressed CC challenges in agriculture through the Strategic Roadmap for Agriculture (SRAZ 2016). The Joint Action Plan of the Ministry of Ecology and Natural Resources and the Ministry of Agriculture to support “green agriculture” (2020-2023) includes “measures to mitigate and adapt to the negative impact of agricultural activities on the environment” as one of its priorities (VNR 2021). However, the specific adaptation and mitigation needs and measures are unfocused.

The thesis' development was based on the Readiness and Preparatory Support programme funded by the Green Climate Fund (GCF) "Strengthening country capacities for Nationally Determined Contributions (NDC) implementation in the Agriculture and Land Use, Land-Use Change and Forestry (LULUCF) sectors and supporting the identification of potential direct access entities from different sectors relevant for the implementation of the Country Work Programme in Azerbaijan" (GCP/AZE/012/GCR, hereafter referred to as the GCF project; FTZ 2021). The project aimed to select appropriate CC technologies for mitigation and adaptation in the agriculture/LULUCF sector, including a feasibility study for their implementation.

The thesis analysed the potential of agroforestry in the lowlands of Azerbaijan. In this area, climate-smart technologies are underutilised, even though they are urgently needed by smallholder farmers struggling with land degradation and declining productivity. The thesis focused on agroforestry practices, which are considered both adaptation and mitigation strategies (Hernández-Morcillo et al. 2018). The selection of agroforestry was based on the Azerbaijani government's efforts to promote agroforestry practices, which have been relatively unsuccessful to date, despite the high potential for this technology in the target area and the local farming systems. The thesis aimed to uncover the main benefits, costs and profitability of agroforestry compared to traditional monocultures. The farmers' awareness of CC effects and agroforestry practices was also investigated. The thesis further aimed to identify the main strengths, weaknesses, opportunities and threats of agroforestry adoption in Azerbaijan's lowlands to provide a complete overview of the feasibility of this technology.

# 2. Literature review

## 2.1. Climate change worldwide

Climate changes such as global warming, unprecedented in millennia, are caused by human influence (IPCC 2021; IPCC 2023). The latest projections indicate that global warming will exceed 1.5°C to 2.7°C during the 21st century if greenhouse gas emissions are not significantly reduced (IPCC 2021; IPCC 2023; UNEP 2021). According to the Paris Agreement (2015), reductions of 30% and 55% of GHG emissions are needed to keep global warming below 2°C and 1.5°C, respectively (UNEP 2021). However, the combined effect of countries participating in efforts to reduce GHG emissions is still insufficient (IPCC 2023).

Increasing global warming affects food and water security through soil degradation and reduced water availability and quality; soil erosion has increased worldwide, especially in semi-arid areas (Ma et al. 2021). In addition to the environmental dimension of global warming, there is also a social dimension, as the poor are more vulnerable to adverse CC impacts (IPCC 2023). The decline of natural capital and ecosystem services can undermine most sustainable development goals (Wood et al. 2016; IPBES 2019). It is predicted that CC impacts could further widen the economic gap between the richest and poorest countries (UN 2019). For example, emerging economies in warmer climates may be negatively affected, while rich countries in colder climates may even benefit from CC (Tan et al. 2021).

Up to 90% of disasters are thought to be caused by weather or climate-related events, pushing millions of people into poverty (FAO 2015a). CC is also considered a serious threat to international peace and security due to competition for resources, leading to socio-economic tensions and mass displacement (UN 2019). As a solution, changes in all aspects of society (food production, land use, transport and energy sources) are needed to counteract CC (IPCC 2018). Nature-based solutions, such as sustainable agricultural practices, land restoration, conservation and greening of food supply chains, have great potential to counteract CC threats if widely adopted. They can support ecosystem services, biodiversity, access to fresh water, healthy diets, and improve livelihoods and food security (UN 2019). For example, among various climate-smart crop management practices, agroforestry was found to be the most promising approach, as it has pronounced benefits for farmers and CC mitigation (Bhattacharyya et al. 2021).

## 2.2. Climate change effects on agriculture

GHG emissions from the agriculture, forestry and other land use (AFOLU) sector account for 22% of global emissions (OECD 2022), and the global food system emits one-third of total GHG emissions annually (Crippa et al. 2021; Mbow et al. 2019). At the same time, CC has far-reaching impacts on agriculture, mainly through soil erosion, droughts, changing rainfall patterns, floods, severe weather events, shifting agro-ecosystem boundaries, threats to biodiversity, and the geographical redistribution of pests and diseases. This may reduce crop yields and the nutritional quality of major cereals and lower livestock productivity (Mbow et al. 2019; World Bank 2021). A projected 10-25% reduction in crop yields by 2050 is likely to increase the price of staple crops such as rice, wheat, maize and soybeans, leading to higher meat prices. In the livestock sector, CC affects animal productivity, forage yield, animal reproduction, biodiversity, and health (IPCC 2023).

Although some northern countries may experience positive impacts of CC on agriculture (longer growing seasons, increased rainfall, etc.), the global impacts are projected to be catastrophic (FAO 2015a). This is particularly the case in developing countries, where agriculture contributes more to the economy, and natural disasters are more frequent (FAO 2015b). Smallholder farmers are particularly vulnerable to climate variability due to their limited resource base, the resilience of their livelihoods and the diversity of their farming systems (Asfaw et al. 2021; Williams at al. 2018). As a result, CC could push 32 - 132 million people into extreme poverty by 2030 (Jafino et al. 2020).

The rate of CC is also expected to exceed the natural adaptive capacity of forest species and ecosystems, threatening ecosystem services and income (Seppälä et al. 2009). In addition, deforestation contributes to about 10% of global greenhouse gas emissions (UN 2018), and more than 90% of deforestation occurs in the tropics

(Ometto et al. 2022). Therefore, forest restoration and agroforestry development offer significant mitigation and adaptation benefits (Hörl et al. 2020). Agricultural practices worldwide need to be adapted to mitigate climate change (Gao et al. 2022) by reducing soil GHG fluxes from croplands (Khatri-Chhetri et al. 2022; Mbow et al. 2019).

## 2.3. Climate change adaptation and mitigation strategies in agriculture

The decision to adopt a specific adaptation strategy is usually based on selecting the most profitable one that fits a target farming system after considering various barriers to effective adoption by the farmers (Lamichhane et al. 2022). However, assessing the profitability of CC adaptation strategies is complex due to the uncertainty of CC impact predictions and the vulnerability of farming systems (UNFCCC 2011; UNFCCC 2023; EEA 2023). Moreover, further uncertainties have been reported among farmers in post-Soviet countries regarding the use of conservation technologies, e.g., no-till, including the economic aspects (Bavorova et al. 2018).

For example, for smallholder farmers in sub-Saharan Africa, climate adaptation strategies have been categorised into crop management, risk management, soil and land management, water management and livestock management (Akinyi et al. 2021), taking into account the synergies that may arise from the simultaneous implementation of two or more adaptation strategies to improve productivity, resilience, yield stability, sustainability, and environmental protection. In addition, it is important to consider that trade-offs may arise implementing the selected strategies due to additional costs, additional labour requirements, and competition between objectives or available resources (Thierfelder et al. 2017).

Various CC adaptation and mitigation strategies are being implemented worldwide as part of climate change policies. When planning climate change policies, it should be taken into account that ecosystem services implicitly contribute to CC adaptation and mitigation (Schetke et al. 2018). Maintaining the adequate provision of ecosystem services is essential. Thus, climate action is intertwined with land restoration, and their complementary application can promote ecosystem services that are otherwise threatened by traditional agricultural practices (Manes et al. 2022).

In addition, climate-resilience is considered a key component of the sustainable intensification of smallholder farming systems (Lal 2016). This is supported by recent efforts in regenerative agriculture, which aims to restore soils and reverse biodiversity loss by diversifying crops, introducing perennial crops, and expanding agroforestry and intercropping (Elmqvist et al. 2022). Conservation agriculture involves similar efforts through minimum soil disturbance, permanent soil cover, and promotion of plant and soil biodiversity and biological processes, leading to increased water and nutrient use efficiency in plants (FAO 2021a). Specifically, carbon sequestration potential, water savings, GHG emission reductions, and yields can be higher using conservation agriculture instead of conventional tillage (Das et al. 2022; Dong et al. 2021; Kiran Kumara et al. 2020). Conservation practices such as reduced tillage are also being introduced in post-Soviet countries (Bavorova et al. 2020).

Global restoration of agricultural drylands is a priority for ecosystem function and biodiversity conservation, as natural dryland areas are biodiversity hotspots. In this context, active restoration practices such as water supplementation are the most effective (Florencia Miguel et al. 2020), and crop water use efficiency can be improved by maintaining low irrigation rates in drylands (Yu et al. 2021). In addition, soil improvement, targeted fertiliser management, mulching and weed control can mitigate drought stress.

Conservation agriculture on arable land can also be effectively combined with other climate-resilient strategies, such as agroforestry (Fonteyne et al. 2022), which incorporates many principles of conservation and regenerative agriculture. Agroforestry systems include a range of practices that combine the cultivation of woody perennials with crops and/or livestock, ecologically and economically interlinked on the same land at the same time, resulting in diversified and more sustainable production (FAO 2015c). Agroforestry practices are used for both CC adaptation and mitigation, as they protect crops from sun and wind, minimise soil erosion, and sequester and store carbon in biomass and soil (Apuri et al. 2018; Hernández-Morcillo et al. 2018).

Globally, agroforestry practices resulted in higher carbon content in tree biomass compared to cropland and pasture without trees, and multi-species agroforestry systems contained more C than single-species systems (Ma et al. 2020). The effect of agroforestry practices on soil C stocks increased with tree age and varied between climatic zones, with faster soil C increases in tropical zones (Feliciano et al. 2018; Ma et al. 2020; Xiang et al. 2022). Furthermore, C stocks in hedgerows are comparable to forest estimates (Drexler et al. 2021). Greater soil and above-ground carbon sequestration occur in silvopastoral systems and improved fallow, respectively. Land use change also affects carbon sequestration in agroforestry systems, such as the transition from grassland to silvopasture (Feliciano et al. 2018). However, insufficient information on the conservation and restoration of soil organic carbon stocks is available from some geographical regions, such as the Middle East and Central Asia (Beillouin et al. 2022).

## 2.4. Situation in Azerbaijan

### 2.4.1. Agroecological zones and farming systems

Azerbaijan's climate comprises nine climate zones: semi-arid zones (centre and east), temperate zones (north), continental zones (west) and cold and tundra zones in mountainous areas (Climate Change Knowledge Portal 2021). Livestock and pastures predominate in the colder, mountainous areas, while crops, orchards and gardens are concentrated in the warmer lowlands. Farming systems are essential to the livelihoods of the rural population, which accounts for 44.3% of the population (FAO 2021b).

Agroforestry can be considered an efficient farming system to reduce the risk of erosion in the CC-affected regions of Azerbaijan. Although agroforestry was practised in Azerbaijan during the Soviet period, most private landowners have abandoned this practice due to a lack of knowledge (The Ministry of Ecology and Natural Resources 2012). The Technological Action Plan for Adaptation Technologies emphasised the need to involve agricultural research institutions to conduct analyses and feasibility studies to assess the suitability of agroforestry systems in the country. The Ministry of Ecology and Natural Resources has recently supported the creation of agroforestry zones consisting of orchards with fruit trees such as olive, almond, mulberry, walnut, hazelnut, chestnut, common jujube, pistachio, pomegranate; the creation of agroforestry zones with a total area of almost 25 thousand ha is planned (Second Biennial Updated Report 2018); along with the promotion of windbreaks (forest strips) in the agricultural landscape (The Ministry of Ecology and Natural Resources 2012).

### 2.4.2. Agricultural production

The collapse of the Soviet Union continues to affect agricultural development in Azerbaijan. Since its independence in 1991, Azerbaijan has undergone significant economic changes, from the initial regression in the early 1990s, through the reform period, the oil boom and the economic slowdown after the fall in oil prices in 2014 (Hampel-Milagrosa et al. 2020). Since the oil crisis, however, Azerbaijan has sought to diversify its economy to reduce dependence on oil revenues and to narrow the gap between poor rural areas and Baku. The country underwent a major land reform in 1996, which divided the land into state, community and private ownership. The focus on local agricultural production was intended to improve food security in rural areas. However, land privatisation led to increased land fragmentation and inequitable distribution of land and other assets (Latifov & Safarov 2013).

The average farm size is 2.6 ha, but most families own between 0.1 and 2 ha, which is insufficient for a decent livelihood (O'Connell & Hradszky 2018), while 95 ha was the average size of production cooperatives according to available historical data (Temel et al. 2002). As new landowners, farmers lacked adequate skills and knowledge in agricultural management (Latifov & Safarov 2013). This, together with a lack of innovation and outdated technology, contributed to land degradation and a decline in agricultural productivity. In addition, exports declined due to farmers' inability to adapt to the free market economy, leading to food insecurity and unemployment (Latifov & Safarov 2013). Smallholders account for 95% of farmers in Azerbaijan, so their role in national agricultural production is crucial. Furthermore, it is predicted that 35-40% of the rural population could lose their livelihoods if large farms replace smallholders (O'Connell & Hradszky 2018).

So far, despite the intervention of international donors, there is still a low level of innovation adoption among local farmers (Sadigov 2017). The government provides some interventions to farmers to improve their livelihoods and agricultural productivity. For example, farmers receive subsidies for planting and sowing and additional subsidies based on crop yield (Regulation on subsidising agricultural production 2019). In addition, the government guarantees the price of some staple crops, such as wheat, and contributes to insurance and fertiliser costs (Cabinet of Ministers of the Republic of Azerbaijan 2022). Producers of some staple crops are also exempt from paying taxes (Ministry of Ecology and Natural Resources 2021).

The government also promotes the formation of farmers' cooperatives (Law No. 270-VQ 2016) and supports training, land lease programmes, new insurance mechanisms, and credit and loan products (O'Connell & Hradszky 2018). In addition, 'the formation of farmers' partnerships and the development of cooperation in agriculture' were set as goals in the Strategic Vision and Roadmap for Azerbaijani Agriculture (Huseynov et al. 2021, SRAZ 2016).

The development of the agricultural sector is one of the state's priorities, as agricultural land covers 55.2% (4,779.8 thousand hectares) of Azerbaijan's territory, while forests cover 1,120.24 thousand hectares (FAO 2019). In 2019, agriculture, forestry and fisheries accounted for 5.7% of the GDP (Agriculture of Azerbaijan 2020). Arable land covers 2,096.1 thousand ha, permanent crops cover 260.3 thousand ha, and permanent meadows and pastures cover 2,423.4 thousand ha (FAOSTAT 2021).

85-90% of all crops are grown on irrigated land (Ministry of Ecology and Natural Resources of Azerbaijan. 2012), which accounts for 30% of agricultural land (World Bank 2018). 90% of the crops produced are cereals (wheat, barley, maize); other important crops are potatoes, other vegetables and fruits such as melons, grapes and berries; livestock production focuses on the production of milk, beef, sheep, goat and poultry meat, and eggs (Ministry of Ecology and Natural Resources of Azerbaijan 2012; van Berkum 2017).

### 2.4.3. Climate change and adaptation and mitigation approaches

The Technology needs assessment report (TNA 2012) showed that agriculture is the most climate-sensitive sector of the economy, as a small change in climate can significantly affect agricultural production. The World Bank (2014) proposed to divide the territory of Azerbaijan into four agricultural regions to assess the country's vulnerability to CC: high rainfall (western and northern mountainous areas), irrigated (central, low-lying plain area), low rainfall (area along the Caspian Sea) and subtropical (southeastern area). The results of this study showed that yields of major crops (alfalfa, maize, cotton, grapes, potatoes and wheat) would decrease overall in all agricultural regions and climate scenarios due to temperature increases and water stress. However, pasture yields are projected to increase significantly in all agricultural regions, especially in the high rainfall and subtropical regions (World Bank 2014).

Three main CC stressors have been identified that are projected to negatively affect crop yields in Azerbaijan (with more pronounced effects in summer): direct effects of temperature and precipitation changes, increased irrigation demand, and reduced water supply due to increased evaporation and reduced precipitation (World Bank 2014).

The Republic of Azerbaijan ratified the Paris Agreement in 2016 with commitments to reduce GHG emissions to mitigate CC (Readiness proposal 2019). Azerbaijan's Intended Nationally Determined Contribution (INDC) aims to reduce GHG emissions by 35% by 2030 compared to the base year (1990). To meet the country's commitments, the INDC includes mitigation actions in all key sectors of the economy: energy, waste, and LULUCF. The most relevant measures have been identified, taking into account the country's specific circumstances. For the agricultural sector, the following measures have been prioritised: collection of methane gas from livestock and poultry manure, alternative energy sources and modern technologies (INDC 2015, Readiness proposal 2019).

These measures complement the priority technologies previously identified in the TNA (2012): (i) optimising the location and structure of agricultural lands with the introduction of CC-resistant crop species; (ii) increasing the use of windbreaks; (iii) using water-saving technologies such as drip or spray irrigation on irrigated lands; (iv) using conservative agricultural technologies. Consequently, Azerbaijan has addressed the challenges of CC in agriculture through the Strategic Roadmap (SRAZ 2016). Here, access to finance, knowledge creation, infrastructure and institutional capacity development, environmental protection and domestic food security are key national priorities for sustainable agricultural development.

Ultimately, the Azerbaijani Joint Action Plan to Support Green Agriculture for the period 2020-2023 (VNR 2021) focuses on the following priorities: (1) measures to mitigate and adapt to the negative impacts of agricultural activities on the environment, (2) rational use of water and land resources, (3) protection, increase and efficient use of forest resources, (4) preservation of biodiversity and ecosystems, (5) measures to develop aquaculture, (6) measures to support the development of organic (environmentally friendly) agriculture, (7) measures to strengthen institutional capacity.

Measures to develop the agricultural sector include exemption of the agricultural sector from taxes, subsidies, provision of preferential loans and other state support mechanisms, improvement of infrastructure, construction of water reservoirs, water harvesting, reclamation measures and the establishment of "Agroleasing" OJSC to improve the quality of agrotechnical services (Ministry of Ecology and Natural Resources 2021). In addition, various projects funded by international donors have been implemented to promote conservation agriculture practices to enhance agricultural sustainability by improving soil health, reducing erosion and saving water in Azerbaijan (Nurbekov et al. 2015).

On the one hand, agriculture is considered to be one of the main sources of GHG in Azerbaijan (Ministry of Ecology and Natural Resources 2015). On the other hand, agriculture is one of the most vulnerable sectors to CC, which can reduce crop productivity by up to 20% (Readiness proposal 2019). Adaptation and mitigation strategies will improve crop productivity, income generation, employment opportunities and food security (Ministry of Ecology and Natural Resources of Azerbaijan 2012).

Several climate change projection scenarios for Azerbaijan differ in terms of the projected level of emissions and the baseline period used. However, the common aspect of these projections is that Azerbaijan will be negatively affected by climate change unless appropriate adaptation and mitigation measures are implemented. According to the Climate Risk Country Profile (2021), Azerbaijan will be exposed to a faster temperature increase compared to the global average; under the highest projected emissions pathway (Representative Concentration Pathway, RCP8.5), average daily temperatures will increase by 4.7°C in 2080-2099 compared to the baseline period (1986-2005) (Table 1), with average summer temperatures increasing by almost 6°C. The World Bank (2014) considers a scenario projected for the 2040s with an average temperature increase of 2.4°C and a summer temperature increase of 4°C in the subtropical region of Azerbaijan. The warm zone is projected to move towards the mountains by 150-300 m by 2050 and by 450-950 m by 2100 (Ministry of Ecology and Natural Resources of Azerbaijan 2012; Figure 1).

**Table 1. Changes in average daily temperatures under four projected emission pathways (climate change scenarios) compared with the baseline period (1986-2005)**

| Scenario | Changes in Average daily temperatures (°C) | |
|---|---|---|
| | 2040-2059 | 2080-2099 |
| RCP2.6 | 1.3 | 1.2 |
| RCP4.5 | 1.7 | 2.3 |
| RCP6.0 | 1.6 | 3.1 |
| RCP8.5 | 2.3 | 4.7 |

Source: Risk Country Profile: Azerbaijan (2021)

Projections of precipitation in Azerbaijan are mixed. However, the prevailing trend indicates a 10-20% increase in precipitation and a 15% increase in evaporation over the period 2021-2050 (Ministry of Ecology and Natural Resources of Azerbaijan 2012; Climate Risk Country Profile: Azerbaijan 2021). Some high-impact scenarios assume an overall decrease in precipitation of 20% and significant decreases in summer precipitation (World Bank 2014). Azerbaijan is also exposed to CC-related extreme weather events, such as heatwaves, droughts and floods, which are exacerbated by the severity of the projected impacts of the CC scenario (Climate Risk Country Profile: Azerbaijan 2021).

In Azerbaijan, where agriculture is based on high water-consuming crops, the combination of conservation agriculture with improved irrigation technologies may be key to increasing yields (Nurbekov et al. 2015). This can be further supported by techniques that enable soil moisture conservation, such as mulching. Composting is another effective measure to improve soil fertility while increasing soil carbon sequestration. Other climate-smart practices, such as agroforestry, including windbreaks, are being promoted to reach climate resilience at the farm level (Apuri et al. 2018). The efficiency of agroforestry as a CC adaptation and mitigation strategy has been largely demonstrated (Tschora & Cherubini 2020)

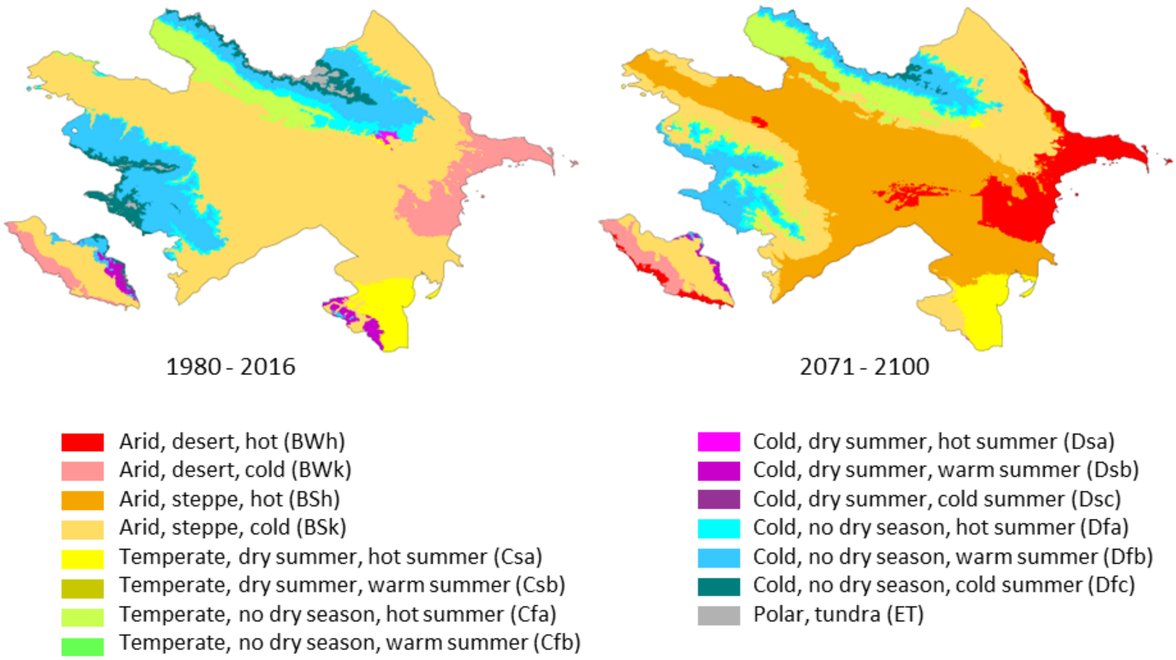



**Figure 1. Projected future climate conditions (2071–2100) under changing climate (scenario RCP8.5) in Azerbaijan compared to the present (1980–2016) according to the Köppen-Geiger climate classification**

Source: Beck et al. (2018)

## 2.5. Issues influencing the adoption of climate change adaptation and mitigation strategies

Technological factors, personal attributes, and social and economic factors are the main determinants of behavioural change that underpin the adoption of new technologies in agriculture (Dissanayake et al. 2022). The adoption and implementation of CC adaptation and mitigation strategies depend on a country's local and national context (UN 2023). Targeting farmers with measures tailored to their needs is essential to create favourable conditions for the adoption of new farming technologies (Kangogo et al. 2021). The adoption of new farming systems in post-Soviet countries may be affected to some extent by path dependency (Hamidov et al. 2015; Sehring 2009), as Soviet institutions forced the implementation of specific farming systems over decades. Thus, switching to another technology may be too costly (in terms of knowledge, effort and time) for farmers who are mentally bound to the past farming systems, which favour monoculture of crops of state interest (Piras et al. 2021).

According to the new institutional economics, the actors (farmers) are entirely driven by optimising behaviour, which is characterised by maximising profit or utility and minimising costs, including production and transaction costs (Opdenbosch & Hansson 2023; Kotir et al. 2022; Williamson 1981). Thus, the main objective of farmers is the efficiency of the farming system and possibly reaching economies of scale (Simelton et al. 2015). According to the transaction cost theory, firms emerge when an economic organisation can reduce production and transaction costs below the market price (Coase 1937).

Transaction costs can be an initial barrier to the adoption of new climate-smart practices, particularly ex-ante costs such as costs related to finding the information on the latest technologies and contract costs, including time, consultancy costs, services, and travel (Gorst et al. 2018; Branca et al. 2021). Moreover, CC also enhance transaction costs in agriculture (Molua et al. 2010). Therefore, the transaction costs can be considered crucial for the analysis of the CC adaptation options (Araral 2013). Other transaction costs are ex-post costs, i.e., monitoring and enforcement costs.

These are the efforts made by the farmer to ensure compliance with an agreement of either a private or a public nature. For example, private agreements can be contracts with suppliers of goods and services, characterised by uncertainty and information asymmetry (Chazovachii et al. 2021). In contrast, public agreements relate to compliance with laws and regulations. For example, the farmers must develop efforts to comply with the rules for obtaining subsidies, which extension services can greatly facilitate (Kangah & Atampugre 2022).

In this context, the role of institutional support is essential to promote the adoption of new technologies, as institutions have the power to influence farmers' behaviour by providing an institutional environment that leads to the reduction of transaction costs (e.g., subsidies, facilitating access to credit, contributing to the cost of agrochemicals, setting the product price, investing in local infrastructure) (Hill et al. 2021). Interim compensation payment schemes or subsidies may positively influence farmers' adoption behaviour of environmentally friendly agricultural practices (Xie & Huang 2021).

For fully efficient institutional arrangements for the adoption of new CC-resilient technologies, it should also be considered that, according to rational choice theory and transaction cost theory, people's behaviour and transactions are determined by bounded rationality (Simon 2000), i.e. people's limited capacity to formulate and solve complex problems and opportunism (self-interest). Clear rules and transparent conditions applied by the institutions within the action plan to promote the new technologies could be the key to overcoming these possible barriers to successful technology adoption and implementation.

The farmers' approach to the adoption of the new technologies might also be affected by risk aversion behaviour, which means, according to the contract theory, that a person prefers a secure outcome over the insecure one, given that the insecure outcome generates the same expected (monetary) value as the secure one. For example, farmers may prefer monocropping with a relatively secure yield to adopting agroforestry, but their willingness to adopt agroforestry may be modulated by incentives based on their degree of risk aversion (Liu & Chuang 2023). Also, the windbreaks reduce cultivation area but prospect similar wheat yield in the future due to the associated environmental benefits (besides the production function of the windbreaks, e.g., sea buckthorn berries). This is in agreement with the prospect theory, in which people will take risks to avoid losses but will avoid risks to protect gains (Kahneman and Tversky 1979). In this regard, informing the farmers of the benefits of the new technology and awareness of the CC effects if no action is taken is indispensable.

When the policymakers set the institutional conditions for the implementation of the new climate-resilient technologies, the emphasis should also be given to the environmental and social benefits obtained through the maintenance of public goods to avoid the tragedy of the commons ("the damage that innocent actions by individuals can inflict on the environment", Hardin 1968). The lowlands are particularly affected by the CC effects in terms of drought and inappropriate irrigation management, leading to salinisation. Thus, it is crucial that the farmers are aware of the appropriate irrigation management and responsible use of water resources for maintaining the long-term sustainability of agricultural production in the region (Huang et al. 2021). Inadequate land management may lead to irreversible environmental damage in terms of soil erosion and increased salinity, affecting not only the farmers but also the local or even national food security and self-sufficiency, along with the effects on all living organisms in the area. An appropriate internalisation of externalities (e.g., improved soil quality and fertility, biodiversity preservation) could be the key to supporting responsible farmers' behaviour, for instance, through specific incentives or other relevant benefits for the farmers (Venance-Pâques Gniayou et al. 2021). Moreover, matching the rules governing the use of common goods (land and water) to local needs and conditions, building responsibility for governing the shared resource, and emphasizing community involvement (Ostrom 1990) would significantly foster the stability of the agri-environmental systems for the soil and water resources management.

Policymakers use a variety of interventions such as economic incentives and various behavioural levers (simplification and framing of information, changes to the physical environment and default policy, use of social norms and comparisons, feedback mechanisms, reward/punishment schemes, target setting and commitment devices) to support policy interventions (Mont et al. 2014). However, smallholders have been found to be less responsive to policies designed to promote 'commercial' agriculture because they are disconnected from markets (Ellis 1993).

As monetary incentives can sometimes have a smaller-than-expected effect on farmers' decisions, behavioural approaches represent a possible solution for promoting climate-resilient technologies. For example, in line with the Theory of Planned Behaviour, it has been shown that farmers' attitudes, subjective norms and perceived behavioural control can significantly influence farmers' intentions to adopt agroforestry practices; an information campaign to strengthen positive attitudes showed great potential to increase intentions to adopt agroforestry (Noeldeke 2022). This points to the essential role of farmers' intrinsic motivations for adopting new agricultural technologies such as agroforestry.

Another form of agricultural policy intervention to encourage specific behaviour by farmers is nudging. A nudge is any aspect of the choice architecture that predictably changes people's behaviour without forbidding any options or significantly changing their economic incentives; the nudge must be easy and cheap to avoid (Thaler & Sunstein 2008). An example is a nudge with information and images showing environmental and health damage presumably caused by violating a rule, such as the minimum distance to water, which had a preventive effect by reducing the number of non-compliant farmers (Peth et al. 2018).

Nevertheless, a fully functioning policy administration is essential for the implementation of the interventions and other measures, as inaccurate policy planning can be an insurmountable barrier to the adoption of new technologies (Campuzano et al. 2023). In fact, policy failure is often associated with mistargeted policies, weak commitment and enforcement, insufficient funding or wasted investments, poorly addressed synergies, poor coordination of different policies, overlooking the importance of traditional institutions, etc. (Kassa et al. 2011). In sub-Saharan Africa, for example, many investments in climate adaptation projects have failed because they focused exclusively on the technology-oriented approach rather than also addressing farmers' knowledge generation (Abegunde et al. 2019). Market failures can also determine failed attempts to adopt sustainable practices (Hill et al. 2021; Partey et al. 2017).

A feasibility study for the GCF project (Banout et al. 2021) identified a number of critical issues affecting the success of the proposed CC adaptation and mitigation strategies in Azerbaijan. These issues were based on the Intended Nationally Determined Contribution and the agricultural vision Strategic Roadmap (INDC 2015; SRAZ 2016). Each of the identified issues serves as a basic condition to focus on during implementation, in addition to considering these issues before and after the adoption of technologies. Underestimating the identified critical issues during the technology adoption and implementation process may undermine the successful technology implementation and reduce the intended impacts on farmers and the environment.

The critical issues were selected based on the contextual environment of the target technologies. In particular, insufficient infrastructure investment, information and training provision are the main barriers to efficient technology adoption by farmers in Azerbaijan (World Bank 2014), as also confirmed for other countries (Branca et al. 2021; Gorst et al. 2018). In addition, environmental policies focused on the agricultural sector can lead to unexpected trade-offs and often harm productivity and food security (OECD 2001). Therefore, infrastructure development and economic aspects such as additional production and investment costs must be considered critical factors for successful technology adoption (Williams et al. 2020). Knowledge creation and access to training and information on the technologies are also essential for successful technology adoption and effective implementation (World Bank 2014; Zakaria et al. 2020; Antwi-Agyei & Stringer 2021; Muench et al. 2021; Mahmood et al. 2020). Table 2 provides an overview of the critical issues, potential actions to be taken, and governance mechanisms required.

**Table 2. Critical issues for the adoption of climate-resilient technologies adoption**

| Critical issues | Potential measures | Governance mechanism |
|---|---|---|
| **1. Knowledge creation** | Extension service provision (training and demonstrations) | National/regional governments; local farmer initiatives; NGOs |
| **2. Additional cost of production** | Compensation payment schemes | Voluntary participation in national schemes |
| **3. Investment costs** | Investment schemes/supporting access to bank credits | Voluntary participation in national programmes |
| **4. Property rights** | Determination and clarification of land use/property rights and titles | Legislation and collective action |
| **5. Coordination of actions** | Assigning local administration offices and cooperatives supporting the coordination | Principal-agent approach and collective action |
| **6. Infrastructure development** | Involvement of water suppliers, state agents, and local cooperatives | State enterprises and local cooperatives |
| **7. Food security** | Coordination of relevant policy framework | National government |

Source: Adapted from Banout et al. (2021)

## 2.6. Benefits and costs of agroforestry as a climate change adaptation and mitigation strategy

### 2.6.1. Non-financial benefits and costs of agroforestry

#### 2.6.1.1. Environmental benefits

Agroforestry systems include different arrangements of trees or shrubs, such as tree plantations, alley cropping, silvopastoral systems, forest farming, buffer strips and windbreaks. Various agroforestry practices are used to restore semi-arid areas suffering from inappropriate agricultural practices and land degradation (FAO 2015c), which is also an option proposed for Azerbaijan.

Fruit orchards are often the most profitable agroforestry systems; in Azerbaijan, persimmon, pomegranate, almond, hazelnut, walnut, cherry and citrus are the most commonly cultivated fruit trees (Streef 2017). However, intensive orchards require high investments and are labour-intensive Azerbaijani conditions (Sefiyev and Qamberova 2022). Intercropped orchards, where fruit trees are planted at a lower density than in traditional orchards, combined with an annual crop, e.g., alternating cereals and legumes, could diversify farmers' incomes compared to the traditional cereal monocultures typical of the study areas of the thesis (Dayal et al. 2015).

The overall agricultural and environmental context of the study sites is based on past land management, which is still reflected in current agricultural practices and environmental conditions. During the Soviet period, the original local steppe was transformed into an agricultural system focused on large-scale production of cereals, cotton and vegetables. The lack of rainfall in the regions was compensated by extensive irrigation systems with artesian wells, which gradually led to soil salinisation (Ministry of Ecology and Natural Resources of Azerbaijan. 2012; SRAZ 2016). At the same time, the Soviet legal system encouraged the establishment of windbreaks around fields, mainly to protect against strong winds (Dajnibekov et al. 2016). However, the simple poplar windbreaks did not achieve their full potential due to uncoordinated efforts in windbreaks management.

Nevertheless, poplar strips have been recognised as a relatively effective strategy against environmental problems related to land degradation and water scarcity in the former Soviet Union. Windbreaks are promoted to control soil erosion and are supported by forestry policies in most countries of the Caucasus and Central Asia (CCA) (Thevs 2019; Worbes et al. 2006). This is mainly because windbreaks can extend forest cover and associated benefits to regions with high agricultural intensity and population density (Worbes et al. 2006). Fast-growing trees such as poplars, elms and mulberries are the main species used to establish windbreaks in CCA countries (Chendev et al. 2015; Maghradzea et al. 2012; Thevs 2019).

In the context of climate change mitigation, the most valued benefit of agroforestry systems is their contribution to carbon sequestration and storage and

GHG emission reduction. After natural forests, agroforestry systems are considered to be the most efficient carbon sequestration technology (Aune et al. 2005; Djanibekov 2016). For example, windbreaks can store higher amounts of aboveground and soil C than cropland (Shi et al. 2018). Soil protection from wind and water erosion by windbreaks was very effective in restoring soil fertility by improving nutrient cycling and availability in Russian steppe soils (Chendev et al. 2015).

Agroforestry systems improve growing conditions for both perennial and annual crops by modifying the microclimate, suppressing weeds, increasing plant's nutrient use efficiency, increasing soil moisture, reducing water use and lowering temperature, resulting in slower C decomposition and higher crop yields (Basche & DeLonghe 2017; Mandila et al. 2015; Partley et al. 2017; Shi et al. 2018; Thevs et al., 2019,). Agroforestry practices can also have positive environmental effects by improving drainage and reducing salt accumulation in the rhizosphere. Improvements in soil fertility also may lead to reduced use of agrochemicals (Agroforestry Network 2018).

In addition, higher numbers of beneficial insects, natural pest control and pollination due to the windbreaks can lead to tangible economic benefits through savings on insecticides and increased fructification over time (Morandin et al. 2016). The positive effects on biodiversity and their magnitude depend on the length, width and porosity of the windbreaks (Weninger et al. 2021).

#### 2.6.1.2. Social benefits

Agroforestry benefits also alleviate various social challenges and problems, such as rural-urban migration, malnutrition and poverty, for example, by providing non-timber products such as fruits, honey and mushrooms for household consumption, contributing to improved livelihoods and food security (Djanibekov 2016). Knowledge creation, capacity building, and technical assistance are also associated benefits of agroforestry adoption (Rahn et al. 2014). In addition, agroforestry can be perceived as prestigious among farmers. Sharing agroforestry products with other community members also strengthens social cohesion (Rahman et al. 2017).

Agroforestry practices can prevent wind damage to houses and crops and improve the health and working or living conditions of farmers and animals through shading, lower temperatures and improved water quality (Mandila et al. 2015). In addition, the adoption of agroforestry practices, especially those with productive outcomes, can lead to job creation (Kareemulla et al. 2005), increased labour intensity and a better spread of labour demand throughout the year; it can also make work more attractive for the poor, women and older workers (Ke et al. 2018). In addition, agroforestry practices can contribute to women's empowerment and financial independence, as women tend to be actively involved in agroforestry farming, collecting, processing and selling products (Barbieri and Valdivia 2010).

More diversified agroforestry practices may increase psychological satisfaction and spirituality, which may also be associated with improved landscape aesthetics (Mandila et al. 2015; Ke et al. 2018; Uwizeyimana et al. 2022). The improved economic and social context may also have other associated benefits in the longer term, such as the attraction of tourism, which can promote rural development and attract investors and new residents (Ke et al. 2018).

#### 2.6.1.3. Non-financial costs

The non-financial costs of agroforestry systems are often neglected because they are minimal in well-managed agroforestry systems. It is also assumed that the non-financial benefits largely outweigh the potential costs, especially when agroforestry is used for CC adaptation and mitigation in agricultural areas severely affected by negative CC impacts or other environmental problems (Zeshan & Shakeel 2020). Therefore, non-financial costs are more often mentioned when comparing agroforestry with forests. In fact, establishing an agroforestry system by replacing a forest could lead to negative environmental impacts in terms of biodiversity loss and overall disruption of ecosystem services in the landscape (Zerbe et al. 2020).

Even on agricultural land, trees or shrubs planted in an agroforestry system may compete with crops for space, sunlight, water and nutrients, leading to decreased crop profitability (Kaur et al. 2017). Potential competition varies between agroforestry systems. For example, almost no competition has been reported in home gardens, whereas competition may be higher when trees are grown in areas with perennial crops, reducing their production (Current et al. 1995). Timber harvesting can also damage other crops in the same field. Furthermore, inappropriate agroforestry management can exacerbate land degradation (Lionelle et al. 2022). Lack of knowledge can also represent a non-financial cost, such as technology knowledge, but also information related to farming system management, i.e., knowledge of potential labour costs and availability or inappropriate estimation of discount rates when planning agroforestry systems (Burgess et al. 2017). A non-financial opportunity cost could be reduced production of a staple crop in the early years of agroforestry establishment (Castella et al. 2013), i.e., before the orchards or productive windbreaks become productive, thus threatening food security.

### 2.6.2. Financial benefits and costs of agroforestry

#### 2.6.2.1. Economic benefits

In addition to protecting fields from climatic and weather phenomena, agroforestry practices also contribute to increased productivity and income, thus generating economic (production) benefits. The extent to which these practices contribute to productivity and income generation varies between agroforestry systems (Uwizeyimana et al. 2022). Fruit orchards naturally generate higher incomes than windbreaks and trees on pastures. Productive windbreaks, which protect agricultural land from weather events and serve as a source of timber, have a long tradition in the Central Asian region. Such systems could be combined, for example, with maize, wheat, barley, rice, potatoes, cotton and legumes. For example, the application of windbreaks can significantly increase wheat biomass and yield (Sida et al. 2018). In addition, the appropriate inclusion of fruit-bearing trees or shrubs could further increase the productive potential of the system, diversify income and production, improve nutrition and food security, and strengthen the overall resilience of the cropland (Miller et al. 2020; Vernooy 2022). Agroforestry can be significantly more profitable than conventional agriculture or even conservation practices (Ombati Mogaka et al. 2022). The benefits of productive windbreaks can help farmers change their production system to a more efficient one by reducing chemical and water use and diversifying production (Weninger et al. 2021). In addition, the transition to a new farming system is often supported by government incentives, such as subsidies, to facilitate the process of change (Agyemang et al. 2022).

#### 2.6.2.2. Costs

There are costs associated with transforming current agricultural systems into more CC-resilient agroforestry systems. These are represented by initial establishment costs, operation and maintenance costs, and transformation costs, and mainly include materials, equipment, tools, labour and services (Costa et al. 2022; Ke et al. 2018).

**Initial establishment costs** are essential and represent one of the main constraints to agroforestry adoption as farmers usually lack the financial resources to pay for all inputs (Andres et al. 2022; Rüegg et al. 2022).

**Operating costs** are associated with the regular maintenance of trees and shrubs, which is essential to keep the agroforestry system sustainable and effective, e.g., replanting dead seedlings, pruning, maintaining the irrigation system, and activities associated with intercropping or grazing (Popovici et al. 2022; Schnepel et al. 2022).

**Transformation costs** are associated with land opportunity costs due to reduced harvested area and competition from other crops with trees for water, soil nutrients and water (Costa et al. 2022; Peguero et al. 2022). However, agroforestry systems also bring various synergy effects between their elements (trees, crops, animals), leading to lower input use (Bicksler et al. 2022; Branca et al. 2021; Partey et al. 2017). The willingness of smallholder farmers to adopt agroforestry depends on the provision of benefits, i.e., better access to water and food, and economic gains, which should offset the opportunity costs (Souza et al. 2022). The main costs of establishing and implementing agroforestry systems are shown in Table 3.

**Table 3. Costs associated with agroforestry practices establishment and implementation**

| |
|---|
| **A. Initial establishment costs** |
| Fallow period before planting of perennials |
| Land preparation: site clearing, ploughing, pitting |
| Planting |
| Planting material (seeds, seedlings, cuttings) |
| Fertilisers (initial dose) |
| Irrigation equipment acquisition and installation |
| Machinery acquisition |
| Tools and other equipment |
| Initial decrease in the yield of field crops due to the reduction of cultivated area |
| **B. Operating costs** |
| Irrigation/watering |
| Phytosanitation/application of agrochemicals |
| Pruning , weeding, mulching |
| Harvesting, Logging |
| Transport, processing, storage |
| Nursery management |
| Fuel |
| Agrochemicals (fertilisers, pesticides, herbicides) |
| Irrigation maintenance/renewal |
| Machinery maintenance |
| Insurance |
| Damages to annual crops and woody perennials (trees, shrubs) |

Source: Andres et al. 2022; Aune et al. 2005; Costa et al. 2022; Dallimer et al. 2018; Dhanya et al. 2016; Ke et al. 2018; Popovici et al. 2022; Rahman et al. 2017, Rüegg et al. 2022, Schnepel et al. 2022

# 3. Aims of the Thesis

**Main objective:** Analysis of the potential of agroforestry as a climate change adaptation and mitigation strategy in the Azerbaijani lowlands.

**Specific objectives:**

**(1)** To review the non-financial and financial benefits and costs of agroforestry.

**(2)** To estimate the profitability of agroforestry and wheat monoculture, including changes in the prices of inputs and outputs.

**(3)** To determine farmers' awareness of CC effects and agroforestry practices and their perceived feasibility.

**(4)** To identify the strengths, weaknesses, opportunities, and threats of agroforestry.

**Research questions**

**(1)** What are the main benefits and costs of agroforestry?

**(2)** How do agroforestry practices and wheat monoculture differ in profitability, including the changes in prices of inputs and outputs?

**(3)** What is farmers' awareness of CC effects and agroforestry practices?

**(4)** What are the main strengths, weaknesses, opportunities, and threats of agroforestry adoption?

**Hypotheses:**

**(1)** Agroforestry practices and wheat monoculture differ in profitability, including the sensitivity to changes in the prices of inputs and outputs.

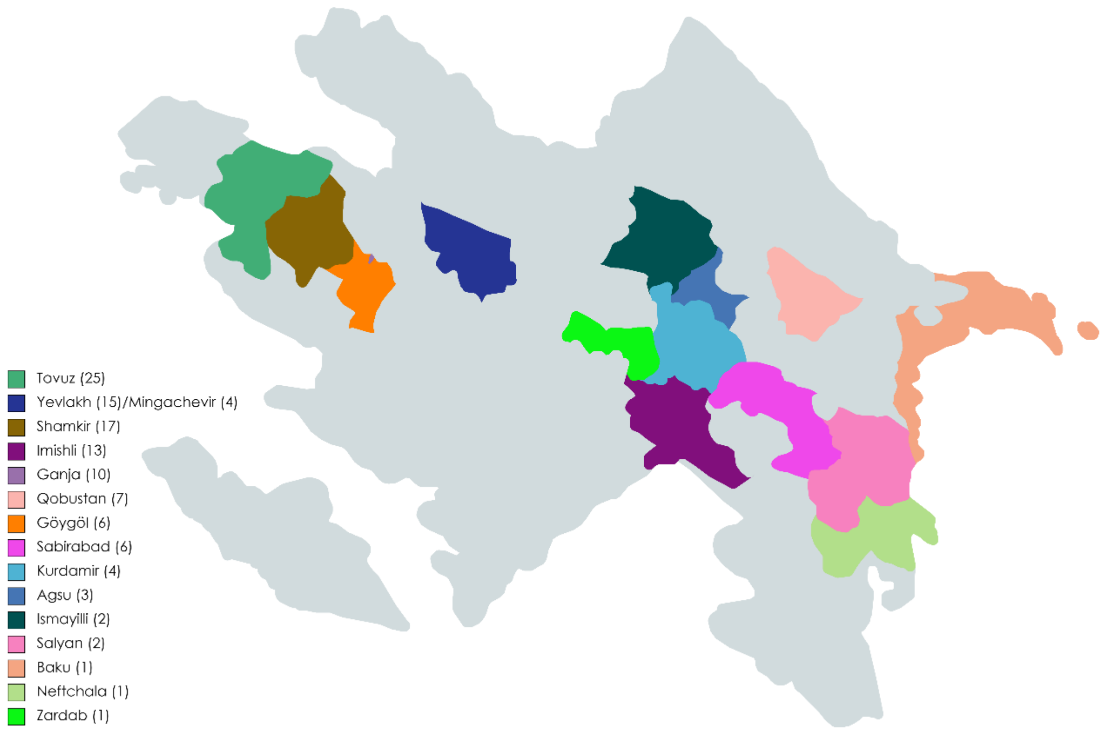
**(2)** The majority of farmers are aware of the CC.

**(3)** Strengths and opportunities of agroforestry adoption outweigh weaknesses and threats.

# 4. Methods

## 4.1. Description of study areas

The selected case study areas comprised 16 districts (Figure 2), which were selected to represent the Azerbaijani lowlands across the country based on the convenient selection of respondents. In total, lowlands of 7 Azerbaijani economic regions are covered by the study sites (Central Aran, Baku, Ganja-Dashkasan, Gazakh-Tovuz, Mil-Mugan, Mountainous Shirvan, Shirvan-Saylan; Ministry of Economy of the Republic of Azerbaijan 2023).




Note: The number of respondents per district is shown in the brackets in the figure caption.

**Figure 2. Study sites, Azerbaijan**

Created with mapchart.net

The original study site was intended to be the Aran economic region, but the country was divided into new regions in 2021 (Decree "On the new division of economic regions in the Republic of Azerbaijan" 2021) during the implementation of the GCF project and the thesis. The former Aran region covered large areas of the Azerbaijani lowlands, including most of the study sites, and covered the central part of the country. Historically, Aran was the largest region in Azerbaijan, rich in natural gas, oil, solar energy, water resources and arable land. Because of these valuable natural resources, the area has become the most important zone for agricultural production. However, the area also faces dramatic CC impacts such as soil erosion, strong winds and droughts (Ministry of Economy 2012).

In the lowlands, crop production began after the original steppes were converted to irrigated fields, mainly for cotton, in the mid-20th century. The extensive irrigation system is fed by the Mingachevir reservoir on the Kura River. The lack of naturally occurring topsoil led to crops being grown on a substrate of seaweed, sand and dung. Cotton, wheat, sugar beet and lucerne are the main crops, together with some orchards and pastures (Ministry of Economy 2012).

The study areas (central, western and southern districts) belong predominantly to the cold semi-arid (steppe) climate zone (BSk according to the Köppen-Geiger climate classification), which is projected to become a hot semi-arid zone under CC (see Figure 1 in Chapter 2.4.3). The eastern study sites (Baku, Salyan and partly Sabirabad districts) belong to the hot semiarid (steppe) zone and are at risk of becoming arid desert zones under CC (Beck et al. 2018). Annual precipitation in most of the lowland study areas ranges from 200 to 400 mm (less in coastal areas); the 25-year (1997-2021) mean annual temperature varies from 12.4°C in the northern study areas to 16°C in the central and southeastern study areas (World Bank 2021). The average temperature values include data for the whole region, so specific lowland temperatures are expected to be higher in the study areas.

The soils in the study areas are mostly degraded, and this is exacerbated by increased temperatures and decreased rainfall, making crop production particularly difficult. In particular, soils are affected by salinity due to improper management of flood irrigation, while water channels and reservoirs have deteriorated over time. It is estimated that one-third of irrigation water is lost before it reaches the field (SRAZ 2016), reducing yields. The difficulties in agricultural production are also determined by agricultural practices inherited from the Soviet era.

## 4.2. Data collection

### 4.2.1. Identification and selection of climate change adaptation and mitigation technologies

This section describes the process of selecting agroforestry as a suitable climate-resilient technology for Azerbaijan. First, candidate climate change adaptation and mitigation technologies, including the criteria for their selection, were identified through a collaborative effort between the GCF project implementation teams and local experts. The process leading to the identification and selection of the prioritised technologies for Azerbaijan is shown in Figure 3.

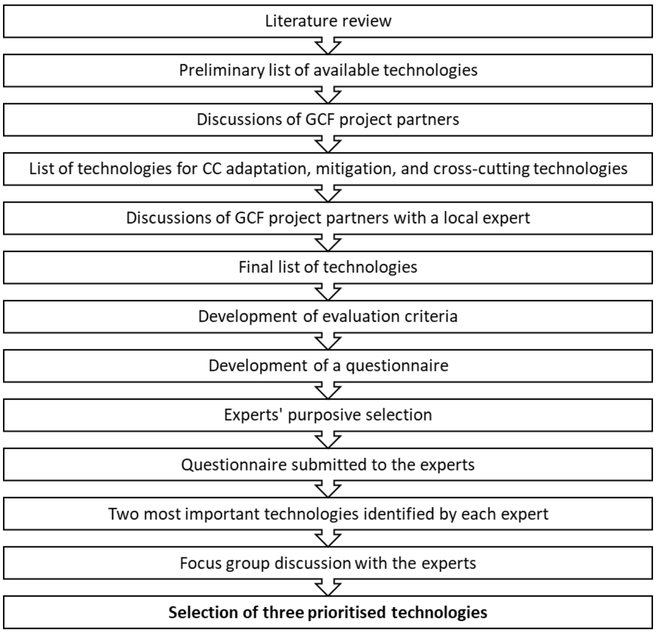



**Figure 3. Process of identification and selection of prioritised technologies for Azerbaijan**

The list of prioritised technologies was finalised based on the literature review carried out by the FTZ project team and discussions between the project teams and a local expert (Dr Issa Aliyev). The technologies were classified into three categories according to the nature of the contrasting CC effects: (1) CC adaptation, (2) CC mitigation, and (3) cross-cutting technologies, i.e. technologies suitable for both CC adaptation and mitigation. Six main criteria were developed to assess the feasibility and importance of the candidate technologies on a scale of 0-10 points. Appendix 1 contains the questionnaire with the evaluation criteria. Based on their expertise, five suitable experts were purposively selected to participate in the technology selection survey. The questionnaire was available to the experts in both English and Azerbaijani. The top two technologies identified by each expert were selected for a qualitative focus group discussion with all participating experts. This resulted in the selection of three technologies most suitable for the Azerbaijani lowlands. The experts also identified the two most suitable regions for the implementation of the selected technologies based on infrastructure, agricultural production, and feasibility of implementation.

### 4.2.2. Cost-benefit analysis

#### 4.2.2.1. Literature review

Web of Science, Scopus and Google Scholar were the databases of scientific articles used to search the literature on the benefits and costs of agroforestry for CC adaptation and mitigation. Boolean search operators were used to search within fields, and the query language was English (Ntawuruhunga et al. 2023). The database search was conducted between August and December 2021 and updated in April 2023. Table A2 in Appendix 2 shows the search terms used and the number of articles retrieved. Due to a large number of articles, only the most relevant articles for the assessment of benefits and costs of agroforestry systems were used based on geographical and climatic relevance and timeliness.

#### 4.2.2.2. Non-financial benefits and costs

Non-financial benefits and costs of agroforestry practices were collected during the literature review (Chapter 2.6.1). The most relevant study sites and agroforestry scenarios hypothesised for the CBA of financial benefits and costs and the SWOT analysis were identified.

#### 4.2.2.3. Financial benefits and costs

Financial benefits and costs were reviewed in Chapter 2.6.2. Based on the literature review and the study sites, four different scenarios were considered for the cost-benefit analysis (CBA) (Table 4). The hypothetical field design is shown in Appendix 3.

**Table 4. Description of four scenarios for cost-benefit analysis**

| **Scenario** | **Crops and trees/shrubs** | **Number trees/shrubs per hectare** | **Spacing of trees/shrubs (m)** [between rows x within the row] | **Area (ha)** | **Source** |
|---|---|---|---|---|---|
| **1. Pomegranate orchard** | pomegranate | 600 | 5.5 x 3 | 1 | Sefiyev and Qamberova (2022) |
| **2. Intercropped pomegranate orchard** | pomegranate<br>wheat | 330 | 10 x 3 | 1*<br>0.8 | Sefiyev and Qamberova (2022) |
| **3. Windbreaks with wheat** | poplar<br>sea buckthorn<br>wheat | 67<br>600 | 4 x 3 (1 row)<br>4 x 1 (3 rows) | 0.05<br>0.25<br>0.7 | OMAFRA (2012)<br>Wolfgramm (2011) |
| **4. Wheat monoculture** | wheat | 0 | | 1 | Wolfgramm (2011) |

*Pomegranate trees are distributed on 1 ha with 0.8 ha of wheat between the pomegranate rows in the same field of the total area of 1 ha.

The selection of target crops was based on local conditions, supported by literature data and the FTZ project team's field visit to Azerbaijan in 2021 (Annex 4). The CBA considered data from the Central Aran region, where available, due to suitable ecological conditions for implementing agroforestry practices and traditional pomegranate and wheat cultivation, representing the Azerbaijani lowlands.

In the absence of direct information on the monetary value of actual costs from farmers, the monetary value of costs and benefits was derived from publicly available sources. In particular, the main costs and benefits associated with the adoption of agroforestry practices and the costs of wheat cultivation were identified based on the official data sources of the Republic of Azerbaijan, literature and supplemented with qualitative data from the expert interview. The information which was not available for Azerbaijan was obtained from similar markets or growing conditions. For monetary values not directly available in AZN, the conversion rates of 1.70 AZN per 1 USD, 1.82 AZN per 1 EUR and 2.05 AZN per 1 GBP (Central Bank of the Republic of Azerbaijan 8-2-2023) were used. All calculations comparing four different scenarios are made for 1 ha. The proportional benefits and costs derived from the pomegranate orchard data were calculated for intercropped pomegranate orchards and windbreaks.

#### *4.2.2.3.1 Benefits*

**Productivity**

**Pomegranate (*Punica granatum* L.).** The average yield of 15.62 t·ha$^{-1}$ was considered for the calculations as an average yield in the Goychay and Yevlakh districts of the former Aran region in 2015-2021 (The State Statistical Committee of the Republic of Azerbaijan 2022). The proportional yield was considered for the analysis in the third year (4.69 t·ha$^{-1}$) and fourth year (9.37 t·ha$^{-1}$), with the full production reached in the fifth year (Sefiyev and Qamberova 2022). For the intercropped pomegranate, a proportional average yield of 2.58 t·ha$^{-1}$ in the second year, 5.15 t·ha$^{-1}$ in the third year, and 8.59 t·ha$^{-1}$ from the fifth year, was considered.

**Wheat (*Triticum aestivum* L.).** The average wheat yields of the Central Aran region derived from available data from 2015 to 2021 (3.06 t·ha$^{-1}$) were considered (The State Statistical Committee of the Republic of Azerbaijan 2022). For a windbreaks scenario, a 15% increase in wheat yield was considered from the third year of cultivation based on available literature data indicating the average wheat yield increase by windbreaks between 10-30% (OMAFRA 2012).

**Sea buckthorn (*Hipopphae rhamnoides* L.)**. The moderate yield of 4 t·ha$^{-1}$, i.e., 1 t per 0.25 ha, was considered based on the data from Latvia (Brūvelis 2015, Orwa et al. 2009). The CBA considered the proportional yield of 25% and 50% of full production for the second and the third year, respectively, with the full production reached in the fourth year (OMAFRA 2022).

## Subsidies

**Pomegranate.** A planting subsidy of 3000 AZN·ha$^{-1}$ is provided to intensive pomegranate orchards with a drip irrigation system where at least 450 saplings are planted per hectare (The Agrarian Subsidy Council 2023). 50% of insurance cost paid by state was considered (The State Seed Fund 2023).

**Wheat.** Wheat producers receive a sowing subsidy of 220 AZN per hectare (The Agrarian Subsidy Council 2023). An additional subsidy of 100 AZN was determined for each ton of food wheat produced in the farms and delivered to the State Reserves Agency of the Republic of Azerbaijan and flour mills (The Agrarian Subsidy Council 2023). The subsidies valid in 2023 were considered for the calculations for the cultivated crops and trees where available. 50% of insurance cost and 40% of agrochemicals' cost paid by state were considered (The State Seed Fund 2023).

## Product selling prices

The monetary value of the production was estimated based on the national market prices (Williams et al. 2020) where available.

An average price of 2000 AZN·t$^{-1}$ of pomegranate was considered (Sefiyev and Qamberova 2022), given the price fluctuations over the years (Ministry of Agriculture of the Republic of Azerbaijan 2022). An actual state supply price of wheat (580 AZN·t$^{-1}$) set for 2023 was considered (Cabinet of Ministers of the Republic of Azerbaijan 2022). A conservative price of sea buckthorn berries 5460 AZN·t$^{-1}$ was based on available prices in Latvia (Brūvelis 2015).

The potential revenues from the poplar timber harvesting and logging were neglected as it was not the primary target of poplar planting and the poplar timber harvest with maximum yield would occur only after the observed period.

#### *4.2.2.3.2 Costs*

**Initial establishment costs**

**Land preparation**

Land preparation comprises agrotechnical works necessary before planting, e.g., cleaning and levelling. Three hours of work at 100 AZN per hour were estimated to prepare 1 ha of land for all four scenarios (Sefiyev and Qamberova 2022).

**Digging of planting holes**

600 and 67 planting holes for pomegranate and poplar trees, respectively, are envisaged per 1 ha at the cost of 1 AZN per planting hole (Sefiyev and Qamberova 2022, OMAFRA 2012). Similarly, 600 planting holes for relatively smaller sea buckthorn plants were considered at an estimated cost of 0.5 AZN per planting hole.

**Seedlings**

5 AZN per two-year-old seedling of pomegranate (State Seed Fund 2023) and 0.73 AZN per poplar seedling (www.kpr-eshop.eu 2023) were considered. 3.69 AZN per sea buckthorn seedling were estimated based on the shrub seedling prices of Azerbaijani State Seed Fund (2023).

**Planting of seedlings**

1 AZN per pomegranate and poplar tree was considered (Sefiyev and Qamberova 2022); 0.5 AZN per planting of one sea buckthorn was considered accordingly.

**Irrigation system installation**

3,400 $AZN \cdot ha^{-1}$ of pomegranate orchard were considered (Sefiyev and Qamberova 2022) for installation of drip irrigation; a proportional cost for irrigation system of 1,870 $AZN \cdot ha^{-1}$ and 1,020 $AZN \cdot ha^{-1}$ was considered for the intercropped pomegranate and windbreaks, respectively. 1,000 $AZN \cdot ha^{-1}$ were considered for the installation of a simple sprinkler irrigation system or for using flood irrigation for wheat as the most common irrigation practice in the study area as observed during on-site visits.

**Equipment, tools**

2,500 AZN were considered for base equipment and tools of the pomegranate orchard, with the proportional amount for the intercropped pomegranate (1,375 AZN) and windbreaks (750 AZN). A reduced amount of 400 AZN was estimated for the wheat monoculture, and a proportional costs were calculated for the cultivated wheat area within the other two wheat-comprising scenarios.

**Fencing, trunk protection**

For fencing of pomegranate orchard, 5,000 AZN were considered, while trunk protectors were envisaged for the use in the intercropped pomegranate orchard (1,695 AZN) and windbreaks (895 AZN).

**Management, unexpected and other costs**

This item was calculated as 10% of total initial establishment costs principally for unforeseen costs of various nature and managerial costs.

Other establishment costs were not considered since Sefiyev and Qamberova (2022) recommended further considerable costs, such as tractor and sprayer purchase, fencing, and construction of well and auxiliary production areas, specifically for large farms. However, most of the agricultural production in Azerbaijan is done by the smallholder farmers who are targeted in this study. Also, the required tractor work will be used as a service, comprised in the labour costs of the tractor driver. Moreover, the existing local or established communal water resources, e.g., water canals used for flood irrigation, are considered. The four analysed scenarios are hypothesised to be implemented on the currently cultivated agricultural land with sufficient existing water resources for conventional cultivation.

**Annual cultivation costs**

**Seeds**

The price of 1.20 AZN·kg$^{-1}$ of wheat (State Seed Fund 2023) was considered with the 200 kg of seeds per hectare. Thus, 160 kg and 140 kg are the proportional seed requirements for the intercropped pomegranate orchard and wheat cultivation combined with windbreaks, respectively. The wheat can be alternated with beans or lucerne which were not considered in the CBA for simplification.

**Insurance**

For receiving the planting subsidy, the insurance of the cultivation areas is required following the Azerbaijani Law "On Agrarian Insurance" (law No. 1617-VG) by the Agrarian Insurance Fund (President's decree No. 809). The insurance price was calculated through a state Crop insurance calculator (Agrarian Insurance Fund 2023) based on the crop, location (Central Aran region), the extent of growing area, expected average yield, and product price. The crops were insured for all considered parameters (quality loss from hail, plant diseases and pests, the spread and attack of special dangerous pests, frosting, and rainfall). The state pays half of the insurance price, which was considered under the subsidies item.

**Agrochemicals**

Agrochemicals comprise the use of fertilisers and pesticides such as fungicides, insecticides, and herbicides. Their use was based on the pomegranate tree requirements along with their growth over the years (Sefiyev and Qamberova 2022), and proportional amounts were considered for the areas covered with poplar and sea buckthorn. The cost of agrochemicals required for wheat was 653 AZN·ha$^{-1}$ was estimated by the Planting calculator of State Seed Fund (2023), out of which 40% is paid by the state and was considered under subsidies item. The proportional cost of agrochemicals was considered for the wheat areas within intercropped pomegranate and windbreaks scenarios.

**Labour costs**

**Irrigation**

1,200 AZN·ha$^{-1}$ per year were considered for the pomegranate orchard (Sefiyev and Qamberova 2022). 120 AZN·ha$^{-1}$ were attributed to wheat monoculture (State seed Fund 2023). The proportional costs of 756 AZN·ha$^{-1}$ and 444 AZN·ha$^{-1}$ were considered for intercropped pomegranate and windbreaks scenarios, respectively.

**Tractor driver**

4,800 AZN·ha$^{-1}$ per year were considered for the pomegranate orchard (Sefiyev and Qamberova 2022). 108 AZN·ha$^{-1}$ were attributed to wheat monoculture (State seed Fund 2023). The proportional costs of 2726 AZN·ha$^{-1}$ and 324 AZN·ha$^{-1}$ were considered for intercropped pomegranate and windbreaks scenarios, respectively.

**Thinning and pruning**

For the pomegranate orchard, 1,200 AZN were considered for thinning and pruning for the second year and 1,920 AZN from the third year (Sefiyev and Qamberova 2022). The proportional costs of 660 AZN·ha$^{-1}$ and 1,056 AZN·ha$^{-1}$ were considered for intercropped pomegranate orchard. For the sea buckthorn, the thinning and pruning cost was omitted, since it was partially comprised within the harvest, when the whole branches with fruits can be cut.

**Harvesting**

Under this item, the workers needed for pomegranate and sea buckthorn fruit harvesting were considered. According to Sefiyev and Qamberova (2022), 20 workers harvest 1 ha of an orchard in one day at a salary 28 AZN per day, i.e. 560 AZN in total. A proportional cost (252 AZN) was calculated for the intercropped pomegranate for nine workers. It was envisaged that 1,500 person-hours are required to harvest 1 ha of sea buckthorn (OMAFRA 2022); therefore, 375 person-hours, i.e., 47 working days (1,316 AZN), were required for 0.25 ha of sea buckthorn windbreaks. For wheat harvesting, 48 AZN·ha$^{-1}$ were considered (State Seed Fund 2023).

**Agronomist consultation**

528 AZN·$ha^{-1}$ annually was considered for the pomegranate orchard and intercropped pomegranate (Sefiyev and Qamberova 2022), out of which 28 AZN were estimated for soil analysis, considered also for windbreaks and wheat monoculture (State Seed Fund 2023).

**Other costs**

10% of total annual cultivation costs were considered for unexpected costs.

#### *4.2.2.3.3 Analysis of profitability*

Based on the estimated benefits and costs, the following financial indicators were calculated for the implementation of the four scenarios:

**Total cultivation costs** were calculated as a sum of all annual costs.

**Total costs** were calculated as a sum of all cultivation costs and initial establishment costs.

**Benefits from sales** were calculated as productivity (t·$ha^{-1}$) multiplied per product selling price.

**Total benefits** were calculated as a sum of benefits from sales and subsidies.

**Net benefits** was calculated as a difference between Total benefits and Total costs.

**Net benefits cumulative** in the second year was calculated as a sum of the net benefits of the present year and the previous year. From the third to the fifth year, it was calculated as a sum of the net benefits of the present year and the net benefits cumulative of the previous year.

**Net present value**

$$\mathrm{NPV} = \sum_{t-1}^{n} \frac{B_t - C_t}{(1+i)^t}$$

where:

$B_t$ incremental benefit in period t

$C_t$ incremental cost in period t

n number of periods (years)

i interest rate (%)

NPV mainly at discount rates of 10% and 20% was considered to compare the scenarios over 20 years of cultivation (Verner et al. 2012), although a general discount rate of 3.5% is recommended for projects with impacts below 50 years (Boardman et al. 2018).

**Cumulative NPV** for a period t was calculated as a sum of the NPV of a period t and a sum of NPVs of previous periods for a specific discount rate.

**Internal rate of return (IRR)**

$$0 = \mathrm{NPV} = \sum_{t-1}^{n} \frac{B_t - C_t}{(1+i)^t}$$

where:

$B_t$ incremental benefit in period t

$C_t$ incremental cost in period t

n number of periods (years)

i interest rate (%)

**Benefit-cost ratio (BCR)** is calculated as a ratio of the sum of discounted benefits and the sum of discounted costs for a period of 20 years.

$$\mathrm{BCR} = \frac{\sum \frac{B_t}{q^t}}{\sum \frac{C_t}{q^t}}$$

**The payback period** was estimated as the number of years needed to recover initial establishment costs and reach a positive cumulative NPV.

### 4.2.3. Sensitivity analysis

For sensitivity analysis, the changes in the prices of inputs and outputs affecting the profitability of the four scenarios of farming systems were considered. In particular, the 50% increase and 50% decrease in product price, subsidies, labour price, and price of agrochemicals were hypothesised for the calculation of NPV and the benefit-cost ratio at two different discount rates (10% and 20%) for the period of 20 years. The NPV values and benefit-cost ratios calculated with unchanged factors were used as a base analysis.

### 4.2.4. Quantitative questionnaire survey

The quantitative data were obtained using a semi-structured questionnaire survey. The questionnaire was based on the evidence on the research topic provided in the literature sources; it was discussed with experts and amended accordingly. The survey was adapted to the Azerbaijan context and translated into the Azerbaijani language. For the purpose of this thesis, only the information useful for SWOT analysis of agroforestry systems, sample description, and farmers' awareness of CC in Azerbaijani lowlands was considered (Appendix 5), in particular, the following topics: (i) climate change perception among farmers, (ii) knowledge of adaptation strategies and subsequent use, (iii) barriers for the use of new innovative technologies.

DALGA (Dalga Environmental and Nature Protection Union), a partner of the GCF project collected data in Azerbaijani lowlands from September to October 2021. Participating farmers were conveniently selected for pen-and-paper surveys, often within the farmers' meetings, to cover the lowlands' geographical area; some farmers were also interviewed by phone. In total, 117 respondents were interviewed. The quantitative data obtained were cleaned and coded, and analysed using IBM SPSS Statistics 28.0 software, performing descriptive statistics.

The questionnaire initially comprised the trees on pastures, which was later revealed as a technology of marginal application by the farmers in the target regions. Thus, it was excluded from further studies within this thesis (CBA, Sensitivity analysis, SWOT analysis) and replaced with intercropped orchards with higher relevance.

### 4.2.5. SWOT analysis

SWOT analysis enabled the analysis of the internal and external factors that might facilitate or hamper the adoption of the proposed technologies to the desirable extent. The internal factors/capacities of the current land use (farming system) are examined and classified to see whether they support the envisaged desirable change (Strength) or are insufficient, or even go against it (Weakness). External factors represent the conditions or environment, current or future, and are rated to see whether they represent Opportunities for the change or rather Threats.

The strengths, weaknesses, opportunities, and threats were categorised into several general issues critical to successfully implementing selected agroforestry practices. The issues were further specified by the sub-categories closely relevant to the selected practices and target region. The agroforestry practices analysed by SWOT were the same as those investigated within the economic evaluation (orchards, intercropped orchards, and windbreaks).

The information obtained from the quantitative questionnaire survey of farmers and focus groups with experts for the technologies' selection was used for the SWOT analysis and was complemented with the literature sources and outcomes of the CBA, according to the principle of triangulation. An additional online expert interview with Dr Issa Aliyev occurred concerning the thesis' specific topic and relevant agro-economic contexts in September 2022. The topics discussed with the expert mainly concerned the potential of agroforestry (fruit orchards, windbreaks), the feasibility of intercropping under the conditions of Azerbaijan, the existence of an infrastructure for the target agroforestry practices, availability of access to bank credit for the farmers, availability of subsidies, and irrigation use in the orchards.

The three agroforestry practices were evaluated by weighted SWOT scoring analysis adapted from Narendra et al. (2013). Each individual strength, weakness, opportunity, and threat was given a score from 0 to 50 (0 = not important, 50 = very important) to indicate its level of importance to a particular agroforestry practice. Each SWOT sub-category was weighted with points 0.1 - 1 based on importance against other sub-categories out of a total score of 1.0 for each category (strengths, weaknesses, opportunities, and threats). Final scores for each agroforestry practice in each category were calculated by multiplying the score by the weighting attributed to the relevant category to produce a weighted importance level for that category. The three practices were compared by checking their ranking (Narendra et al. 2013).

# 5. Results

## 5.1. Identification and selection of climate change adaptation and mitigation technologies

Table 5 shows the average degree of application of the main CC adaptation and/or mitigation technologies in the agricultural sector of Azerbaijan. The table presents the results of the experts' assessment of the technologies listed in the questionnaire presented in Appendix 1. Most of the values show a medium to low application rate, with average values ranging from 4.4 to 7.2 (based on the range 0 = high - 10 = low) (Banout et al. 2021). The results indicate that all technologies listed are being used to some degree, but none of the measures is being applied to its full potential in Azerbaijan.

Based on the results of the questionnaire and the subsequent focus group discussion with the participating experts, the three most relevant technologies with the highest potential for adoption and effectiveness against CC under the conditions of Azerbaijan were selected: agroforestry, improved irrigation systems, and carbon sequestration and soil conservation through organic matter management (e.g. mulching, composting, reduced tillage). Furthermore, the expert discussion revealed that the Azerbaijani lowlands, in particular the former Aran and Absheron regions, are the most suitable for the adoption of CC adaptation and mitigation technologies in terms of infrastructure, agricultural activities and feasibility of implementation. For the purposes of this thesis, agroforestry was selected for further analysis. This was due to its versatility for different cultivation areas, the wide range of possible species combinations in agroforestry systems, and its traditional use in the Azerbaijani lowlands, where the study areas of the thesis are located.

**Table 5. The average degree of application rate of each adaptation/mitigation technology in the agricultural sector of Azerbaijan**

| **Climate change adaptation/mitigation technology** | **Status / current degree of application (0=high-10=low)** | **Category - application rate: 0-3 = High 4-7 = Medium 7-10 = Low** |
|---|---|---|
| **Technologies for climate change adaptation** | | |
| Climate resilient varieties | 6.4 | Medium |
| Crop diversification | 5.4 | Medium |
| Crop rotation | 5.9 | Medium |
| Crop insurance | 6.2 | Medium |
| Livestock management | 5.4 | Medium |
| Schedule for moving of livestock in different zones | 6.3 | Medium |
| Supplemental feed and vaccinations for livestock | 5.4 | Medium |
| **Technologies for climate change mitigation** | | |
| Adjustment of grazing methods | 6.0 | Medium |
| Biogas production with manure management | 4.8 | Medium |
| **Carbon sequestration and soil conservation** | 7.2 | Low |
| No tillage or minimum tillage farming | 5.1 | Medium |
| **Cross-cutting technologies** | | |
| **Agroforestry** | 6.3 | Medium |
| Cover crops | 7.2 | Low |
| Precision agriculture | 5.4 | Medium |
| Mulching | 5.0 | Medium |
| Pasture management | 4.4 | Medium |
| **Improved irrigation systems** | 5.3 | Medium |

Note: selected prioritised technologies are displayed in bold letters
Source: Adapted from Banout et al. (2021)

Based on the results of the questionnaire and the subsequent focus group discussion with the participating experts, the three most relevant technologies with the highest potential for adoption and effectiveness against CC under the conditions of Azerbaijan were selected: agroforestry, improved irrigation systems, and carbon sequestration and soil conservation through organic matter management (e.g. mulching, composting, reduced tillage). Furthermore, the expert discussion revealed that the Azerbaijani lowlands, in particular the former Aran and Absheron regions, are the most suitable for the adoption of CC adaptation and mitigation technologies in terms of infrastructure, agricultural activities and feasibility of implementation. For the purposes of this thesis, agroforestry was selected for further analysis. This was due to its versatility for different cultivation areas, the wide range of possible species combinations in agroforestry systems, and its traditional use in the Azerbaijani lowlands, where the study areas of the thesis are located.

## 5.2. Cost-benefit analysis

### 5.2.1. Non-financial benefits and costs

The selection of non-financial benefits and costs was based on the literature review in the chapter 2.6.1, taking into account the agroforestry practices suitable for the Azerbaijani lowlands, i.e., orchards and windbreaks. In this context, the main environmental benefit is the protection of land from erosion caused by adverse weather and climatic conditions, such as the devastating strong winds typical of the Azerbaijani steppe. Several environmental benefits are linked to soil ecosystem services. For example, preventing and reducing erosion also supports water and moisture retention, which helps to improve overall soil properties and fertility. The main environmental benefits are listed in Table 6.

**Table 6. Environmental benefits of agroforestry**

| Environmental benefits |
|---|
| Water and moisture retention |
| Improved soil properties and fertility |
| Soil erosion prevention and reduction |
| Carbon sequestration and storage |
| Reduced GHG emissions |
| Biodiversity maintenance and promotion |
| Promotion of pollinators |

Source: Aune et al. 2005; Dallimer et al. 2018; Lojka et al. 2018; Mandila et al. 2015; Morandin et al. 2016; Sharma et al. 2016; Uwizeyimana et al. 2022

Social benefits are closely linked to economic benefits and are also driven by environmental benefits. For example, preventing wind damage to crops contributes to increased farm productivity and improved livelihoods and food security. Income diversification, access to new knowledge, increased labour intensity and employment generation are also significant benefits of agroforestry practices, especially orchards and productive windbreaks, in the Azerbaijani lowlands. Table 7 lists the main social benefits identified.

**Table 7. Social benefits of agroforestry**

| **Social benefits** | |
|---|---|
| Income diversification | Psychological satisfaction |
| Increased farm productivity | Improved landscape aesthetic |
| Improved livelihood | Social cohesion |
| Improved food security | Prestige |
| Poverty alleviation<br>Improved working conditions | Labour demand more dispersed throughout the year |
| Access to new knowledge<br>Capacity building | Labour more attractive for the poor, women and elderly labourers |
| Technical assistance<br>Employment generation | Prevention of crop damages caused by wind |
| Increased labour intensiveness | |

Source: Djanibekov 2016; Kareemulla et al. 2005; Ke et al. 2018; Rahman et al. 2017; Rahn et al. 2014; Sharma et al. 2016; Uwizeyimana et al. 2022

Lack of knowledge on how to properly manage the agroforestry system emerged as the most relevant non-financial cost for the Azerbaijani lowlands. In fact, inappropriate agroforestry management could exacerbate land degradation. Also, reduced production of a staple crop in the early years of agroforestry establishment may represent some non-financial opportunity cost (Castella et al. 2013). The competition of the agroforestry system with crops for space, sunlight, water and nutrients could be relevant to the intercropped orchard to some extent (Current et al. 1995).

### 5.2.2. Financial benefits and costs

The pomegranate orchard had the highest initial establishment costs, while the wheat monoculture had the lowest (Table 8). Installation of the irrigation system was the highest planned cost for the intercropped pomegranate and wheat monoculture, accounting for 28.80% and 53.48%, respectively. Fencing was the highest initial cost for establishing the pomegranate orchard (29.52%), while irrigation system installation and seedling costs accounted for 20.07% and 17.71%, respectively. For windbreaks, seedlings represented the highest initial cost (29.10%). Fencing or trunk protection, together with equipment and tools, was a high initial cost for all three agroforestry systems. Equipment and tools also accounted for 21.39% of the initial costs of establishing wheat monoculture, which had higher proportional land preparation costs (16.04%) than the agroforestry systems (1.77 – 3.96%).

**Table 8. Initial establishment costs for the four scenarios (AZN·ha$^{-1}$)**

| Initial establishment costs (AZN·ha$^{-1}$) | Pomegranate | % | Pomegranate & wheat | % | Windbreaks & wheat | % | Wheat | % |
|---|---|---|---|---|---|---|---|---|
| Seedlings (pomegranate, sea buckthorn, poplar) | 3,000 | 17.71 | 1,650 | 17.80 | 2,203 | 29.10 | 0 | 0.00 |
| Land preparation | 300 | 1.77 | 300 | 3.24 | 300 | 3.96 | 300 | 16.04 |
| Digging the planting holes | 600 | 3.54 | 330 | 3.56 | 367 | 4.85 | 0 | 0.00 |
| Planting | 600 | 3.54 | 330 | 3.56 | 367 | 4.85 | 0 | 0.00 |
| Installation of irrigation system | 3,400 | 20.07 | 2,670 | 28.80 | 1,720 | 22.72 | 1,000 | 53.48 |
| Fencing, trunk protection | 5,000 | 29.52 | 1,452 | 15.66 | 895 | 11.82 | 0 | 0.00 |
| Equipment, tools | 2,500 | 14.76 | 1,695 | 18.29 | 1,030 | 13.61 | 400 | 21.39 |
| Management, unexpected and other costs | 1,540 | 9.09 | 843 | 9.09 | 688 | 9.09 | 170 | 9.09 |
| **Total** | **16,940** | 100.00 | **9,270** | 100.00 | **7,570** | 100.00 | **1,870** | 100.00 |

The pomegranate orchard was the most labour-intensive scenario, followed by intercropped pomegranate, windbreaks and wheat monoculture (Table 9). Tractor driver costs was the highest labour cost, followed by thinning, pruning, and irrigation costs for the two pomegranate scenarios. Harvesting was the highest labour cost for the windbreaks, while irrigation represented the highest annual cost for the wheat monoculture. The three agroforestry systems had higher benefits from product sales than the wheat monoculture; the pomegranate orchard had the highest benefits of all four scenarios (Table 10). Table 11 shows the distribution of undiscounted benefits and costs and NPVs at 10% and 20% over the first five years. None of the scenarios was profitable within the first year. For windbreaks and wheat monoculture, benefits exceeded costs from the second year; for pomegranate orchard and pomegranate intercropping, benefits exceeded costs from the fourth year (BCR > 1).

## Table 9. Labour costs for the four scenarios over five years (AZN·ha$^{-1}$)

| | Pomegranate | | | | | Pomegranate & wheat | | | | | Windbreaks & wheat | | | | | Wheat | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Labour costs (AZN·ha$^{-1}$)** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5** |
| Irrigation | 1,200 | 1,200 | 1,200 | 1,200 | 1,200 | 756 | 756 | 756 | 756 | 756 | 444 | 444 | 444 | 444 | 444 | 120 | 120 | 120 | 120 | 120 |
| Tractor driver | 4,800 | 4,800 | 4,800 | 4,800 | 4,800 | 2,726 | 2,726 | 2,726 | 2,726 | 2,726 | 324 | 324 | 324 | 324 | 324 | 108 | 108 | 108 | 108 | 108 |
| Thinning and pruning | 0 | 1,200 | 1,920 | 1,920 | 1,920 | 0 | 660 | 1,056 | 1,056 | 1,056 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Harvesting | 0 | 0 | 168 | 336 | 560 | 38 | 38 | 114 | 189 | 290 | 34 | 363 | 692 | 1350 | 1350 | 48 | 48 | 48 | 48 | 48 |
| Agronomist consultation | 528 | 528 | 528 | 528 | 528 | 528 | 528 | 528 | 528 | 528 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| **Total** | **6,528** | **7,728** | **8,616** | **8,784** | **9,008** | **4,049** | **4,709** | **5,180** | **5,256** | **5,357** | **830** | **1,159** | **1,488** | **2,146** | **2,146** | **304** | **304** | **304** | **304** | **304** |

## Table 10. Benefits from sales for the four scenarios over five years (AZN·ha$^{-1}$)

| | | Pomegranate | | | | | Pomegranate & wheat | | | | | Windbreaks & wheat | | | | | Wheat | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Benefits from sales** | **Unit** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5** |
| Fruit yield | t·ha$^{-1}$ | - | - | 4.69 | 9.37 | 15.62 | - | - | 2.58 | 5.15 | 8.59 | - | 0.25 | 0.50 | 1.00 | 1.00 | - | - | - | - | - |
| Fruit price | AZN·ha$^{-1}$ | - | - | 2,000 | 2,000 | 2,000 | - | - | 2,000 | 2,000 | 2,000 | - | 5,460 | 5,460 | 5,460 | 5,460 | - | - | - | - | - |
| Wheat yield | t·ha$^{-1}$ | - | - | - | - | - | 2.45 | 2.45 | 2.45 | 2.45 | 2.45 | 2.14 | 2.14 | 2.46 | 2.46 | 2.46 | 3.06 | 3.06 | 3.06 | 3.06 | 3.06 |
| Wheat price | AZN·ha$^{-1}$ | - | - | - | - | - | 580 | 580 | 580 | 580 | 580 | 580 | 580 | 580 | 580 | 580 | 580 | 580 | 580 | 580 | 580 |
| **Total** | **AZN·ha$^{-1}$** | **-** | **-** | **9,380** | **18,740** | **31,240** | **1,420** | **1,420** | **6,580** | **11,720** | **18,600** | **1,242** | **2,607** | **4,159** | **6,889** | **6,889** | **1,775** | **1,775** | **1,775** | **1,775** | **1,775** |

## Table 11. Overview of total benefits and costs, benefit-cost ratio, and net present values for the four scenarios over five years (AZN·ha$^{-1}$)

| | Pomegranate | | | | | Pomegranate & wheat | | | | | Windbreaks & wheat | | | | | Wheat | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Benefits & costs (AZN·ha$^{-1}$)** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5 & onwards** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5 & onwards** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5 & onwards** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5 & onwards** |
| **Benefits** | | | | | | | | | | | | | | | | | | | | |
| Benefits from sales | 0 | 0 | 9,380 | 18,740 | 31,240 | 1,420 | 1,420 | 6,580 | 11,720 | 18,600 | 1,242 | 2,607 | 4,159 | 6,889 | 6,889 | 1,775 | 1,775 | 1,775 | 1,775 | 1,775 |
| Subsidies | 3,200 | 200 | 200 | 341 | 569 | 630 | 630 | 630 | 630 | 630 | 551 | 551 | 583 | 583 | 583 | 816 | 816 | 816 | 816 | 816 |
| **Costs** | | | | | | | | | | | | | | | | | | | | |
| Insurance | 400 | 400 | 400 | 682 | 1,137 | 225 | 225 | 225 | 412 | 663 | 41 | 41 | 41 | 41 | 41 | 58 | 58 | 58 | 58 | 58 |
| Wheat seeds | 0 | 0 | 0 | 0 | 0 | 192 | 192 | 192 | 192 | 192 | 168 | 168 | 168 | 168 | 168 | 240 | 240 | 240 | 240 | 240 |
| Agrochemicals | 2,930 | 3,364 | 3,720 | 3,820 | 3,820 | 2,134 | 2,373 | 2,568 | 2,623 | 2,623 | 1,190 | 1,190 | 1,190 | 1,190 | 1,190 | 653 | 653 | 653 | 653 | 653 |
| Labour costs | 6,528 | 7,728 | 8,616 | 8,784 | 9,008 | 4,049 | 4,709 | 5,180 | 5,256 | 5,357 | 830 | 1,159 | 1,488 | 2,146 | 2,146 | 304 | 304 | 304 | 304 | 304 |
| Other costs | 986 | 1,149 | 1,274 | 1,329 | 1,397 | 660 | 750 | 817 | 848 | 884 | 223 | 256 | 289 | 354 | 354 | 126 | 126 | 126 | 126 | 126 |
| Total cultivation costs | 10,843 | 12,641 | 14,009 | 14,615 | 15,362 | 7,260 | 8,248 | 8,983 | 9,332 | 9,719 | 2,451 | 2,813 | 3,175 | 3,898 | 3,898 | 1,381 | 1,381 | 1,381 | 1,381 | 1,381 |
| Initial establishment costs | 16,940 | 0 | 0 | 0 | 0 | 9,270 | 0 | 0 | 0 | 0 | 7,570 | 0 | 0 | 0 | 0 | 1,870 | 0 | 0 | 0 | 0 |
| **Total benefits** | **3,200** | **200** | **9,580** | **19,081** | **31,809** | **2,050** | **2,050** | **7,210** | **12,350** | **19,230** | **1,793** | **3,158** | **4,742** | **7,472** | **7,472** | **2,591** | **2,591** | **2,591** | **2,591** | **2,591** |
| **Total costs** | **27,783** | **12,641** | **14,009** | **14,615** | **15,362** | **16,529** | **8,248** | **8,983** | **9,332** | **9,719** | **10,021** | **2,813** | **3,175** | **3,898** | **3,898** | **3,251** | **1,381** | **1,381** | **1,381** | **1,381** |
| **Net benefits (balance)** | **-24,584** | **-12,441** | **-4,430** | **4,466** | **16,447** | **-14,480** | **-6,199** | **-1,773** | **3,018** | **9,510** | **-8,227** | **346** | **1,568** | **3,574** | **3,574** | **-660** | **1,210** | **1,210** | **1,210** | **1,210** |
| **Net benefits (cumulative)** | | **-37,025** | **-41,454** | **-36,988** | **-20,541** | | **-20,679** | **-22,452** | **-19,434** | **-9,923** | | **-7,881** | **-6,314** | **-2,740** | **834** | | **551** | **1,761** | **2,971** | **4,181** |
| **Benefit-cost ratio** | **0.12** | **0.02** | **0.68** | **1.31** | **2.07** | **0.12** | **0.25** | **0.80** | **1.32** | **1.98** | **0.18** | **1.12** | **1.49** | **1.92** | **1.92** | **0.80** | **1.88** | **1.88** | **1.88** | **1.88** |
| **Net Present Value (i = 10%)** | **-22,349** | **-10,282** | **-3,328** | **3,051** | **10,212** | **-13,164** | **-5,123** | **-1,332** | **2,061** | **5,905** | **-7,479** | **286** | **1,178** | **2,441** | **2,219** | **-600** | **1,000** | **909** | **827** | **751** |
| **Net Present Value (i = 20%)** | **-20,486** | **-8,640** | **-2,563** | **2,154** | **6,610** | **-12,067** | **-4,305** | **-1,026** | **1,455** | **3,822** | **-6,856** | **240** | **907** | **1,724** | **1,436** | **-550** | **840** | **700** | **584** | **486** |

Appendix 6 provides a full overview of the calculated net present values for all four scenarios over 20 years. Two discount rates (10% and 20%) were applied to reflect future social costs and market borrowing rates over 20 years of cultivation. The IRR for the four scenarios is shown in Figure 4. For the first scenario, the pomegranate orchard, the NPV reached the positive value of 54,980 AZN (BCR = 1.40) and 7,978 AZN (BCR = 1.10) at a discount rate of 10% and 20%, respectively (Appendix 6: Table A6.1). The IRR is 25.05%. In the second scenario, pomegranate intercropped with wheat, the NPV reached positive values of 33,264 AZN (BCR = 1.38) and 5,750 AZN (BCR = 1.11) at a discount rate of 10% and 20%, respectively (Appendix 6: Table A6.2). The IRR is 26.13%. In the third scenario, windbreaks with wheat, the NPV reached the positive value of 15,524 AZN (BCR = 1.42) and 4,167 AZN (BCR = 1.18) at a discount rate of 10% and 20%, respectively (Appendix 6: Table A6.3). The IRR is 29.88%. In the fourth scenario, wheat monoculture, the NPV reaches the positive value of 8 604 AZN (BCR = 1.64) and 4 335 AZN (BCR = 1.52) at a discount rate of 10% and 20%, respectively (Appendix 6: Table A6.4). The IRR is 183.85%.

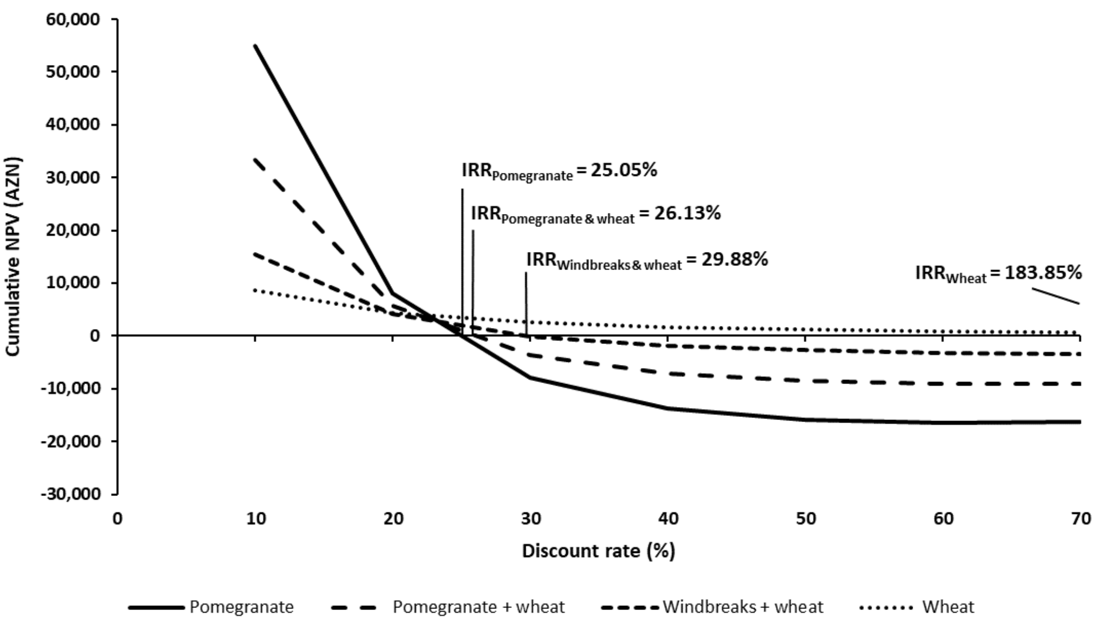



**Figure 4. Cumulative net present value (NPV) at different discount rates and internal rate of return (IRR) of four scenarios**

At both discount rates, wheat monoculture had the shortest payback period (1 year), followed by windbreak with wheat (5 and 7 years), pomegranate with wheat (7 and 10 years) and pomegranate orchard (7 and 11 years; Figures 5 and 6).

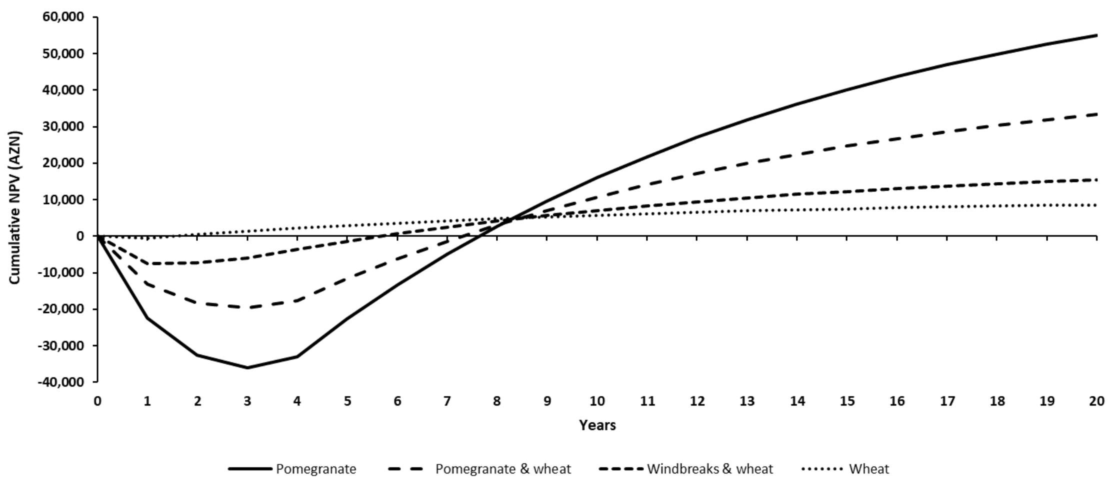



**Figure 5. Payback period of four different scenarios with cumulative net present value (NPV) at a 10% discount rate**

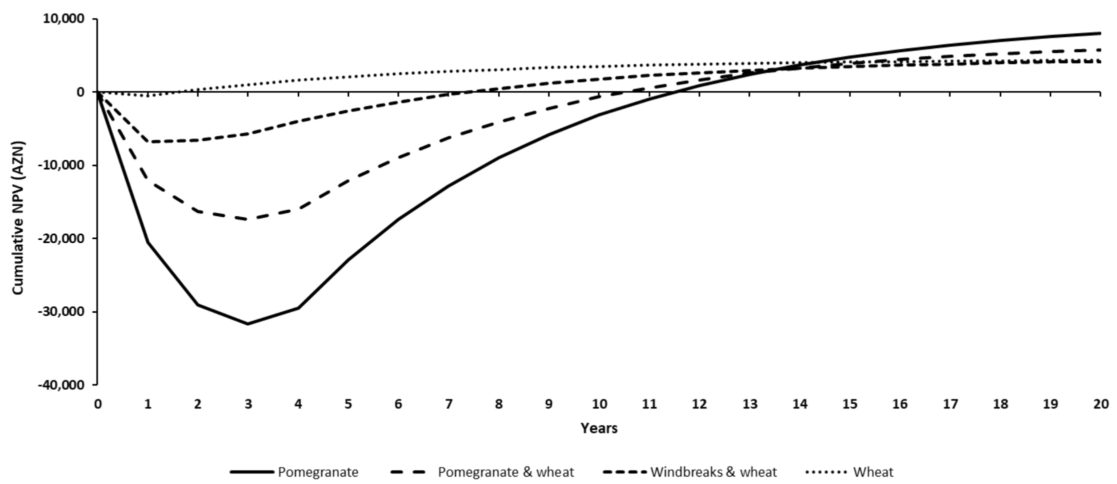



**Figure 6. Payback period of four different scenarios with cumulative net present value (NPV) at a 20% discount rate**

## 5.3. Sensitivity analysis

In the sensitivity analysis (Table 12), two discount rates (10% and 20%) were considered to calculate the changes in input and output prices affecting profitability over 20 years of cultivation. The discounted net present values resulting from the CBA (base analysis) provided the baseline values for the sensitivity analyses. Product selling price, followed by labour costs, had the greatest impact on profitability in all four scenarios. For the agroforestry systems with pomegranate (scenarios 1 and 2), the increase in product selling price, the decrease in labour and agrochemical costs, and the increase in subsidies were progressively the most important changes that positively affected profitability. The increase in subsidies would have a greater impact on the profitability of the wheat monoculture (scenario 4) than on the agroforestry systems, which were more affected by the changes in labour costs.

**Scenario 1: Pomegranate orchard**

In the pomegranate orchard, a 50% increase in pomegranate price would lead to an increase in NPV of 170% (i = 10%, BCR = 2.07) and 537% (i = 20%, BCR = 1.62), while a 50% decrease in pomegranate price would lead to negative NPV and BCR < 0 at both discount rates. A 50% reduction in labour costs would increase the NPV by 73% (i = 10%, BCR = 1.97) and 280% (i = 20%, BCR = 1.51). The pomegranate orchard would remain profitable with a 50% increase in labour costs at a 10% discount rate, while it would not be profitable at a 20% discount rate. The 50% reduction in the price of agrochemicals would lead to an increase in NPV of 31% (i = 10%, BCR = 1.60) and 121% (i = 20%, BCR = 1.24). The pomegranate orchard would remain profitable if the price of agrochemicals increased by 50% at a discount rate of 10%, while it would not be profitable at a discount rate of 20%. The changes in subsidies had a limited effect on the profitability of the pomegranate orchard; a 50% increase in subsidies would lead to an increase in NPV of 6% (BCR = 1.37) and 27% (BCR = 1.07) at 10% and 20% discount rates respectively; remaining profitable in the case of a 50% decrease in subsidies at both discount rates.

**Scenario 2: Intercropped pomegranate orchard**

For pomegranate intercropped with wheat, a 50% increase in pomegranate price would lead to an increase in NPV of 154% (i = 10%, BCR = 1.97) and 410% (i = 20%, BCR = 1.57), while a 50% decrease in pomegranate price would lead to negative NPV and BCR < 0 at both discount rates. Scenario 2 was also affected by the change in wheat price. Specifically, the 50% increase in wheat price would increase the NPV by 14% (i = 10%, BCR = 1.44) and 41% (i = 20%, BCR = 1.16). In the case of a 50% reduction in the price of wheat, scenario 2 would still be profitable at both discount rates. A 50% decrease in labour costs would result in NPV increases of 72% (i = 10%, BCR = 1.91) and 233% (i = 20%, BCR = 1.51). Scenario 2 would remain profitable with the 50% increase in labour costs at a 10% discount rate, but not at a 20% discount rate. The 50% decrease in the price of agrochemicals would lead to an increase in NPV of 36% (i = 10%, BCR = 1.60) and 116% (i = 20%, BCR = 1.28). Scenario 2 would remain profitable with the 50% increase in the price of agrochemicals at a 10% discount rate but not at a 20% discount rate. Similarly to Scenario 1, the changes in subsidies had a limited impact on the profitability of Scenario 2; the 50% increase in subsidies would lead to an increase in NPV of 8% (BCR = 1.41) and 27% (BCR = 1.14) at 10% and 20% discount rates respectively; it would remain profitable with a 50% decrease in subsidies at both discount rates.

**Scenario 3: Windbreaks with wheat**

In the windbreaks scenario, the 50% increase in wheat price would increase the NPV by 38% (i = 10%, BCR = 1.57) and 80% (i = 20%, BCR = 1.33). In the case of a 50% decrease in the price of wheat, scenario 3 would remain profitable at both discount rates. A 50% increase in the price of sea buckthorn would lead to an increase in NPV of 116% (i = 10%, BCR = 1.90) and 211% (i = 20%, BCR = 1.57). Scenario 3 would not be profitable at either discount rate if the price of sea buckthorn were to fall by 50%. A 50% reduction in labour costs was the second most influential aspect of the profitability of the wheat windbreaks, leading to NPV increases of 56% (i = 10%, BCR = 1.84) and 109% (i = 20%, BCR = 1.48). Scenario 3 would remain profitable despite the 50% increase in labour costs at a 10% discount rate, but not at a 20% discount rate. The 50% increase in subsidies would increase the NPV by 16% (BCR = 1.48) and 33% (BCR = 1.24) at 10% and 20% discount rates respectively and would remain profitable at both discount rates in the case of a 50% decrease in subsidies. The 50% reduction in the price of agrochemicals would lead to an increase in NPV of 36% (i = 10%, BCR = 1.66) and 76% (i = 20%, BCR = 1.37). Scenario 3 would still be profitable if the price of agrochemicals increased by 50% at both discount rates.

**Scenario 4: Wheat monoculture**

In the wheat monoculture scenario, a 50% increase in the price of wheat would result in an 88% increase in NPV (BCR = 2.20) at a 10% discount rate. At a 20% discount rate, the effect of a 50% wheat price increase would be a 100% increase in NPV (BCR = 2.05). In the case of a 50% reduction in the wheat price, scenario 4 would be profitable at 10%, but the NPV would be 0 at a 20% discount rate. The 50% increase in subsidies would lead to an increase in NPV of 40% (BCR = 1.90) and 46% (BCR = 1.76) at 10% and 20% discount rates respectively. The 50% reduction in labour costs would lead to an increase in NPV of 17% (BCR = 1.83) and 19% (BCR = 1.69) at a discount rate of 10% and 20% respectively. The 50% reduction in the price of agrochemicals would lead to an increase in NPV of 40% (i = 10%, BCR = 2.12) and 76% (i = 20%, BCR = 1.93) respectively. Scenario 4 would remain profitable if subsidies were reduced by 50% or if labour costs or the price of agrochemicals increased by 50% at both discount rates.

**Table 12. Sensitivity analysis of four scenarios after 20 years with Net Present Value at 10% and 20% discount rates**

| Sensitivity analysis | | Pomegranate | | Pomegranate & wheat | | Windbreaks & wheat | | Wheat | |
|---|---|---|---|---|---|---|---|---|---|
| **Changes in price** | **Discount rate** | **10%** | **20%** | **10%** | **20%** | **10%** | **20%** | **10%** | **20%** |
| **Base analysis** | NPV (AZN) | 54,980 | 7,978 | 33,264 | 5,750 | 15,524 | 4,167 | 8,604 | 4,335 |
| | Benefit-cost ratio | 1.40 | 1.10 | 1.38 | 1.11 | 1.42 | 1.18 | 1.64 | 1.52 |
| **Pomegranate price +50%** | NPV (AZN) | **148,372** | **50,837** | **84,622** | **29,319** | 15,524 | 4,167 | 8,604 | 4,335 |
| | Benefit-cost ratio | **2.07** | **1.62** | **1.97** | **1.57** | 1.42 | 1.18 | 1.64 | 1.52 |
| **Pomegranate price -50%** | NPV (AZN) | -38,413 | -34,882 | -18,094 | -17,819 | 15,524 | 4,167 | 8,604 | 4,335 |
| | Benefit-cost ratio | 0.72 | 0.58 | 0.79 | 0.65 | 1.4 | 1.2 | 1.64 | 1.52 |
| **Wheat price +50%** | NPV (AZN) | 54,980 | 7,978 | **38,076** | **8,122** | **21,445** | **7,504** | **16,159** | **8,656** |
| | Benefit-cost ratio | 1.40 | 1.10 | **1.44** | **1.16** | **1.57** | **1.33** | **2.20** | **2.05** |
| **Wheat price -50%** | NPV (AZN) | 54,980 | 7,978 | 28,452 | 3,378 | 9,603 | 830 | 1,049 | 14 |
| | Benefit-cost ratio | 1.40 | 1.10 | 1.33 | 1.07 | 1.26 | 1.04 | 1.08 | 1.00 |
| **Sea buckthorn price +50%** | NPV (AZN) | 54,980 | 7,978 | 33,264 | 5,750 | **33,566** | **12,974** | 8,604 | 4,335 |
| | Benefit-cost ratio | 1.40 | 1.10 | 1.38 | 1.11 | **1.90** | **1.57** | 1.64 | 1.52 |
| **Sea buckthorn price -50%** | NPV (AZN) | 54,980 | 7,978 | 33,264 | 5,750 | -2,519 | -4,640 | 8,604 | 4,335 |
| | Benefit-cost ratio | 1.40 | 1.10 | 1.38 | 1.11 | 0.93 | 0.80 | 1.64 | 1.52 |
| **Subsidies +50%** | NPV (AZN) | **58,227** | **10,169** | **35,945** | **7,283** | **17,979** | **5,562** | **12,078** | **6,322** |
| | Benefit-cost ratio | **1.42** | **1.12** | **1.41** | **1.14** | **1.48** | **1.24** | **1.90** | **1.76** |
| **Subsidies -50%** | NPV (AZN) | 51,732 | 5,786 | 30,583 | 4,217 | 13,069 | 2,771 | 5,129 | 2,348 |
| | Benefit-cost ratio | 1.37 | 1.07 | 1.35 | 1.08 | 1.35 | 1.12 | 1.38 | 1.28 |
| **Labour cost +50%** | NPV (AZN) | 14,868 | -14,339 | 9,240 | -7,667 | 6,856 | -390 | 7,180 | 3,521 |
| | Benefit-cost ratio | 1.08 | 0.86 | 1.08 | 0.88 | 1.15 | 0.99 | 1.48 | 1.39 |
| **Labour cost -50%** | NPV (AZN) | **95,091** | **30,294** | **57,287** | **19,167** | **24,192** | **8,724** | **10,027** | **5,149** |
| | Benefit-cost ratio | **1.97** | **1.51** | **1.91** | **1.51** | **1.84** | **1.48** | **1.83** | **1.69** |
| **Agrochemicals price +50%** | NPV (AZN) | 37,786 | -1,639 | 21,361 | -939 | 9,954 | 981 | 5,546 | 2,586 |
| | Benefit-cost ratio | 1.24 | 0.98 | 1.22 | 0.98 | 1.23 | 1.04 | 1.34 | 1.26 |
| **Agrochemicals price -50%** | NPV (AZN) | **72,173** | **17,595** | **45,166** | **12,439** | **21,094** | **7,353** | **11,661** | **6,084** |
| | Benefit-cost ratio | **1.60** | **1.24** | **1.60** | **1.28** | **1.66** | **1.37** | **2.12** | **1.93** |

Notes: The scenarios with higher profitability compared to the base analysis are displayed in bold letters. Red letters indicate not profitable scenarios.

## 5.4. Quantitative questionnaire survey

As the quantitative survey was entrusted to the Azerbaijani third-party institution (DALGA) involved in the GCF project, the FTZ team could not directly supervise the data collection and processing. As a result, the data was only used to a limited extent in the thesis, i.e., for descriptive statistics. The information obtained was also used as input for the qualitative SWOT analysis.

### Sample description analysis

The average age of the respondents was 45.07 years, with 17.27 years of experience in agriculture (Appendix 7: Table A7.1). The men (69.2%) predominated among the respondents, while 30.8% of women participated (Appendix 7: Figure A7.1). 48.7% of the respondents had a university degree, followed by secondary school (35.9%) and primary school (7.7%). Only 0.9% reported having no school education, but 6.8% of respondents did not provide any information on their education for unknown reasons (Appendix 7: Figure A7.2).

Table A7.2 in Appendix 7 shows the proportion of agricultural land held by farmers. More than half of the respondents (51.3%) possessed the arable land of 1 ha or less. Overall, 75.5% of the respondents possessed the arable land of 5 ha or less. Only one farmer reported to cultivate partly on rented land (data not shown). Most of the farmers (64.1%) cultivated crops on the area of less than 1 ha, 88% of the farmers cultivated fruit on the area of 0.4 ha or less and 96.6% of the farmers cultivated vegetables on the area of 0.5 ha or less. 70% of the farmers grew crops on irrigated land of 1.1-5 ha, but 11.1% of the farmers did not use irrigated land. 68.4% of the farmers did not cultivate wheat, 13.7% of the farmers cultivated wheat on 1-5 ha and 5-10 ha and 4.2% of the farmers cultivated more than 10 ha of wheat. The average area under wheat was 2.5 ha, followed by fruit (1.3 ha), vegetables (0.7 ha) and a small area under sunflower. The average fallow area was 0.9 ha. The farmers participating in the survey did not actually grow cotton and beans (Appendix 7: Figure A7.3). With regard to animal production, poultry was the most common animal kept (19.3 animals per farm), followed by sheep (5.71 animals per farm) and cattle (1.09 animals per farm); the farmers also kept goats, buffaloes and horses, but no pigs (Appendix 7: Figure A7.4).

**Climate change effects and respondents' awareness**

All farmers believed that their farm was affected by climate change, with 59% of farmers strongly believing this. Most farmers (76.9%) were also very concerned about their future as farmers in the face of CC, while 19.7% of farmers were only somewhat concerned (Figure 7). Most farmers (64.1%) indicated that the use of CC adaptation and mitigation strategies was very important for their farm (Figure 8).

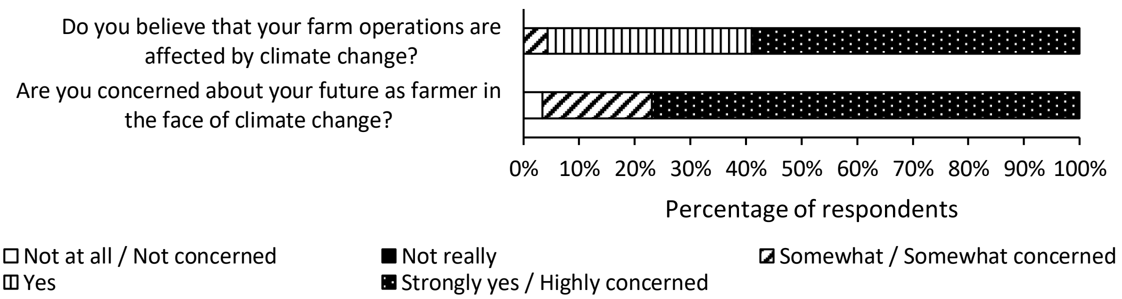



**Figure 7. Farmers' awareness of climate change**

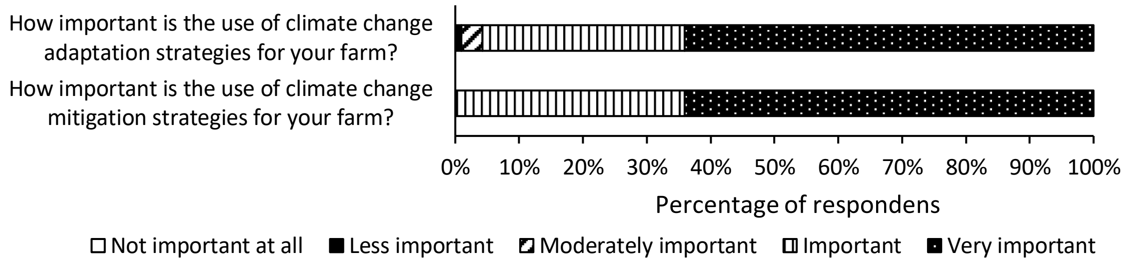



**Figure 8. Importance of using climate change adaptation and mitigation strategies for farmers**

Most farmers either strongly agreed or agreed that several CC effects influence their farms (Figure 9). In particular, 95.7% of farmers consider CC to be a serious problem for their agricultural production. In addition, water and wind erosion have become more frequent in recent years, according to 94.9% and 95.7% of farmers respectively. Most farmers (94.9%) also believed that technological change can reduce the impact of CC on agricultural production.

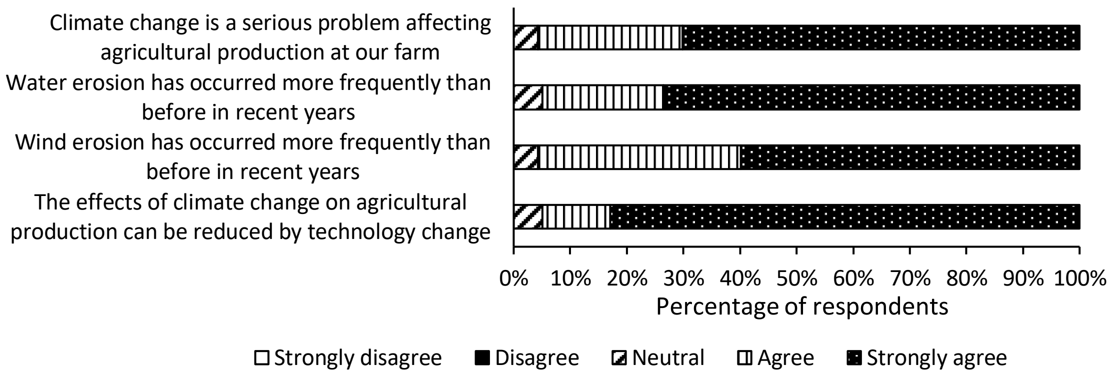



**Figure 9. Farmers' opinion on climate change effects on their farms**

Most farmers reported the severity of all climate change impacts included in the survey to be very high or high. In particular, the majority of farmers perceived changes in the distribution of rainfall during the growing season, increased variability of temperature and rainfall, increased frequency of extreme weather events, decreased availability of water during the growing season, changes in harvest dates, outbreaks of crop pests and diseases and outbreaks of livestock pests and diseases as very high in severity. With regard to shorter growing cycles and changes in sowing dates, most farmers perceived these CC effects to be of high severity. Overall, shorter growing cycles and changes in sowing and harvesting dates were perceived to be less severe than other CC effects included in the survey, based on the distribution of responses assigned to low, medium, high and very high severity categories in the questionnaire (Appendix 6, Figure A6.5).

**Adoption and feasibility of implementation of agroforestry practices**

Most respondents (92.3%) reported some use of orchards on their farms and 34.2% of farmers used windbreaks. Trees on pastures were not used by the participating farmers. The extent to which farmers used these agroforestry practices was also reflected in their awareness of each practice. 84.6% of the farmers had ever heard of windbreaks, while only 28.8% had ever heard of trees on pastures. Farmers used orchards and windbreaks for an average of 8.4 and 7.6 years respectively. 22.2% of farmers plan to use windbreaks and pasture trees within three years. 29.9% and 6% of farmers not using windbreaks and trees on pastures respectively planned to use them later or not at all. Most farmers considered climate change to be only partly important for the adoption of all target agroforestry practices (Appendix 6: Figures A6.6, A6.7, A6.8).

Most farmers (65.8%) were undecided about the feasibility of orchards. 31.6% of the farmers disagreed that the use of orchards is feasible in the target region. 46.2% of the respondents disagreed that the use of windbreaks is feasible, while 35.7% of the respondents strongly agreed that the use of windbreaks is feasible. 88% of farmers either agreed or strongly agreed that trees on pastures were feasible (Figure 10).   Lack of financial resources was a less important reason for most farmers for whom orchards and trees on pastures might not be a feasible technology to implement. For most farmers, lack of financial resources is a moderately important reason why windbreaks might not be a feasible technology. Lack of information was either an important or moderately important reason why windbreaks and trees on pastures might not be a feasible technology for most farmers. On the contrary, lack of information was not an obstacle to the implementation of orchards for most farmers. Economic viability, difficulty of implementation and lack of confidence in the effects of the technologies were not barriers to the adoption of all three technologies for all farmers (Figure 11).

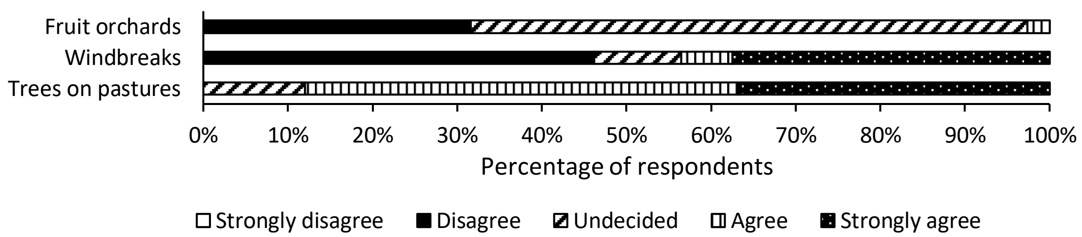



**Figure 10. Do you agree that the use of the following technologies is feasible in your region?**

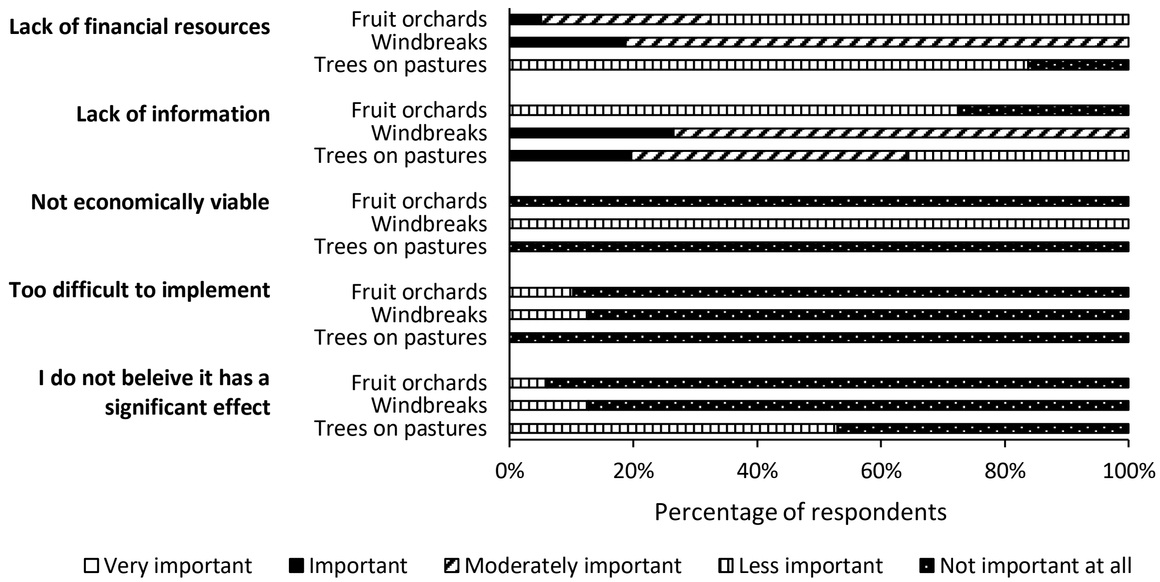



**Figure 11. What are the main reasons that it is not feasible for you to use the following technologies/strategies at all or not to the full extent?**

## 5.5. SWOT analysis

The SWOT analysis showed the severity of the critical issues identified (Table 13). The orchard had the relatively highest score for strengths, but it was also the agroforestry practice most vulnerable to the weaknesses, due to the high initial costs and poor access to machinery. Windbreaks scenario took relatively more advantage of the opportunities presented, followed by intercropped orchard. Both orchard scenarios were more affected by threats compared to windbreaks. For all three agroforestry practices, the strengths outweighed the weaknesses. Opportunities outweighed the threats for intercropped orchard and windbreaks, while the opportunities were equal to threats for orchards. Nevertheless, overall, the outcome of the SWOT analysis was positive for all three scenarios, based on the weighted criteria. The adoption and implementation of windbreaks was the least affected by internal and external factors, while the orchard was the most affected.

The SWOT analysis revealed that smallholder farmers' knowledge of CC risks and adaptation solutions is rather limited, and their awareness of the environmental impacts of their farming practices is low. Adoption and implementation of new farming practices is severely hampered by poor infrastructure, especially deteriorated irrigation systems. Scarce water quality and soil salinity would urgently require specific improvement measures and new approaches to crop composition in the Azerbaijani lowlands, which can be supported by general agricultural and environmental policies as well as commodity subsidies. Established market relations could facilitate the introduction of orchards, although high initial establishment costs may be a barrier to investment in new technologies.

From interviews and meetings with farmers, it is clear that they feel disoriented and helpless in the face of production problems and environmental degradation. Support from the agricultural authorities in the form of advice and extension services is limited. On the one hand, the policy supports the planting of fruit trees and afforestation; on the other hand, the policy shows a somewhat unfocused effort and provides misleading guidelines, e.g., supporting crops that worsen agri-environmental conditions, such as cotton. Overall, limited awareness of climate change risks and adaptation solutions, lack of technical guidance on climate-resilient practices, poor infrastructure, insufficient institutional coordination, and limited community capacity are the main barriers to the adoption of agroforestry practices (Banout et al. 2021).

**Table 13. SWOT analysis**

| Category | Issue | Sub-category | Weight | Score | | |
|---|---|---|---|---|---|---|
| | | | | Orchard | Intercropped orchard | Windbreaks |
| Strengths | Knowledge creation | Farmers extend their knowledge in agroforestry practices | 0.20 | 50 | 50 | 40 |
| | Improved livelihood | Income diversification and mid/long-term increase | 0.25 | 50 | 50 | 50 |
| | Market capacity to cover the additional costs | Established markets for the production of some tree-derived fruits | 0.20 | 50 | 40 | 30 |
| | General agricultural policy | Strategic agricultural roadmaps by the Ministry of Agriculture, e.g., support for windbreaks (pilot) | 0.15 | 40 | 40 | 50 |
| | Commodity subsidies | Direct support to fruit tree planting | 0.20 | 40 | 30 | 20 |
| | | | **a = score x weight** | **46.5** | **42.5** | **38.0** |
| Weaknesses | Investment costs | High installation costs and operational costs | 0.40 | 40 | 30 | 20 |
| | Access to technology and innovation | Poor machinery and equipment stock of small farmers, lack of knowledge on the western mechanisation | 0.35 | 50 | 50 | 20 |
| | Market capacity to cover the additional costs | High transportation costs for smallholders to reach consumers (e.g., in Baku area) | 0.05 | 30 | 30 | 20 |
| | Commodity subsidies | Direct crop payments favouring unsustainable crop cultivation (e.g., cotton) | 0.05 | 20 | 30 | 30 |
| | Lack of knowledge | Farmers are not aware of the adverse environmental effects of their agricultural practices, CC risks and appropriate adaptation solutions | 0.15 | 40 | 30 | 20 |
| | | | **b = score x weight** | **42.0** | **37.0** | **20.5** |
| | | | **x = a - b** | **4.5** | **5.5** | **17.5** |

| Category | Issue | Sub-category | Weight | Score | | |
|---|---|---|---|---|---|---|
| | | | | Orchard | Intercropped orchard | Windbreaks |
| Opportunities | Food security | Improvement of soil fertility and productivity | 0.30 | 30 | 40 | 50 |
| | Infrastructure development | Access to irrigation system/ water resources governed by the Melioration joint-stock company of the government | 0.25 | 50 | 50 | 30 |
| | General financial situation | Oil resources (good price) | 0.10 | 40 | 30 | 20 |
| | Market capacity | Cover costs for "environmental quality" (internalisation of externalities)<br>Compensation for temporarily reduced harvests | 0.20 | 30 | 40 | 50 |
| | Environmental policies | Environmental strategy, Water strategy Ministry of Ecology and Natural Resources. State programs on improvement of – irrigation infrastructure, soil fertility, support to forest planting | 0.15 | 40 | 40 | 50 |
| | | | **c = score x weight** | **37.5** | **41.5** | **42.0** |
| Threats | Coordination of agroforestry adoption | Low coordination capacity without external assistance (extension services, donors, etc.) | 0.2 | 30 | 40 | 50 |
| | Property rights | Unclear land property rights, state-owned land, too fragmented land | 0.1 | 30 | 30 | 20 |
| | Credit policy of banks for agriculture | High interests and risks, land cannot be a collateral, banking system instability | 0.15 | 50 | 40 | 30 |
| | Policy context | Low level of implementation of the strategies in practical policy, programmes, and measures | 0.25 | 30 | 30 | 50 |
| | Infrastructure | Deteriorated irrigation systems, poor network of local roads | 0.3 | 50 | 40 | 20 |
| | | | **d = score x weight** | **37.5** | **36.5** | **35.0** |
| | | | **y = c - d** | **0** | **5.0** | **7.0** |
| | | | **z = (a+c) – (b+d)** | **4.5** | **10.5** | **24.5** |

Weight: Importance of a sub-category. Points from the range 0.01 – 1.00 are attributed to each S, W, O, T; the sum must be equal to 1.00 per each category. Probability of occurrence (score): it expresses how a particular a sub-category can affect each agroforestry practice; to each subcategory scores of 0 – 50 (0 = not important at all, 50 = highly important) are attributed. (Adapted from Narendra et al. 2013; Banout et al. 2021).

# 6. Discussion

## 6.1. Identification and selection of climate change adaptation and mitigation technologies

In the GCF project on which this thesis was based, two cross-cutting technologies, agroforestry and improved irrigation systems, and one CC mitigation technology, carbon sequestration and soil conservation through organic matter management, were selected as the most appropriate technologies to counteract CC effects in Azerbaijan (Banout et al. 2021). Similarly, these three technologies were considered as the most relevant climate-smart practices also for smallholder farmers in Ethiopia (Zerssa et al. 2021). Additionally, agroforestry was also perceived very positively by various experts for degraded tropical landscapes (Reith et al. 2020).

According to the experts, agroforestry and improved irrigation systems had a medium application rate, while carbon sequestration and soil conservation technologies had a low application rate in the agricultural sector of Azerbaijan. It has been shown that improved irrigation systems are among the most efficient CC adaptation and mitigation technologies (Liao et al. 2019; Nguyen & Mitsuyasu 2017). Therefore, the application rate should reach a high level as it is a priority of many CC adaptation efforts (Huang et al. 2018; Iglesias & Garote 2015; World Bank 2014). Considering that different improved irrigation systems can be applied to most types of cropping systems, their impact in target areas can be enormous; drip irrigation in rural areas with limited water resources is one example (Singh et al. 2020). Thus, irrigation can have an impact even where the implementation of other climate-smart technologies is not possible in a short time horizon for economic, social, or environmental reasons (Iglesias & Garote 2015).

Moreover, the appropriate combination of the selected technologies, adapted to the specific agroecological contexts, could further increase their benefits and the profitability of the farming system, e.g., an agroforestry system with high-value trees under irrigation (Dhanya et al. 2016). Agroforestry systems could be a promising solution for local farmers who are somewhat familiar with some agroforestry practices, such as fruit orchards or home gardens. At the same time, the farmers can diversify their income through agroforestry by producing different products. This is an added value compared to other climate-resilient practices such as improved irrigation, mulching, composting, reduced tillage, etc. (Baker et al. 2023).

The improved irrigation systems are among the most efficient CC adaptation technologies (Fonseca et al. 2022; Zhao et al. 2022). Although high investment costs could significantly hamper their implementation, the reduced production losses outweigh the costs (Zeshan & Shakeel 2020). High investment costs could also be a constraint for adopting some carbon sequestration and soil conservation technologies, such as composting, without subsidies (Galgani et al. 2014). Also, insecure property rights might represent a constraint for adopting climate-smart technologies, as observed for mulching in tropics and sub-tropics (Erenstein 2003). In addition, farmers usually tend to find the cheapest and less risky solutions. For example, the design of single-row poplar windbreaks is more acceptable to farmers because it takes up less space and grows faster (Thevs et al. 2019). As a result, technologies being more demanding economically and technically may require higher institutional support in terms of direct incentives and extension services to convince especially smallholder farmers to adopt them.  Indeed, the small farm size, along with the lack of incentives, credits, and information on CC were reported as major barriers to adoption of climate resilient agricultural practices (Kibue et al. 2015).

The technology identification process within GCF project revealed that some other CC adaptation technologies related to crop production (climate-resilient varieties, crop diversification, crop rotation and crop insurance) and one CC mitigation technology (reduced tillage) are currently applied at a medium level in Azerbaijan. Two cross-cutting technologies, precision agriculture and mulching, are also applied at a medium level, while the use of cover crops tends to be low. This suggests that the identified climate-smart technologies are being applied to some extent in the Azerbaijani context, although the distribution of applied technologies may vary considerably across different regions, which may also be due to associated transaction costs (Cohn et al. 2017). Most technologies can be relatively easily combined to act in synergy as demonstrated, for example, for agroforestry with water harvesting (Salazar et al. 2011).

The selection of the study sites for the implementation of agroforestry in the thesis was driven by the aim to achieve a wider impact compared to other parts of Azerbaijan. The vast area of the lowlands offers a high potential for the adoption of CC-resilient technologies, including a higher variability of technologies that can be achieved within the area. The future benefits from the adoption of these technologies in the lowlands, where most of the crop production is concentrated, could, in the longer term, have a positive impact on the whole country in economic, social and environmental terms.

## 6.2. Cost-benefit analysis

The evaluation of agroforestry systems presented in the thesis provides new insights into CC adaptation and mitigation options for smallholder farmers in the Caucasus region. In contrast to previously reported cost-benefit analyses focusing on different CC adaptation and mitigation strategies (improving irrigation-related aspects, switching to new crop varieties, optimising fertilisation, improving hydro-meteorological services, extension services, etc.) under different CC scenarios in Azerbaijan (World Bank 2014), the thesis compared the costs and benefits of different agroforestry systems and wheat monoculture.

Within the CBA, the pomegranate orchard emerged as the most profitable scenario, despite having the highest initial establishment costs and total annual costs. In particular, fencing represents 29.52% of the initial cost of establishing pomegranate orchards and may therefore be a barrier to the adoption of this practice. The intercropped pomegranate was the second most profitable scenario, and the higher profitability of intercropping systems over monocultures has also been demonstrated by other studies (Swamila et al. 2022).

As a high initial investment may reduce the willingness of smallholder farmers to adopt new technologies (Williams et al. 2020), it is essential to provide the farmers in the target areas with other options. In this regard, intercropped orchards and windbreaks may be perceived as less risky options. Farmers are usually more prone to adopt more profitable but less demanding conservation technologies (Cramb et al. 1999; Thierfelder et al. 2017). In addition, agroforestry, followed by intercropping, resulted to be more profitable compared to various conservation practices (Ombati Mogaka et al. 2022).

Alternatively, adequate subsidies for the installation of fences and irrigation systems could stimulate farmers' interest in establishing agroforestry systems (Koh et al. 2020). However, the current subsidies for pomegranate planting (AZN 3,000) would only cover the purchase of seedlings and only apply to intensive plantations with higher plant densities than the intercropped orchard analysed. Also, interventions to increase household savings are recommended for adopting climate-smart strategies based on evidence from Kenya (Gikonyo et al. 2022).

Although the economic benefits can be directly calculated, other associated benefits (social and environmental) of the agroforestry systems are often more difficult to quantify financially (Boardman et al. 2018). Furthermore, each type of agroforestry system provides different benefits (Venance-Pâques Gniayou et al. 2021; Vu et al. 2015). For example, orchards, which generate high economic benefits, may lead to higher social benefits in terms of improved livelihoods, food security and labour but to less environmental benefits compared to the other two agroforestry systems (intercropped pomegranate and windbreaks) analysed, which were less profitable but also less intensive farming systems (Magne et al. 2014). At the same time, less intensive farming systems could generate higher environmental benefits in terms of plant and animal diversity, preservation of soil fertility and natural soil processes, reduced use of agrochemicals and associated hazards, etc., compared to intensive farming systems. Indeed, environmental benefits are one of the main reasons for adopting agroforestry as a climate-resilient technology (Smith et al. 2021); and these benefits drive policy action in CC adaptation and mitigation efforts. However, accurate planning is necessary to ensure the profitability of agroforestry systems, such as orchards, on degraded lands, as it can significantly decrease over time (Wang et al. 2016).

An important consideration when assessing co-benefits is that the costs of implementing sustainable land management practices are overly concentrated on individual farms, while most of the associated benefits, such as improved ecosystem services, C sequestration and national food security, have a greater impact (Dallimer et al. 2018). This is supported by a meta-analysis showing that the positive effects of agroforestry on ecosystem services are more evident at the landscape and regional scales than at the farm scale (Torralba et al. 2016). Therefore, it is important that the associated benefits, considered as positive externalities, are internalised through the institutional interventions within the incentives (Venance-Pâques Gniayou et al. 2021). In fact, some agroforestry systems, e.g., sylvoarable systems, had a lower profitability than the arable farming without trees, but greater benefits were obtained when also the environmental externalities were included (García de Jalón et al. 2018).

Nevertheless, within the proposed scenarios, which focus on smallholder farmers owning and cultivating smaller plots of land, orchards in this context can likely provide benefits comparable to less intensive systems. In the thesis, the analysed agroforestry systems were more profitable than wheat monoculture. On the contrary, under different climate and geographical conditions, monocropping can be more profitable than agroforestry, although its environmental benefits are higher (Legaspi et al. 2021). In fact, it has been demonstrated that large shares of agroforestry in the landscape enhanced ecosystem service provision (Reith et al. 2020).

Farmers are often reluctant to adopt and implement new technologies due to a lack of evidence and information that the benefits may outweigh the costs (Mandila et al. 2015), which is also due to cultural and capacity reasons (Rahman et al. 2017). Moreover, smallholder farmers mostly require that the new (or improved) farming system is more profitable than the existing one (Lojka et al. 2008). The proposed agroecological transformation of production to agroforestry systems should be seen by farmers as a promising alternative to industrial and input-based monocultures rather than a top-down transition imposed by the state (Kombat et al. 2021). Farmers' positive perception of the transition to agroforestry would thus contribute significantly to structural change in local unsustainable agricultural systems, such as the degraded fields in the Azerbaijani lowlands.

It should also be noted that the environmental benefits associated with agroforestry are significant when applied to an existing, usually unsustainable, agricultural system. However, where agroforestry replaces natural forests or other valuable ecosystems, the transition to agroforestry systems would not necessarily achieve the environmental benefits of the previous land use (Wood et al. 2016). In particular, in Azerbaijan, forests are mainly designed to protect soils and watersheds, thus providing regulating ecosystem services, and only a small part is intended for the exploitation of forest products (Thevs 2019), providing provisioning ecosystem services. In line with this land use status, the Azerbaijani government's efforts are more focused on reforestation and the introduction of climate-resilient technologies in degraded agricultural areas, with the aim of maintaining food security and self-sufficiency while simultaneously combating CC. Large government investments in climate-resilient technologies are planned to intensify CC mitigation throughout the country. In addition, the rehabilitation of saline soils and the reconstruction of irrigation channels in the lowlands will require significant additional costs (SRAZ 2016).

The limitation of the cost-benefit analysis may be the lack of direct information on specific benefits and costs from farmers. Nevertheless, the Azerbaijani state provides a lot of publicly available information on establishment and implementation costs and benefits, including subsidies. This was particularly useful for the wheat and pomegranate scenarios, while there was a lack of information directly from Azerbaijan on the sea buckthorn and poplar crops. Also, some estimates for pomegranate varied widely; for example, some authors (Sefiyev and Qamberova 2022) proposed a full production yield of 50 t-ha-1 for an unspecified location in Azerbaijan, which appears overestimated compared to the available official data used in the thesis. In addition, the CBA did not include the costs and benefits associated with harvesting and felling, as the life span of the poplar trees to be harvested at full production potential was estimated at 20 years (Worbes et al. 2006). However, some hybrid poplars could be harvested earlier and replaced by new plantlets, or the trees could be harvested gradually but sold at a lower price of timber (Kareemula et al. 2005; Worbes et al. 2006). In addition, the farmers could harvest some wood from poplars and sea buckthorn annually, which was not considered in the CBA as this would be mainly for subsistence purposes.

## 6.3. Sensitivity analysis

A 10% discount rate was used in the sensitivity analysis, in line with the recommendations for developing countries and agroforestry systems, and an additional 20% discount rate was considered to reflect some unexpected future scenario variations (Boardman et al. 2018; Mishra & Rai 2014; Verner et al. 2012). Wheat monoculture emerged as the least sensitive scenario to all the changes tested. This could be mainly due to the low production costs and higher proportional subsidies compared to other scenarios. However, the long-term subsidies may also lead to inappropriate use of inputs, resource and land degradation and a decline of crop yields, as reported for wheat and rice in Asia (Pingali et al. 2021; Wichelns 2004). Moreover, the diversified farming systems, i.e., consisting of more than one crop, can be considered more stable economically and environmentally, providing substantially greater biodiversity, pest and weed control, soil health, nutrient and water management, and carbon sequestration compared to non-diversified farming (Nyberg et al. 2020; Rosa-Schleich et al. 2019). In fact, the windbreaks scenario, containing different plant species, was the least affected of the three agroforestry practices, followed by intercropped pomegranate and pomegranate orchard.

Nevertheless, the probability and profitability of diversified farming systems could be threatened particularly if some risks co-occur (Jamal et al. 2022). Therefore, simulating the effect of a single factor separately for each scenario might be a certain limitation of the results of the sensitivity analysis. However, the sensitivity analysis did allow a distinction to be made between the magnitude of the impact of each price change likely to affect the profitability of the four scenarios. In addition, more or less relevant variations of different price changes affecting agricultural production occur spontaneously or intentionally influenced by the macroeconomic context of the country.

The selling price of products had the greatest impact on profitability in all four scenarios, which was also confirmed by other authors, comparing agroforestry, intercropping, and various conservation practices (Ombati Mogaka et al. 2022). Smallholder farmers can be highly vulnerable to price fluctuations, but this risk can be mitigated through crop diversification (FAO 2015d). Labour costs were the second most important aspect affecting the profitability of the scenarios analysed. The agroforestry scenarios were more affected by changes in labour costs than wheat monoculture, as they are more labour-intensive farming systems. This is an important observation as labour demand may influence the farmers' choice of cropping system (Kotir et al. 2022). However, smallholder farmers could cover labour costs by involving household members since family labour can be positively related to farm production (Nyberg et al. 2020).

Wheat monoculture was the scenario most affected by the subsidy changes. It is typical of the farming systems that are strongly incentivised and controlled by the state, i.e., the state supply price for wheat (Cabinet of Ministers of the Republic of Azerbaijan 2022). On the contrary, farming systems with higher overall profitability may be less affected by the subsidy policy. For example, the impact of input subsidies on productivity has been found to be higher for smallholders than for large-scale farmers (Agyemang et al. 2022). This is supported by the result of the sensitivity analysis for the windbreak scenario, which is less affected by changes in subsidies than wheat, but more than the two scenarios with pomegranate, which were more profitable. Similarly, the moderate effect of subsidies was reported for windbreaks, which were economically competitive with various conservation practices, whether subsidised or not (Countryman & Murrow 2000).

The agroforestry systems with pomegranate were more affected by the change in the price of agrochemicals than the farming systems with wheat. This reflects the higher input requirements of perennial crops compared to annual crops. However, the need for agrochemicals in wheat monoculture can increase significantly when grown on degraded soils and can be further increased if crop rotation is not regular.

## 6.4. Quantitative questionnaire survey

**Sample description analysis**

Among the participating farmers, men predominated (69.2%), which may reflect the social context of the country and rural areas. It was reported that male and female farmers have different coping strategies against CC and tend to engage in different agroforestry systems, i.e., men in more intensive agroforestry, while women in subsistence farming (Awazi et al. 2022). Almost half of the respondents (48.7%) had a university degree, while 35.9% had completed secondary school. The education providing up-to-date knowledge in agriculture and horticulture is limited in Azerbaijan (Streef 2017). Thus, a higher proportion of university graduates in the sample of respondents could be due to the purposive selection of participants. This may be a limitation for the interpretation of the research data, as university graduates may be more open-minded to adopting new technologies. The average of 17.27 years of work in agriculture indicates that most of the participants were rather experienced farmers; thus, some influence of the legacies of the former Soviet organisation might persist.

The crops and livestock raised by the respondents reflect the public data on farming practices and cultural backgrounds in the region. The data also showed the prevalence of cropping systems typical of smallholder farmers, as crops were mainly concentrated on smaller plots, with 64.1% of farmers cultivating less than 1 ha, 88% of farmers growing fruit on an area equal to or less than 0.4 ha, and 96.6% of farmers growing vegetables on an area equal to or less than 0.5 ha. Most of the farmers (68.4%) did not cultivate wheat; of the farmers who did cultivate wheat, most of them cultivated on the area larger than 2 ha. These data suggest that farmers prefer larger areas for wheat cultivation, which could be due to the access to higher subsidies, so that farmers who do not have enough land might prefer other crops.

**Climate change effects and respondents' awareness**

Most of the farmers believed that their farm was affected by various severe impacts of climate change, which was a serious problem. Overall, farmers were very concerned about their future as farmers in relation to climate change. This is in line with the theory of planned behaviour, which suggests that farmers are mainly influenced by their attitudes (Noeldeke 2022). Most farmers stated that it was very important to apply climate change adaptation and mitigation strategies on their farms. 94.9% of the farmers also believed that the impact of CC on agricultural production can be reduced through technology change. This corresponds to the higher educational level of many participating farmers, who may be more inclined to accept innovations (Dissanayake et al. 2022).

According to the farmers, environmental problems related to land degradation, such as water and wind erosion, have become more frequent in recent years. The majority of farmers perceived changes in rainfall distribution during the growing season, increased temperature and rainfall variability, increased frequency of extreme weather events, decreased water availability during the growing season, changes in harvest dates, outbreaks of crop pests and diseases, and outbreaks of livestock pests and diseases as very serious. Similar perceptions of the severity of CC effects were observed among the smallholder farmers in Ecuador, where agroforestry farmers were less affected by CC effects than conventional farmers (Córdova et al. 2019).

**Adoption and feasibility of implementation of agroforestry practices**

Most of the respondents reported some use of orchards. Considering the predominance of small orchard plots of less than 0.4 ha, the proportion of commercial orchard production compared to subsistence orchard production may be rather low. However, the questionnaire did not collect data on the share of subsistence production among the participating farmers. This could be a limitation to illustrate the socio-economic context in the target region.

34.2% of the farmers used windbreaks, which to some extent reflects the past initiatives of the former Soviet regime to establish windbreaks (Chendev et al. 2015). On the contrary, the participating farmers did not use trees on pastures. The level of use of agroforestry practices among farmers was also reflected in their awareness of each practice. In particular, farmers were much more aware of windbreaks than of trees on pastures. Similarly, in some countries, uneven awareness of agroforestry practices was observed in smallholder farmers in Uganda, who were prevalently willing to adopt agroforestry practices (Mutonyi & Fungo 2011). On the contrary, only 22 - 30% of the farmers involved in the quantitative questionnaire within the thesis intended to adopt new agroforestry practices (windbreaks or trees on pastures). Which is in contrast with the results from Philippines where the farmers were very favourable to the adoption of windbreaks (Cramb et al. 1999). Most farmers within the survey considered climate change as only partly an important reason for the adoption of all target agroforestry strategies. This may indicate a low level of awareness of the potential of agroforestry to mitigate the effects of climate change, as also observed in Vietnam (Simelton et al. 2015). However, experience from Pakistan has shown that farmers are also driven by their local context in adopting agroforestry, which is underpinned by different motivations (Ullah et al. 2023).

Although all participating farmers used orchards, their opinion on the prospects of this practice was rather unfocused, as most farmers (65.8%) were undecided and 31.6% of the farmers disagreed on the feasibility of orchards in their area. These results could indicate the difficulties of fruit growing in the target region, based on the farmers' experience, as lack of information was not an obstacle to the implementation of orchards for most farmers. Lack of financial resources was also a less important reason for the feasibility of implementing orchards for most farmers. Thus, the perception of lower feasibility of orchards could also be due to unfavourable environmental conditions related to land degradation (Wang et al. 2016).

Farmers' opinions on the feasibility of windbreaks were mixed, with 46.2% of respondents disagreeing and 35.7% agreeing that the use of windbreaks is feasible in the target area. These results may indicate that the level of knowledge of windbreaks technology among the participating farmers was not uniform (Makate 2020). In fact, the participating farmers perceived the lack of information as either an important or moderately important constraint to the implementation of windbreaks. In addition, lack of financial resources was perceived by most farmers as a moderately important reason why windbreaks might not be a feasible technology. On the contrary, 88% of the farmers agreed that trees on pastures were feasible in the farmers' location, which could indicate that this agroforestry practice is perceived as an easy to implement and rather low-cost technology. In fact, lack of financial resources was perceived as a less important barrier to implementation by most of the participating farmers, while lack of information was either an important or moderately important reason.

Economic viability, difficulty of implementation and lack of confidence in the effects of the technologies were not barriers to adoption of all three technologies for all participating farmers. These results may indicate that farmers perceive the barriers in their specific contexts and circumstances (Cramb et al. 1999).

The limitations of the quantitative questionnaire survey were that the data collection was outsourced to a third party, which excluded direct interaction with the respondents and implied limited control over the accuracy of the data collected. Therefore, an attempt was made to reduce these limitations by using the collected data exclusively for a simple descriptive analysis of the sample of respondents and as input for the SWOT analysis. A further limitation is the uneven distribution of respondents across the different districts, due to the fact that the questionnaire was administered at farmers' meetings. In particular, half of the respondents were over-concentrated in the north-western part of the country. For example, in the Tovuz district, which is the most represented, viticulture is widespread and this specific cultivation may have influenced the farmers' responses. However, the environmental conditions, including the problems of degraded land, are generally very similar throughout the lowlands of Azerbaijan (Ministry of Economy. 2012). Thus, farmers' experiences and farming conditions are likely to be similar, and the information obtained from farmers from 16 different districts provided a valuable insight into the current situation of farmers in relation to CC effects in the Azerbaijani lowlands.

## 6.5. SWOT analysis

Strengths with opportunities outweighed weaknesses with threats for all three agroforestry practices within the weighted SWOT analysis. Overall, the adoption and implementation of windbreaks proved to be the least affected by internal and external factors, while the orchard was the most affected scenario. This result indicates that the scenarios with greater opportunities for higher profits are also those that are more vulnerable to changes in their production environment (Molua et al. 2010). This is in line with the CBA, where the most profitable scenario (pomegranate orchard) was the scenario most vulnerable to negative changes in pomegranate selling price and labour costs.

The internal conditions for adoption and implementation of agroforestry practices appeared positive for the Azerbaijani lowlands, as strengths outweighed weaknesses for all three scenarios. The orchard had the most strengths but was also the most vulnerable to the weaknesses, being most affected by the high initial costs and poor machinery in line with the CBA.

In terms of external factors influencing the adoption and implementation of agroforestry practices, the windbreaks offered more opportunities than the other two scenarios, although the rating of the windbreak was very close to that of the orchard. In the case of the orchard, the threats were equal to the opportunities, indicating that the implementation of this scenario could be severely hampered by problems related mainly to poor infrastructure and partly to credit policy (O'Connell & Hradszky 2018). Property rights were considered to have a limited impact, as farmers almost exclusively cultivated on their own land, but land fragmentation could pose a problem for the implementation of agroforestry on a larger scale, implicating higher transaction costs as observed in other cases (Heider et al. 2018). In particular, windbreaks provide environmental and production benefits by improving ecosystem services in larger areas; and monetary valuation of expected wind-induced crop losses was suggested as an important aspect of promoting windbreaks (Thapa et al. 2022).

Overall, the research in the study area revealed that smallholders have limited knowledge of CC risks and related adaptation solutions. This was identified as a common barrier for smallholder farmers to overcome in the face of CC impacts (Mu et al. 2023). Another barrier is the lack of knowledge about agroforestry technologies. Although most farmers stated that lack of knowledge about orchards was not an obstacle, they were very sceptical about the feasibility of orchards in their location. This finding may indicate that farmers have not been successful enough with tree crops in their farming contexts. At the same time, the region faces catastrophic land degradation, exacerbated by CC, and these circumstances significantly undermine efforts to adopt new technologies (Climate Risk Country Profile 2021). In addition, inappropriate land management due to lack of knowledge leads to further degradation of degraded land (The Ministry of Ecology and Natural Resources 2012). Under these conditions, improving the environmental situation and the livelihoods of farmers appears to be a vicious circle of failed attempts at structural change.

Lack of financial capital is generally another barrier to investment in new agroforestry technologies (Streef 2017), with high initial costs, especially for orchard establishment, as shown in the CBA. However, the lack of financial resources was not perceived as a major constraint to agroforestry adoption by farmers. This may be indicative of other persistent social and environmental problems in the region. For example, irrigation systems in the study areas have mostly deteriorated and access to them is rather uncoordinated. In addition, poor water quality and high soil salinity are long-term problems that urgently require large-scale intervention (SRAZ 2016). This would require joint efforts at community level, but in Azerbaijan the capacity of communities to address local agricultural issues is rather limited, as resulted from SWOT analysis.

In conclusion, the situation regarding the adoption and implementation of CC effects in the Azerbaijani lowlands is characterised by the agricultural situation requiring urgent interventions against land degradation and to support farmers' livelihoods, on the one hand, and the willingness of the state to provide these interventions, on the other. Indeed, financial commitments from governments and development agencies are essential for large scale adoption of climate-smart agriculture (Zougmoré et al. 2018). However, the target area lacks the capacity to transfer the desired changes and support from the policy level to the farm level due to limited support from the agricultural authorities in the form of advisory and extension services, as observed also in other countries (Mu et al. 2023). Lack of coordination between institutions at different levels also affects institutional functionality in supporting sustainable practices (Pali et al. 2023). This hinders economic growth and development and makes the desired structural changes inefficient. An efficient network of extension services should be developed and embedded in the structures of the agricultural authorities to ensure long-term support (Molua et al. 2005). Careful planning at policy level would be required to manage the considerable time and resources involved and to ensure that up-to-date knowledge on agroforestry is transferred to the farmers (Rüegg et al. 2022). In fact, the lack of policies promoting specific innovative practices were reported as a principal barrier for the adoption of sustainable agricultural practices in various countries (Campuzano et al. 2023).

Azerbaijan's policy efforts should therefore be constructively coordinated so that they can be effectively delivered to farmers. So far, there are some misleading guidelines, such as the support for cotton cultivation, which may compete in effectiveness and application rate with the policy to support the planting of fruit trees and afforestation. In this respect, locally adapted solutions and recommendations for crop composition and farming practices could be transferred to farmers (Samuel et al. 2022). Farmers should not only be provided with technical knowledge on crop cultivation and CC awareness, but the state should provide a whole 'toolbox' of solutions within the specific guidelines for the prioritised crops or farming practices through a functional institutional framework (Mwangi & Kariuki 2015; Shiferaw et al. 2009).

Local extension services are an effective way of transferring information and knowledge, and a bottom-up approach to implementing climate-smart strategies is therefore recommended (Fuchs et al. 2019; Kombat et al. 2021). This is supported by the experience of smallholder farmers in sub-Saharan Africa, where the active involvement of local communities and their indigenous institutions in the planning of climate adaptation programmes enabled the scaling up of climate-smart innovations (Makate 2020). In addition, farmers may perceive formal institutions as ineffective, while informal institutions may be seen as valuable providers of financial resources to support their agricultural production and to meet their livelihood needs (Pali et al. 2023).

The efficiency of the information and knowledge transfer could be further promoted by the involvement of farmers' cooperatives to improve farmers' livelihoods and increase productivity, as envisaged by the Azerbaijani government (Law No. 270-VQ 2016, O'Connell & Hradszky 2018). There is evidence from various countries that participation in social institutions, along with access to information, and assets, promoted adoption of climate-resilient farming practices by smallholder farmers (Wood et al. 2014). Therefore, knowledge and technology transfer should be addressed from the holistic perspective of Azerbaijan in order to develop a fully functional mechanism capable of actively supporting the agricultural sector in different agricultural contexts.

The limitation of the SWOT analysis could be represented by the limited transferability of the results to all lowland areas, as the survey participants were not homogeneously distributed.

# 7. Conclusions

## 7.1. General conclusions

The novelty of the thesis lies in the study of the potential of agroforestry practices as climate resilient technologies in the Caucasus region. The thesis contributed to the identification of the most appropriate technologies for CC adaptation and mitigation in the Azerbaijani lowlands. It focused on the potential of agroforestry practices for smallholder farmers.

In the cost-benefit analysis, all agroforestry practices analysed (pomegranate orchard, pomegranate intercropping and wheat windbreak) were more profitable than wheat monoculture and also provided various environmental and social benefits. Several input and output price changes (product selling price, labour costs, subsidies, agrochemicals costs) affected the four scenarios to varying degrees. Product selling price was the most important aspect affecting profitability in all four scenarios, while the impact of changes in labour costs varied between scenarios. Agroforestry practices were more sensitive to the hypothesised changes in all factors tested than wheat monoculture. These results support the first hypothesis.

The questionnaire survey showed that, overall, farmers were very concerned about their future in relation to climate change. Farmers also perceived the severity of some CC impacts to be very high and mostly recognised the importance of adopting CC adaptation and mitigation strategies. This supports the second hypothesis. However, farmers were somewhat reluctant and had conflicting opinions on the feasibility of implementing orchards and windbreaks in their area.

All agroforestry practices analysed (orchard, intercropped orchard, windbreaks) appeared promising in the SWOT analysis, as strengths and opportunities outweighed weaknesses and threats. This confirms the third hypothesis. The adoption and implementation of windbreaks proved to be the scenario least affected by internal and external factors, while the orchard was the most affected scenario. Improved livelihoods and knowledge generation were the main strengths identified for all three practices, while investment costs and lack of access to technology and innovation were the main weaknesses, particularly relevant for the orchard systems. Infrastructure development and improved food security through improved soil fertility and productivity were identified as opportunities for agroforestry practices. However, limited knowledge and awareness of climate change risks and adaptation solutions, lack of technical guidance on climate-resilient practices, insufficient institutional coordination, deteriorating irrigation infrastructure and limited community capacity were among the most critical issues threatening the successful adoption and implementation of agroforestry in the Azerbaijani lowlands.

In conclusion, agroforestry practices have emerged as a valuable alternative to traditional monoculture in the Azerbaijani lowlands. The implementation of some form of agroforestry could contribute to climate change adaptation and mitigation at the country level in the long term, as well as to the restoration of large areas of degraded land. Careful policy planning, including substantial investment and ongoing institutional support and monitoring, is essential to achieve the expected impacts on CC, increase agricultural production and improve farmers' livelihoods.

## 7.2. Policy recommendations

Policy efforts to improve the adoption of CC adaptation and mitigation technologies should be intensified, with a focus on smallholder farmers, who constitute the majority of agricultural producers in Azerbaijan. The goal of mitigating the negative impacts of CC should be pursued simultaneously with the goal of improving farmers' livelihoods, as this will increase farmers' willingness to adopt new technologies. Nevertheless, farmers should be aware of the positive externalities, i.e., the environmental and social benefits of the promoted technologies, which would be internalised by government support. Thus, the farmers' perception of the desired increase in agricultural production should be embedded in the context of sustainable agriculture.

CC-related interventions in Azerbaijan will require careful planning of various agricultural and food policies, especially those related to food security, irrigation, inputs, and credit. It is desirable to combine these with policies that correct market imperfections, such as policies that reduce transaction costs, risk mitigation policies, subsidies for externalities and inputs, etc. For example, a combination of input and credit provision can be effectively used to provide organic matter to farmers for land restoration and the establishment of agroforestry systems.

The state should consider a long-term investment in agricultural interventions, in parallel with the development of a solid network of extension services through the establishment of local or regional extension centres since the transfer of information and knowledge determines the success of the impact of interventions. Institutional coordination can be strengthened by building community capacity, which is of direct interest to farmers.

Interventions should be carefully tailored to specific technologies and widely accessible to smallholders, i.e., without significant restrictions on the number of trees planted or the area cultivated. Fair access to interventions and support for poor farmers would ensure the equity and inclusiveness of the policy. In addition, the subsidy system should be updated to significantly promote the adoption of desired technologies, as subsidies appear insufficient in the agroforestry scenarios analysed.

It should be noted that direct interventions to farmers to adopt climate-smart technologies may not be sufficient to render these technologies fully efficient under local farming conditions. Therefore, in parallel with government support for specific technologies, the highly degraded soils of Azerbaijan's lowlands will require substantial investment in land restoration and the rehabilitation of water sources and canals to ensure the sustainability of the farming systems.

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## Appendices

## Appendix 1: Questionnaire on the evaluation of potential climate change adaptation measures for the agricultural sector in Azerbaijan

### Explanation of evaluation criteria:

1. **Aligning with recent CC adaptation goals in AZB:** Desertification, salinisation and soil erosion are major CC effects in Azerbaijan, making efficient irrigation an importation driver for climate change adaptation (Aliyev 2018). A more sustainable management of water resources and the application of flexible solutions in agriculture in Azerbaijan is necessary (UNDP 2021). As pointed out by the Ministry of Ecology and Natural Resources of Azerbaijan (2012) and the World Bank 2014, the introduction of climate resilient crop species, the application of windbreaks, the usage of irrigation technologies (e.g., drip irrigation, sprinklers) as well as the focus on conservation agriculture (e.g.no till) are key priorities for the agricultural sector. Focus points of the Joint Action Plan of the Ministry of Ecology and Natural Resource (2020-2023) are: Measures to mitigate and adapt to the negative effects of agricultural activities on the environment, rational use of water and land resources, efficient use of forest resources, conservation of biodiversity and ecosystem, developing aquaculture, support of organic agriculture, strengthening institutional capacities.
2. **Status/ current degree of application:** The goal is to prioritise technologies which have not yet been applied to a full extend among farmers in Azerbaijan. Therefore, technologies with a lower application rate will be graded with more points within the questionnaire.
3. **Technology adoption rate:** Any potential issues faced during the implementation of a technology might be a threat to the successful completion of this project. It is therefore desired, that any chosen technology will have possibly fast adoption rate and low implementation costs. The technology should be easy to implement in a short time frame and be easily accepted by farmers in Azerbaijan.
4. **Enhancing farm resilience towards/against CC through the technology:** The selected technologies aim to support farmers in reducing harvest losses and strengthen their resilience towards extreme weather events, droughts, and other potential effects of climate change on their farm operations.
5. **Effectiveness of the technology in improving ecosystem services:** Within this criterion it is important to consider factors such as the potential for reducing salinisation and increasing the biodiversity (e.g., through mixed crop systems).
6. **Preferred region for implementation:** Please, select at least one of the 10 economic regions in Azerbaijan per technology. This helps to determine which areas are most suitable for implementing the selected technologies: Absheron (1), Ganja-Qazakh (2), Shaki-Zaqatala (3), Lankaran (4), Guba-Khachmaz (5), Aran (6), Upper Karabakh (7), Kalbajar-Lachin (8), Mountainous Shirvan (9), Nakhchivan (10)

| Title of the of the CC adaptation/mitigation technology<br><br>*Please check the detailed explanation of each evaluation criteria before completing the questionnaire. | Aligning with existing CC adaptation goals in AZB* | Status/ current degree of application* | Technology adoption rate* | Enhancing farm resilience towards/ against CC through the technology* | Effectiveness of the technology in improving ecosystem services* | Preferred region for implementation* | Further Comments |
|---|---|---|---|---|---|---|---|

| | I | II | III | IV | V | VI | VII |
|---|---|---|---|---|---|---|---|
| Evaluation of each selection criteria I-VII | Not at all (0 points) – Yes, fully (10 points) | High application rate (0 points) –Currently not applied (10 Points) | Slow adoption rate (0 points) – Fast adoption rate (10 points) | Low resilience capacities (0 points) –High resilience capacities (10 points) | Low potential (10 points) – High potential (10 points) | According to the economic regions in Azerbaijan | |
| Technologies focused on climate change adaptation | | | | | | | |
| Climate resilient varieties with higher draught/heat resistance (e.g., grapes, cotton) | | | | | | | |
| Crop diversification (several crops grown simultaneously) | | | | | | | |
| Crop rotation (e.g., cereals and legumes) | | | | | | | |
| Crop insurance | | | | | | | |
| Livestock management (change in breeding patterns, breed choice) | | | | | | | |
| Schedule for moving of livestock in different zones | | | | | | | |
| Supplemental feed and vaccinations to make livestock more resistant to climatic variations | | | | | | | |
| Technologies focused on climate change mitigation | | | | | | | |
| Adjustment of grazing methods (e.g., rotational grazing, herding, zero grazing-stall feeding, reduction of livestock) | | | | | | | |
| Biogas production with manure management | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Carbon sequestration and Soil conservation through organic matter management (e.g., composting) | | | | | | | |
| No tillage or minimum tillage farming | | | | | | | |
| Cross-cutting technologies focusing on climate change mitigation AND adaptation | | | | | | | |
| Agroforestry (e.g., Windbreaks or sun protection forest strips; agrobiodiversity) | | | | | | | |
| Cover crops (N-fixation, soil protection) | | | | | | | |
| Precision agriculture (through site specific crop management) | | | | | | | |
| Mulching (conservation of soil moisture and improving soil fertility) | | | | | | | |
| Pasture management (rotational grazing, cultivation of forage crops) | | | | | | | |
| Improved irrigation systems (rainwater storage, water reclamation etc.) | | | | | | | |

## Appendix 2: Outputs of literature database search

### Table A2. Outputs of literature database search

| Search strings | Web of Science | Scopus | Google Scholar |
|---|---|---|---|
| agroforestry AND “cost-benefit analysis” | 65 | 152 | 1,740 |
| agroforestry AND “cost-benefit analysis” AND Asia | 4 | 14 | 969 |
| agroforestry AND profitability AND Asia | 11 | 13 | 6,790 |
| agroforestry AND profitability OR agroforestry AND benefits AND costs | 816 | 438 | 23,900 |
| agroforestry AND profitability AND "meta-analysis" | 5 | 4 | 3,670 |
| Agroforestry AND “environmental benefits” OR Agroforestry AND “social benefits” OR Agroforestry AND “economic benefits” | 429 | 219 | 7,220 |
| Agroforestry AND “production benefits” OR Agroforestry AND “production costs” OR Agroforestry AND “initial costs” | 52 | 10 | 267 |
| agroforestry AND benefits AND costs AND “climate change” AND adaptation AND mitigation | 16 | 7 | 15,300 |
| agroforestry AND "climate change" AND adaptation OR agroforestry AND "climate change" AND mitigation | 1,169 | 538 | 25,600 |
| windbreaks AND "climate change" OR "fruit orchard" AND "climate change" | 92 | 78 | 5,040 |
| agroforestry AND "ecosystem services" OR "windbreaks" AND "ecosystem services" OR "fruit orchard" AND "ecosystem services" | 1,579 | 1,107 | 17,200 |
| **Total** | **4,238** | **2,580** | **107,696** |

Note: Web of Science search field: All fields, no time restrictions; Elsevier Scopus search field: article title, abstract, and keywords, no time restriction; Google Scholar search field: unique search field available, time restriction: 2020 – 2023.
Source: webofscience.com; scopus.com; scholar.google.com

## Appendix 3: Field design

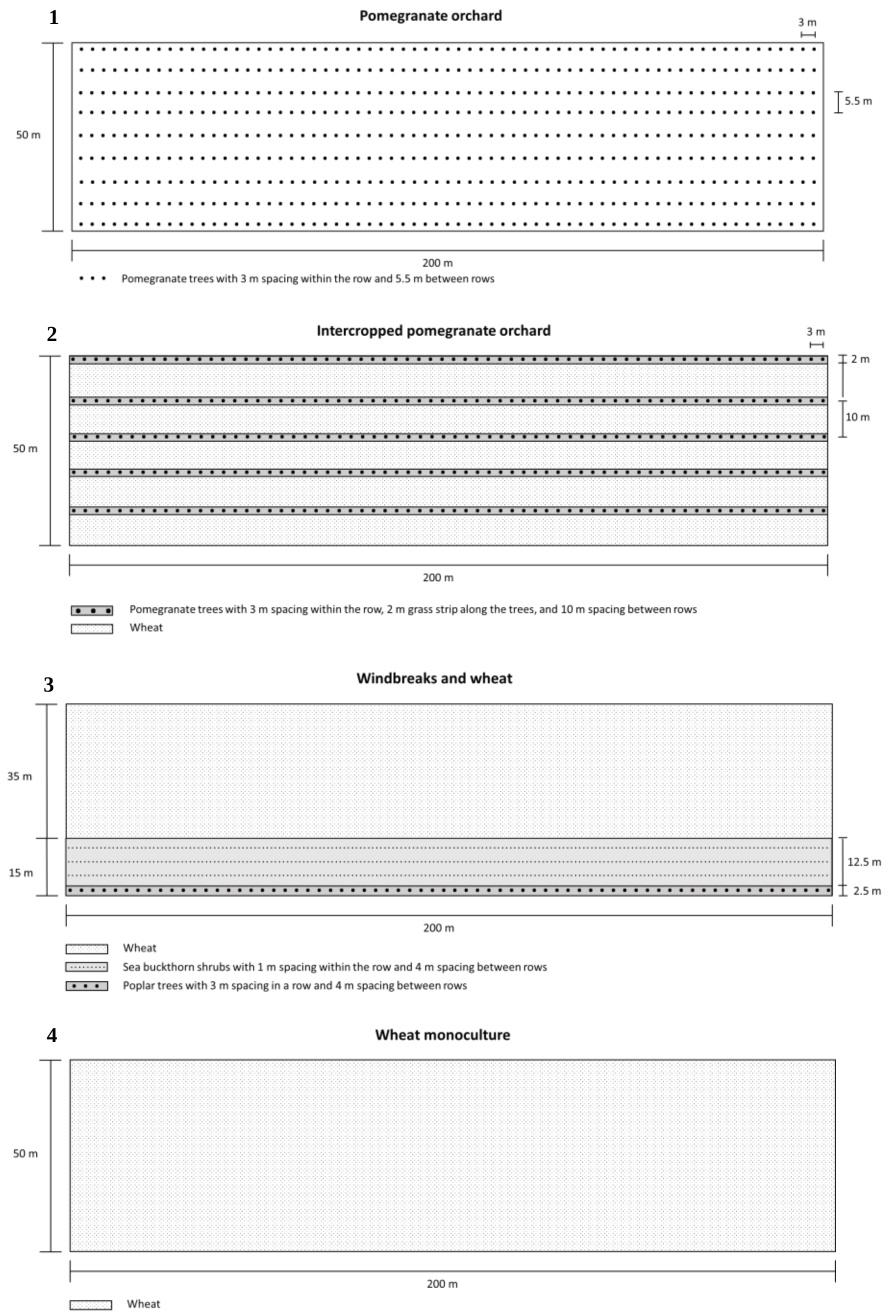


**Figure A3. Field design of four scenarios analysed at an area of 1 ha: (1) pomegranate orchard, (2) pomegranate intercropped with wheat, (3) windbreaks with wheat, (4) wheat monoculture**

## Appendix 4: Images from on-site visit of FTZ team in Azerbaijan

**Figure A4.1. Pomegranate orchard, Azerbaijan** Source: FTZ team (2021)

**Figure A4.2. Windbreaks in Azerbaijani lowlands** Source: FTZ team (2021)

**Figure A4.3. Land affected by salinisation, Azerbaijan** Source: FTZ team (2021)

**Figure A4.4. Field visit of FTZ team in Azerbaijan** Source: FTZ team (2021)

**Figure A4.5. Meeting of FTZ team with experts, Azerbaijan** Source: FTZ team (2021)

**Figure A4.6. Meeting of FTZ team with farmers, Azerbaijan** Source: FTZ team (2021)

## Appendix 5: Questionnaire on climate change in Azerbaijan

This survey aims to uncover your perception on climate change and the application rate of adaptation/mitigation strategies connected to climate change. Additional questions were included to identify perceived barriers to climate change adaptation/mitigation and how climate change impacts your economic performance as a farmer.

**A. Climate change effects and awareness**

| 1. Do you believe that your farm operations are affected by climate change? | | | | |
|---|---|---|---|---|
| Not at all ☒ | Not really ☐ | Somewhat ☐ | Yes ☐ | Strongly yes ☐ |

| 2. Are you concerned about your future as farmer in the face of climate change? | | |
|---|---|---|
| Not concerned ☐ | Somewhat concerned ☐ | Highly concerned ☐ |

| 3. How important is use of climate change adaptation strategies for your farm? | |
|---|---|
| Pls indicate on a five-point scale: 0-not important at all- 1,2,3 -4 very important: | |
| 4. How important is use of climate change mitigation strategies (to help to reduce the occurrence of climate change globally) for your farm? | |
| Pls indicate on a five-point scale: 0-not important at all- 1,2,3 -4 very important: | |

| 5. Do you agree with the following statements? | | | | | |
|---|---|---|---|---|---|
| Statement/Category | Strongly agree | Agree | Neutral | Disagree | Strongly disagree |
| Climate change is a serious problem affecting agricultural production at our farm | ☐ | ☐ | ☐ | ☐ | ☐ |
| Water erosion has occurred more frequently than before in recent years | ☐ | ☐ | ☐ | ☐ | ☐ |
| Wind erosion has occurred more frequently than before in recent years | ☐ | ☐ | ☐ | ☐ | ☐ |
| The effects of climate change on agricultural production can be reduced by technology change | ☐ | ☐ | ☐ | ☐ | ☐ |

| 6. Please indicate the severity of the following climate change effects on your farm | | | | | |
|---|---|---|---|---|---|
| Effects/Impact | Very low | Low | Medium | High | Very high |
| Increasing temperature during the growing season | ☐ | ☐ | ☐ | ☐ | ☐ |
| Changes in precipitation distribution during the growing season | ☐ | ☐ | ☐ | ☐ | ☐ |
| Increasing variability of temperatures and precipitation | ☐ | ☐ | ☐ | ☐ | ☐ |
| Higher incidence of extreme events (e.g drought, heavy rainfalls, floods) | ☐ | ☐ | ☐ | ☐ | ☐ |
| Decreasing of water availability in growing season | ☐ | ☐ | ☐ | ☐ | ☐ |
| Shorter growing cycles | ☐ | ☐ | ☐ | ☐ | ☐ |

| | | | | | |
|---|---|---|---|---|---|
| Changes in sowing dates | ☐ | ☐ | ☐ | ☐ | ☐ |
| Changes in harvest dates | ☐ | ☐ | ☐ | ☐ | ☐ |
| Crop pest and disease outbreak | ☐ | ☐ | ☐ | ☐ | ☐ |
| Livestock pest and disease outbreak | ☐ | ☐ | ☐ | ☐ | ☐ |

## B. Application of climate change adaptation technologies, and barriers

| 1. Do you know and use following technologies related to Climate Change? | Have you heard about this technology/ approach before? | If you use it, pls indicate how many years already | Not applied but I am planning to do so within 3 years' time | Not applied, planned for later or not planned at all | If you use it, is climate change an important reason why you use the technology? | | |
|---|---|---|---|---|---|---|---|
| | Indicate if yes | years | | | yes | partly | no |
| Windbreaks | ☐ | | ☐ | ☐ | ☐ | ☐ | ☐ |
| Trees on pastures | ☐ | | ☐ | ☐ | ☐ | ☐ | ☐ |
| Fruits orchards | ☐ | | ☐ | ☐ | ☐ | ☐ | ☐ |

2. What are the main reasons that it is not feasible for you to use the following technologies/strategies at all or not in full extend?
Pls indicate on a five-point scale: 0-very important reason – 2,3,4- not important reason at all

| Technology/Reason | Lack of financial resources | Lack of information | It is not economically viable (high cost/low benefit) | Too difficult to implement | I do not believe it has a significant effect | Other, pls mention which |
|---|---|---|---|---|---|---|
| Windbreaks | | | | | | |
| Trees on pastures | | | | | | |
| Fruits orchards | | | | | | |

**3. Do you agree that use of following technologies is feasible in your district?**

| | Strongly agree | Agree | Undecided | Disagree | Strongly disagree | If bad or very bad, what is the main reason in your opinion? |
|---|---|---|---|---|---|---|
| Windbreaks | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Fruit orchards | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Trees on pastures | ☐ | ☐ | ☐ | ☐ | ☐ | |

## C. Socio-demographic, economic and farm's characteristics

| Please indicate your gender: | | | | |
|---|---|---|---|---|
| Male ☐ | Female ☐ | | | |
| Please indicate your current age (years): | | | | |
| How many years do you already work in agriculture? : | | | | |
| Please indicate the degree of your school education | | | | |
| No school ☐ | Primary School ☐ | Secondary School ☐ | University Degree ☐ | Other ☐ |

**Please indicate the ratio of crop to animal production on your farm in (%):**

| |
|---|
| Please indicate the agricultural land size of your farm (in ha): |
| Pls indicate the size of arable land (in ha): |

| |
|---|
| Pls indicate the size of pastures (in ha): |
| Pls indicate the length of windbreaks at your farm (in m)?: |
| Pls indicate the size of land used for trees on pastures (in ha)?: |
| Pls indicate the size of land used for fruit orchards (in ha)?: |
| Please indicate the size of your farm land that is irrigated (in ha): |

| | |
|---|---|
| Pls indicate the size of land that is rented (ha)? | |

**Which crops did you grow at your enterprise in 2021? Please, indicate approximately.**

| | | | |
|---|---|---|---|
| Wheat | _______ha | Beans (peas, soybeans etc) | _______ha |
| Vegetable | _______ha | Fruits | _______ha |
| Sunflower | _______ha | Fallow | _______ha |
| Cotton | _______ha | Other ___________ | _______ha |

**Animal production**

| Animal | Number |
|---|---|
| Cattle | |
| Sheep | |
| Goat | |
| Poultry | |
| Pigs | |
| Horses | |
| Buffaloes | |

# Appendix 6: Cost-benefit analysis

## Table A6.1. Net present value (AZN) of 1 ha of pomegranate orchard over 20 years at 10% and 20% discount rate

| Pomegranate | | | Discount factor (q) i = 10% | | | | Discount factor (q) i = 20% | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year (t) | Costs (C) | Benefits (B) | $q^t$ | $C_t/q^t$ | $B_t/q^t$ | NPV | $q^t$ | $C_t/q^t$ | $B_t/q^t$ | NPV |
| **1** | 27,783 | 3,200 | 1.10 | 25,258 | 2,909 | -22,349 | 1.20 | 23,153 | 2,666 | -20,486 |
| **2** | 12,641 | 200 | 1.21 | 10,447 | 165 | -10,282 | 1.44 | 8,778 | 139 | -8,640 |
| **3** | 14,009 | 9,580 | 1.33 | 10,525 | 7,197 | -3,328 | 1.73 | 8,107 | 5,544 | -2,563 |
| **4** | 14,615 | 19,081 | 1.46 | 9,982 | 13,033 | 3,051 | 2.07 | 7,048 | 9,202 | 2,154 |
| **5** | 15,362 | 31,809 | 1.61 | 9,538 | 19,751 | 10,212 | 2.49 | 6,174 | 12,783 | 6,610 |
| **6** | 15,362 | 31,809 | 1.77 | 8,671 | 17,955 | 9,284 | 2.99 | 5,145 | 10,653 | 5,508 |
| **7** | 15,362 | 31,809 | 1.95 | 7,883 | 16,323 | 8,440 | 3.58 | 4,287 | 8,877 | 4,590 |
| **8** | 15,362 | 31,809 | 2.14 | 7,166 | 14,839 | 7,673 | 4.30 | 3,573 | 7,398 | 3,825 |
| **9** | 15,362 | 31,809 | 2.36 | 6,515 | 13,490 | 6,975 | 5.16 | 2,977 | 6,165 | 3,188 |
| **10** | 15,362 | 31,809 | 2.59 | 5,923 | 12,264 | 6,341 | 6.19 | 2,481 | 5,137 | 2,656 |
| **11** | 15,362 | 31,809 | 2.85 | 5,384 | 11,149 | 5,765 | 7.43 | 2,067 | 4,281 | 2,214 |
| **12** | 15,362 | 31,809 | 3.14 | 4,895 | 10,135 | 5,240 | 8.92 | 1,723 | 3,568 | 1,845 |
| **13** | 15,362 | 31,809 | 3.45 | 4,450 | 9,214 | 4,764 | 10.70 | 1,436 | 2,973 | 1,537 |
| **14** | 15,362 | 31,809 | 3.80 | 4,045 | 8,376 | 4,331 | 12.84 | 1,196 | 2,477 | 1,281 |
| **15** | 15,362 | 31,809 | 4.18 | 3,677 | 7,615 | 3,937 | 15.41 | 997 | 2,065 | 1,067 |
| **16** | 15,362 | 31,809 | 4.59 | 3,343 | 6,922 | 3,579 | 18.49 | 831 | 1,720 | 890 |
| **17** | 15,362 | 31,809 | 5.05 | 3,039 | 6,293 | 3,254 | 22.19 | 692 | 1,434 | 741 |
| **18** | 15,362 | 31,809 | 5.56 | 2,763 | 5,721 | 2,958 | 26.62 | 577 | 1,195 | 618 |
| **19** | 15,362 | 31,809 | 6.12 | 2,512 | 5,201 | 2,689 | 31.95 | 481 | 996 | 515 |
| **20** | 15,362 | 31,809 | 6.73 | 2,283 | 4,728 | 2,445 | 38.34 | 401 | 830 | 429 |
| **Total** | **314,835** | **540,998** | **63** | **138,300** | **193,279** | **54,980** | **224** | **82,124** | **90,101** | **7,978** |

## Table A6.2. Net present value (AZN) of 1 ha of intercropped pomegranate orchard (pomegranate & wheat) over 20 years at 10% and 20% discount rate

| Pomegranate & wheat | | | Discount factor (q) i = 10% | | | | Discount factor (q) i = 20% | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year (t) | Costs (C) | Benefits (B) | $q^t$ | $C_t/q^t$ | $B_t/q^t$ | NPV | $q^t$ | $C_t/q^t$ | $B_t/q^t$ | NPV |
| **1** | 16,529 | 2,050 | 1.10 | 15,027 | 1,863 | -13,164 | 1.20 | 13,775 | 1,708 | -12,067 |
| **2** | 8,248 | 2,050 | 1.21 | 6,817 | 1,694 | -5,123 | 1.44 | 5,728 | 1,423 | -4,305 |
| **3** | 8,983 | 7,210 | 1.33 | 6,749 | 5,417 | -1,332 | 1.73 | 5,198 | 4,172 | -1,026 |
| **4** | 9,332 | 12,350 | 1.46 | 6,374 | 8,435 | 2,061 | 2.07 | 4,500 | 5,956 | 1,455 |
| **5** | 9,719 | 19,230 | 1.61 | 6,035 | 11,940 | 5,905 | 2.49 | 3,906 | 7,728 | 3,822 |
| **6** | 9,719 | 19,230 | 1.77 | 5,486 | 10,855 | 5,368 | 2.99 | 3,255 | 6,440 | 3,185 |
| **7** | 9,719 | 19,230 | 1.95 | 4,987 | 9,868 | 4,880 | 3.58 | 2,712 | 5,367 | 2,654 |
| **8** | 9,719 | 19,230 | 2.14 | 4,534 | 8,971 | 4,437 | 4.30 | 2,260 | 4,472 | 2,212 |
| **9** | 9,719 | 19,230 | 2.36 | 4,122 | 8,155 | 4,033 | 5.16 | 1,884 | 3,727 | 1,843 |
| **10** | 9,719 | 19,230 | 2.59 | 3,747 | 7,414 | 3,667 | 6.19 | 1,570 | 3,106 | 1,536 |
| **11** | 9,719 | 19,230 | 2.85 | 3,406 | 6,740 | 3,333 | 7.43 | 1,308 | 2,588 | 1,280 |
| **12** | 9,719 | 19,230 | 3.14 | 3,097 | 6,127 | 3,030 | 8.92 | 1,090 | 2,157 | 1,067 |
| **13** | 9,719 | 19,230 | 3.45 | 2,815 | 5,570 | 2,755 | 10.70 | 908 | 1,797 | 889 |
| **14** | 9,719 | 19,230 | 3.80 | 2,559 | 5,064 | 2,504 | 12.84 | 757 | 1,498 | 741 |
| **15** | 9,719 | 19,230 | 4.18 | 2,327 | 4,603 | 2,277 | 15.41 | 631 | 1,248 | 617 |
| **16** | 9,719 | 19,230 | 4.59 | 2,115 | 4,185 | 2,070 | 18.49 | 526 | 1,040 | 514 |
| **17** | 9,719 | 19,230 | 5.05 | 1,923 | 3,804 | 1,882 | 22.19 | 438 | 867 | 429 |
| **18** | 9,719 | 19,230 | 5.56 | 1,748 | 3,459 | 1,711 | 26.62 | 365 | 722 | 357 |
| **19** | 9,719 | 19,230 | 6.12 | 1,589 | 3,144 | 1,555 | 31.95 | 304 | 602 | 298 |
| **20** | 9,719 | 19,230 | 6.73 | 1,445 | 2,858 | 1,414 | 38.34 | 254 | 502 | 248 |
| **Total** | **198,598** | **331,332** | **63** | **86,902** | **120,166** | **33,264** | **224** | **51,369** | **57,119** | **5,750** |

## Table A6.3. Net present value (AZN) of 1 ha of windbreaks with wheat over 20 years at 10% and 20% discount rate

| Windbreaks & wheat | | | Discount factor (q) i = 10% | | | | Discount factor (q) i = 20% | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year (t) | Costs (C) | Benefits (B) | $q^t$ | $C_t/q^t$ | $B_t/q^t$ | NPV | $q^t$ | $C_t/q^t$ | $B_t/q^t$ | NPV |
| **1** | 10,021 | 1,793 | 1.10 | 9,110 | 1,630 | -7,479 | 1.20 | 8,351 | 1,495 | -6,856 |
| **2** | 2,813 | 3,158 | 1.21 | 2,324 | 2,610 | 286 | 1.44 | 1,953 | 2,193 | 240 |
| **3** | 3,175 | 4,742 | 1.33 | 2,385 | 3,563 | 1,178 | 1.73 | 1,837 | 2,744 | 907 |
| **4** | 3,898 | 7,472 | 1.46 | 2,663 | 5,104 | 2,441 | 2.07 | 1,880 | 3,604 | 1,724 |
| **5** | 3,898 | 7,472 | 1.61 | 2,421 | 4,640 | 2,219 | 2.49 | 1,567 | 3,003 | 1,436 |
| **6** | 3,898 | 7,472 | 1.77 | 2,201 | 4,218 | 2,017 | 2.99 | 1,306 | 2,502 | 1,197 |
| **7** | 3,898 | 7,472 | 1.95 | 2,000 | 3,835 | 1,834 | 3.58 | 1,088 | 2,085 | 997 |
| **8** | 3,898 | 7,472 | 2.14 | 1,819 | 3,486 | 1,667 | 4.30 | 907 | 1,738 | 831 |
| **9** | 3,898 | 7,472 | 2.36 | 1,653 | 3,169 | 1,516 | 5.16 | 756 | 1,448 | 693 |
| **10** | 3,898 | 7,472 | 2.59 | 1,503 | 2,881 | 1,378 | 6.19 | 630 | 1,207 | 577 |
| **11** | 3,898 | 7,472 | 2.85 | 1,366 | 2,619 | 1,253 | 7.43 | 525 | 1,006 | 481 |
| **12** | 3,898 | 7,472 | 3.14 | 1,242 | 2,381 | 1,139 | 8.92 | 437 | 838 | 401 |
| **13** | 3,898 | 7,472 | 3.45 | 1,129 | 2,164 | 1,035 | 10.70 | 364 | 698 | 334 |
| **14** | 3,898 | 7,472 | 3.80 | 1,027 | 1,968 | 941 | 12.84 | 304 | 582 | 278 |
| **15** | 3,898 | 7,472 | 4.18 | 933 | 1,789 | 856 | 15.41 | 253 | 485 | 232 |
| **16** | 3,898 | 7,472 | 4.59 | 848 | 1,626 | 778 | 18.49 | 211 | 404 | 193 |
| **17** | 3,898 | 7,472 | 5.05 | 771 | 1,478 | 707 | 22.19 | 176 | 337 | 161 |
| **18** | 3,898 | 7,472 | 5.56 | 701 | 1,344 | 643 | 26.62 | 146 | 281 | 134 |
| **19** | 3,898 | 7,472 | 6.12 | 637 | 1,222 | 584 | 31.95 | 122 | 234 | 112 |
| **20** | 3,898 | 7,472 | 6.73 | 579 | 1,111 | 531 | 38.34 | 102 | 195 | 93 |
| **Total** | **82,280** | **136,724** | **63** | **37,313** | **52,837** | **15,524** | **224** | **22,912** | **27,079** | **4,167** |

## Table A6.4. Net present value of wheat monoculture over 20 years at 10% and 20% discount rate

| Wheat | | | Discount factor (q) i = 10% | | | | Discount factor (q) i = 20% | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year (t) | Costs (C) | Benefits (B) | $q^t$ | $C_t/q^t$ | $B_t/q^t$ | NPV | $q^t$ | $C_t/q^t$ | $B_t/q^t$ | NPV |
| **1** | 3,251 | 2,591 | 1.10 | 2,955 | 2,355 | -600 | 1.20 | 2,709 | 2,159 | -550 |
| **2** | 1,381 | 2,591 | 1.21 | 1,141 | 2,141 | 1,000 | 1.44 | 959 | 1,799 | 840 |
| **3** | 1,381 | 2,591 | 1.33 | 1,037 | 1,947 | 909 | 1.73 | 799 | 1,499 | 700 |
| **4** | 1,381 | 2,591 | 1.46 | 943 | 1,770 | 827 | 2.07 | 666 | 1,250 | 584 |
| **5** | 1,381 | 2,591 | 1.61 | 857 | 1,609 | 751 | 2.49 | 555 | 1,041 | 486 |
| **6** | 1,381 | 2,591 | 1.77 | 779 | 1,463 | 683 | 2.99 | 462 | 868 | 405 |
| **7** | 1,381 | 2,591 | 1.95 | 709 | 1,330 | 621 | 3.58 | 385 | 723 | 338 |
| **8** | 1,381 | 2,591 | 2.14 | 644 | 1,209 | 565 | 4.30 | 321 | 603 | 281 |
| **9** | 1,381 | 2,591 | 2.36 | 586 | 1,099 | 513 | 5.16 | 268 | 502 | 235 |
| **10** | 1,381 | 2,591 | 2.59 | 532 | 999 | 467 | 6.19 | 223 | 418 | 195 |
| **11** | 1,381 | 2,591 | 2.85 | 484 | 908 | 424 | 7.43 | 186 | 349 | 163 |
| **12** | 1,381 | 2,591 | 3.14 | 440 | 826 | 386 | 8.92 | 155 | 291 | 136 |
| **13** | 1,381 | 2,591 | 3.45 | 400 | 751 | 351 | 10.70 | 129 | 242 | 113 |
| **14** | 1,381 | 2,591 | 3.80 | 364 | 682 | 319 | 12.84 | 108 | 202 | 94 |
| **15** | 1,381 | 2,591 | 4.18 | 331 | 620 | 290 | 15.41 | 90 | 168 | 79 |
| **16** | 1,381 | 2,591 | 4.59 | 300 | 564 | 263 | 18.49 | 75 | 140 | 65 |
| **17** | 1,381 | 2,591 | 5.05 | 273 | 513 | 239 | 22.19 | 62 | 117 | 55 |
| **18** | 1,381 | 2,591 | 5.56 | 248 | 466 | 218 | 26.62 | 52 | 97 | 45 |
| **19** | 1,381 | 2,591 | 6.12 | 226 | 424 | 198 | 31.95 | 43 | 81 | 38 |
| **20** | 1,381 | 2,591 | 6.73 | 205 | 385 | 180 | 38.34 | 36 | 68 | 32 |
| **Total** | **29,485** | **51,820** | **63** | **13,455** | **22,059** | **8,604** | **224** | **8,282** | **12,617** | **4,335** |

## Appendix 7: Results of quantitative questionnaire survey

**Table A7.1. Summary of descriptive statistics of the sample**

| | | Gender | Age (years) | Highest formal education | Years of work in agriculture |
|---|---|---|---|---|---|
| N | Valid | 117 | 117 | 117 | 109 |
| | Missing | 0 | 0 | 0 | 8 |
| | Mode | 1 (male) | 44 | 3 (University degree) | 20 |
| | Mean | | 45.07<br>Min: 25<br>Max: 77 | | 17.27<br>Min: 2<br>Max: 40 |

Notes: Mode represents the most frequent value. Mean represents an average value.

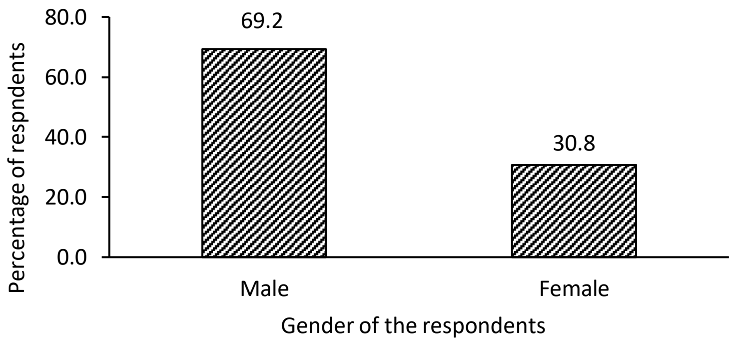


**Figure A7.1. Gender of the respondents**

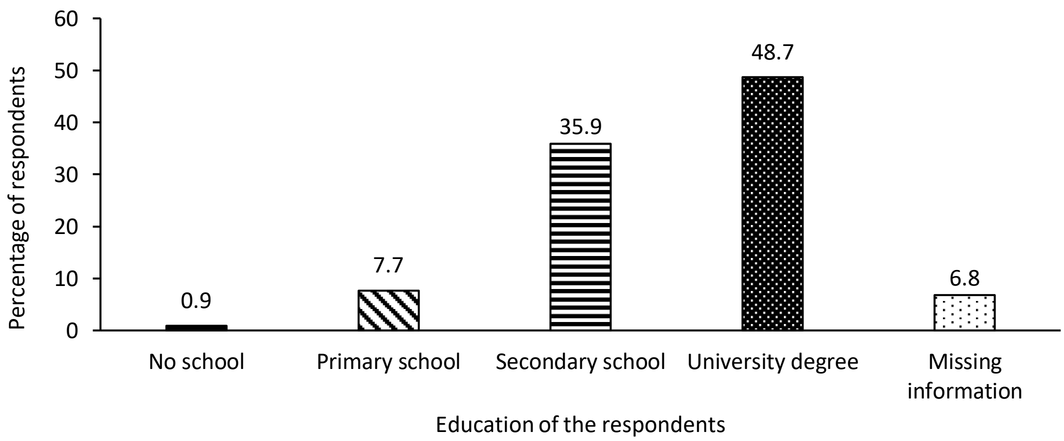


**Figure A7.2. Education of the respondents**

**Table A7.2. Agricultural land of respondents (ha): A. Total crop cultivation, B. Wheat cultivation, C. Fruit cultivation, D. Vegetable cultivation**

| A. Farm agricultural land | Farmers (%) | | |
|---|---|---|---|
| **Area (ha)** | **Arable land** | **Crop cultivation area** | **Irrigated land** |
| **0** | 0 | 0 | 11.1 |
| **≤ 1** | 51.3 | 64.1 | 0.9 |
| **1.1 - 5 ha** | 22.2 | 14.5 | 70.0 |
| **5.1 - 10 ha** | 17.9 | 13.7 | 11.1 |
| **> 10 ha** | 8.5 | 7.7 | 6.8 |

| B. Wheat cultivation | |
|---|---|
| **Area (ha)** | **Farmers (%)** |
| **0** | 68.4 |
| **0.1 - 5** | 13.7 |
| **5.1 - 10** | 13.7 |
| **> 10** | 4.2 |

| C. Fruit cultivation | |
|---|---|
| **Area (ha)** | **Farmers (%)** |
| **0** | 7.7 |
| **≤ 0.4** | 88.9 |
| **≥ 2** | 3.4 |

| D. Vegetable cultivation | |
|---|---|
| **Area (ha)** | **Farmers (%)** |
| **≤ 0.5** | 96.6 |
| **> 0.5** | 3.4 |

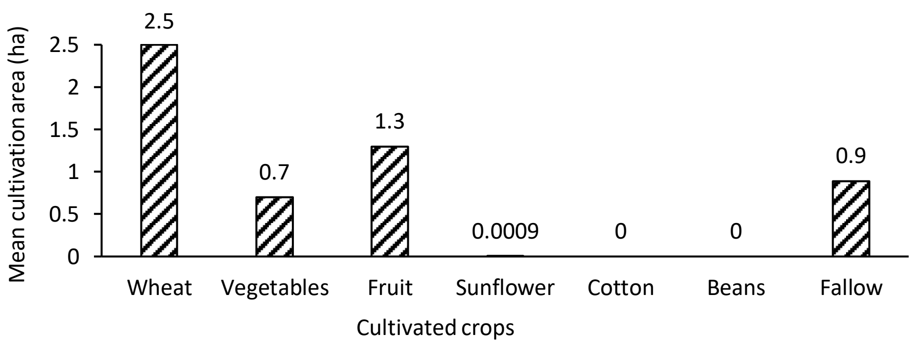


**Figure A7.3. The mean crop cultivation area and fallow (ha)**

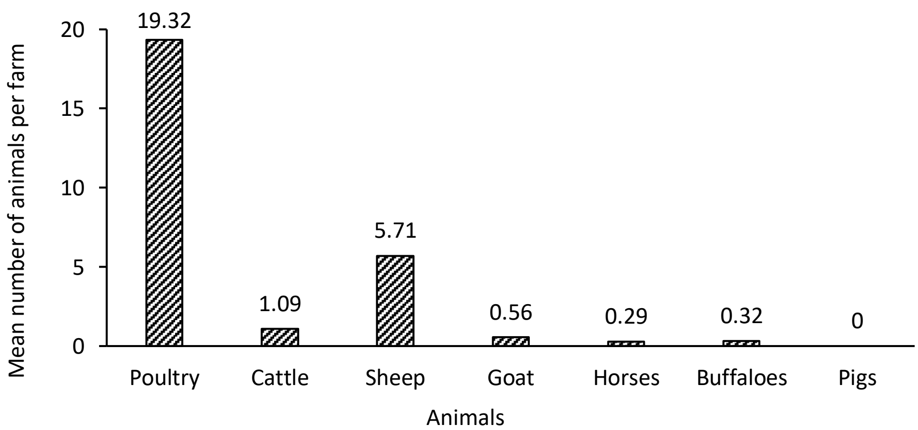


**Figure A7.4. The mean number of animals per farm**

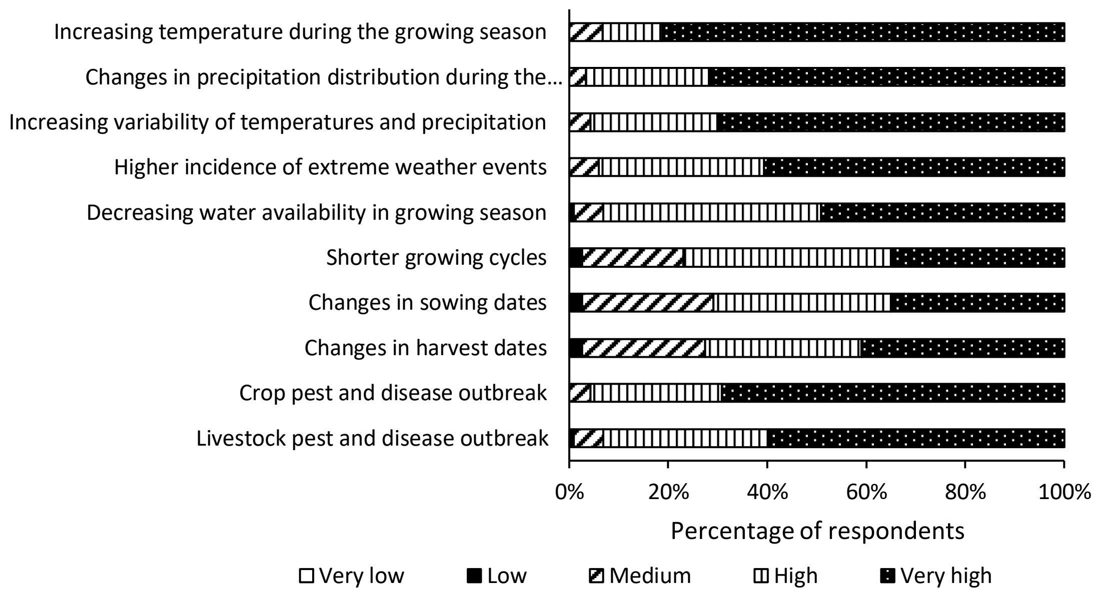


**Figure A7.5. The severity of the climate change effects perceived by the farmers**

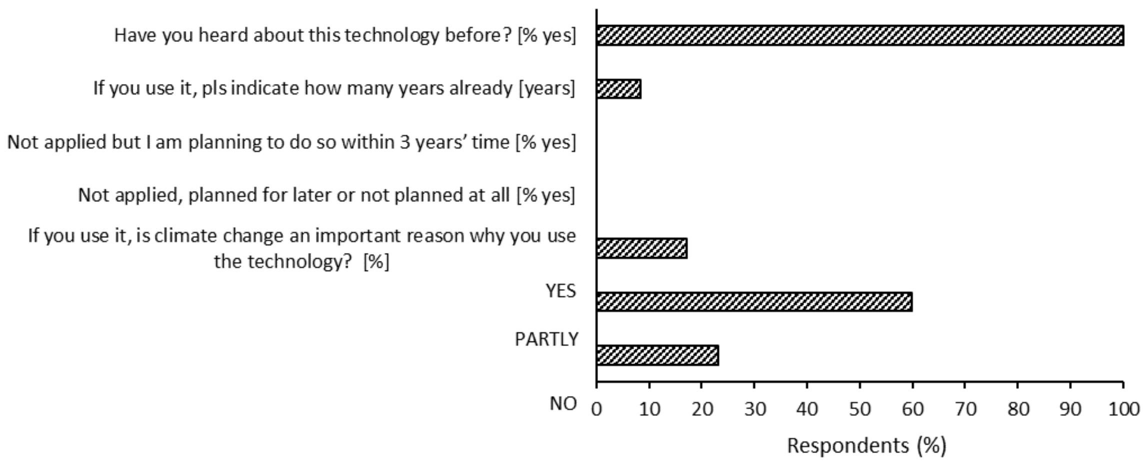


**Figure A7.6. Awareness of respondents and use of fruit orchards**

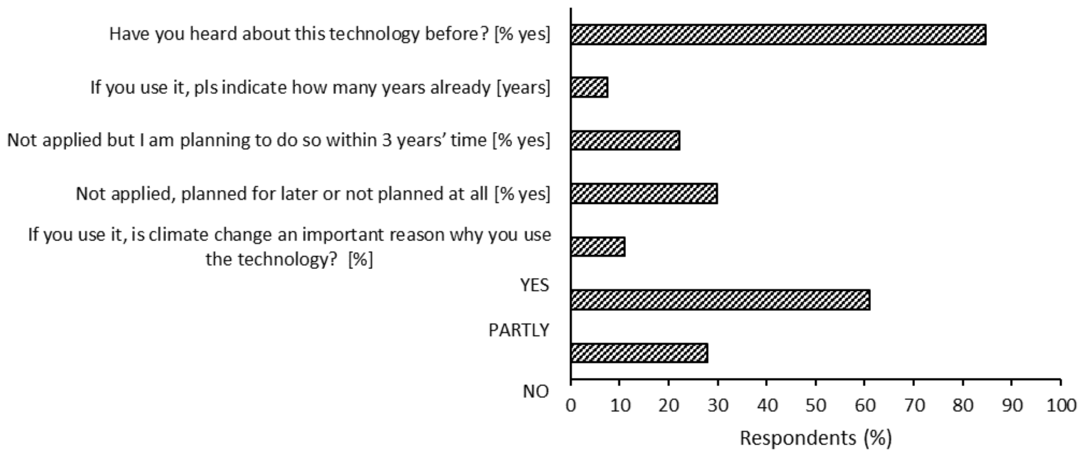

**Figure A7.7. Awareness of respondents and use of windbreaks**

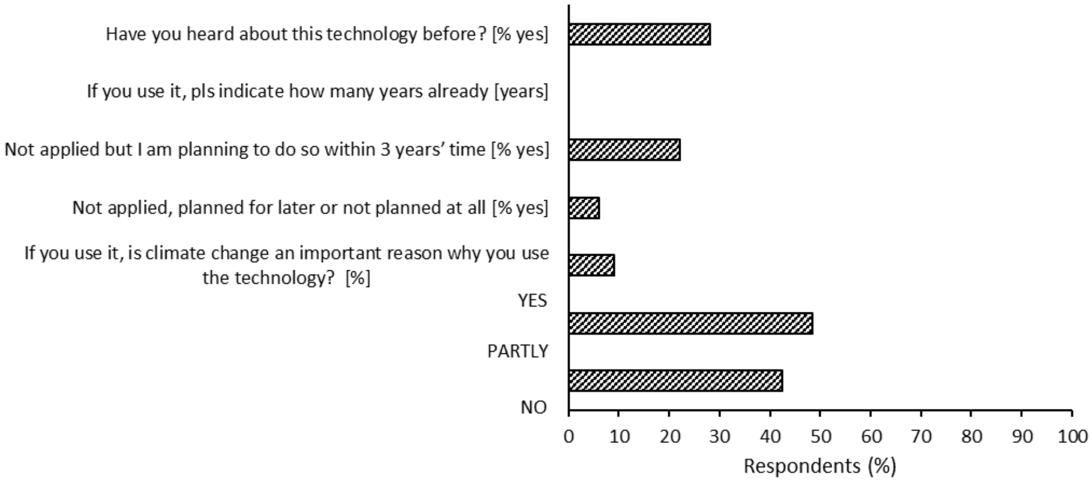


**Figure A7.8 Awareness of respondents and the use of trees on pastures**