

The Nexus Between Agriculture, Cattle Breeding and Climate Change in The Island of Crete, Greece

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ABSTRACT: Climate change threatens human prosperity as it affects many economic sectors including food production. Agriculture, cattle breeding and climate change are interrelated and interconnected affecting each other. Agriculture in Crete was in the past an important pillar in the local economy while nowadays its role has been decreased. The linkages between food production and climate change in the island of Crete, Greece have been analyzed. It has been indicated that climate change affects crops, trees and cattle breeding in Crete. These impacts are mainly negative while the increase in atmospheric CO₂ concentration has positive impacts on plants' photosynthesis and pastures' productivity. Current agricultural and cattle breeding practices in the island have negative impacts on climate change increasing the emissions of greenhouse gases such as CO₂, CH₄, N₂O and NH₃. Therefore, climate change and food production in Crete are interconnected and interlinked affecting each other. Therefore, there is urgent need to develop policies and measures to reduce the impacts of agriculture and cattle breeding on climate change in the island and adapt the local food production systems to the new climate conditions. Our results could be useful to policy makers, public authorities and to all stakeholders of food production systems in the island.

KEYWORDS: Agriculture, Cattle Breeding, Climate Change, Crete-Greece, Interrelation, Nexus.

1. INTRODUCTION

Climate change consists of the main environmental challenge in our era which affects and is affected by agriculture and cattle breeding [1], [2], [3], [4], [5]. Several agriculture crops are cultivated in Crete nowadays while sheep and goat breeding is developed in the island [6]. The agricultural sector is an important economic sector in many countries as well as in Crete which is negatively affected by climate change and extreme weather events [7], [8], [9], [10], [11]. Agriculture and cattle breeding contribute in the emission of significant amounts of greenhouse gases (GHGs) including CO₂, CH₄, NH₃ and N₂O [12], [13], [14]. These facts necessitate the development of policies and measures for climate change mitigation and adaptation in agriculture and cattle breeding in Crete [15], [16], [17], [18].

The aim of the present work is the study of the mutual interrelation between climate change, agriculture and cattle breeding in the island of Crete, Greece.

The text is structured as follows. After the literature survey the sectors of agriculture and cattle breeding in the island as well as the characteristics of climate change in Crete are described. Next, the impacts of Cretan agriculture and cattle breeding on climate change are mentioned. After that, the impacts of climate change on agriculture and cattle breeding in Crete are analyzed. The text ends with discussion of the findings, the conclusions drawn and the citation of the references used.

The work is innovative since there are no many studies related with the mutual relations between climate change,

agriculture and cattle breeding in Crete while it covers an existing gap on this topic. The results could be useful to policy makers, local and municipal authorities as well as to organizations and companies related to agriculture and cattle breeding in Crete.

2. LITERATURE SURVEY

The implications of climate change on agriculture in the early 21st century have been studied [1]. The authors stated that anthropogenic GHG emissions and climate change have several implications in agricultural productivity but their aggregate impacts are not precisely known. They mentioned that currently it is not possible to provide a robust assessment of the impacts of climate change on agriculture. The relation between climate change and agriculture has been reviewed [2]. The authors stated that the overall impacts of climate change on agriculture are not yet clear. They mentioned that the increase in atmospheric CO₂ concentration increases plant photosynthesis and productivity which is counter-balanced by several negative impacts. The impact of climate change on agriculture in Pakistan has been reviewed [3]. The authors stated that climate change has many effects on agriculture. They mentioned that adaptation methods are critical for strengthening the resilience in agricultural systems. The impact of climate change on agriculture has been explored [4]. The authors stated that the implications are profound. They mentioned that food production chains are extremely sensitive to climate change. The effects of climate change on agriculture in USA and their assessment have been examined

[5]. It is stated that increases in atmospheric CO₂ concentration, rising temperatures and altered precipitation patterns will affect agricultural productivity. It is mentioned that increasing extreme weather events will have a higher negative influence on agricultural productivity while livestock production systems are vulnerable to heat stresses. The food production system including crops, trees and cattle's breeding in Crete has been reported [6]. The nexus between climate change and agricultural sustainability has been examined [7]. The author stated that water, energy and food systems are interconnected and climate change affects agriculture while the intensive practices in agriculture affect the climate. She mentioned that the complexities of the interconnections should be understood and the challenge of adaptation should be accepted. The nexus between climate change and food security has been explored [8]. The authors stated that increase in food production negatively affects climate change. They proposed to start substantial changes in agricultural production to reduce carbon emissions using environmentally friendly production processes. A report regarding the impacts of climate change on agriculture has been published [9]. The report stated that the new climate conditions will reduce the yields of several crops such as maize and wheat in Europe. It is also mentioned that the water scarcity in Mediterranean countries is going to intensify. A report assessing the impacts of climate change on agricultural sector in the southern Mediterranean region has been published [10]. The report stated that the quantity and quality of the cultivated crops as well as the water availability are negatively affected by climate change. It is mentioned that there are various types of farming systems in the region that will be differently impacted by climate change. The impacts of climate change on agriculture in Latin America and the Caribbean have been studied [11]. The authors stated that climate change will have negative impacts on agricultural productivity in 20 countries studied except Argentina, Brazil and Uruguay which are soybean producers. They also mentioned that in some countries the impacts of climate change will be more intense. The nexus between climate change and agriculture soil emissions has been studied [12]. The authors investigated the effect of land temperature, fertilizer consumption, crop and livestock production and energy use on GHG emissions of agricultural soils. They stated that there is a mutual link between climate change and soil emissions while the adoption of sustainable agricultural practices can reduce soil emissions. The relation between modern cattle breeding and climate change has been examined [13]. The authors stated that animal husbandry is a significant source of anthropogenic GHG emissions. They mentioned that climate change affects livestock production by increasing the frequency of animal diseases, changing several environmental factors and impacting on grassland composition. The climate change consequences on agriculture and food security have been explored [14]. The authors stated that climate change increases the frequency and intensity of droughts, floods and storms making worse

the risk of hunger. They mentioned that climate change affects all dimensions of food security and nutrition. The impacts of climate change on global agriculture have been studied [15]. The authors stated that climate change threatens the global food systems but it is not clear the extent to which adaptation will reduce losses. They estimated a global production decline at 120 Kcal per person per day for 1°C rise of the mean global surface temperature. The impacts of climate change on agriculture have been studied [16]. The authors stated that agriculture accounts for approximately 10% - 12% of the total anthropogenic GHG emissions while it accounts for 60% of N₂O and 50% of CH₄ emissions. They mentioned that successful adaptation should take into account the effectiveness, efficiency, equity and legitimacy of actions and policies. A review on the nexus of agriculture and climate change has been conducted [17]. The authors stated that agriculture is highly vulnerable to climate-induced stresses while predictions indicate that the yield of several crops might decline by up to 30%. They proposed several innovative approaches including the development of climate-smart agriculture, improved water and soil management and the use of stress-tolerant crop varieties for enhancing agriculture resilience. The impacts of climate change on agricultural productivity have been reviewed [18]. The authors stated that low-income countries lack the necessary infrastructure to adapt their agriculture to climate change compared to developed countries. They mentioned that climate change has a significantly negative role on agriculture on low-income countries and mitigation and adaptation measures should be urgently taken. The future climate change stresses on agriculture have been studied [19]. The authors stated that climate change severely affects food security. They mentioned that the more severe issue that will cause significant yield losses is insect outbreak due to abrupt climate change. The nexus among climate change, sustainable agriculture and farm livelihood has been investigated [20]. The authors stated that in countries dependent on agrarian economy the adoption of a balanced mix of adaptation measures is necessary to derisk the vulnerable farm livelihoods and to reroute them towards smart interventions increasing resilience in the agricultural sector. The agricultural adaptation to climate change has been assessed [21]. The authors studied several adaptation interventions including agronomic measures, genetic improvements and combination of individual adaptations. They stated that these interventions can compensate for crop yield losses to some extent. The role of technological development for sustainable agriculture in Vietnam has been analyzed [22]. The authors stated that crops' productivity is negatively impacted by climate change. However, the use of fertilizers and pesticides has the potential to enhance agricultural yield. The nexus between agriculture and climate change in Bangladesh has been explored [23]. The authors stated that climate change has undesired impacts on weather-dependent agriculture in the country. They proposed the use of improved tolerant seedlings and improved irrigation

systems as well as the use of chemical fertilizers and pesticides to offset the harmful impacts of climate change on agricultural productivity. The technological interventions in agriculture to reduce the impact of climate change have been investigated [24]. The authors stated that several climate-friendly technologies can be used in agriculture to combat the effects of climate change. These include the development of stress-tolerant crop varieties, soil health improvements, agroforestry systems, drip irrigation, zero tillage, use of renewable energies, integrated pest management et cetera. The integration of water, energy and agriculture in climate change in South Africa has been studied [25]. The authors stated that Southern Africa is highly exposed to climate change and its undesired impacts on water resources and agricultural production. They mentioned that climate change will reduce agricultural productivity by 15%-50% by 2080. The bidirectional nexus between climate change and agriculture has been evaluated [26]. The authors stated that rising sea levels and global temperature increases have adverse impacts on crops' productivity while increase in atmospheric CO₂ concentration boosts it. They mentioned that agriculture is a cause and a victim of climate change and adaptation measures are necessary. The nexus between agriculture and climate change in Nigeria has been examined [27]. The authors stated that there is a long-run relationship between climate change and crops' production but not a long-run relationship between climate change and livestock production. They mentioned that higher rainfall and CO₂ emissions have a positive effect on crops' yield while higher temperatures have a negative effect on crop yield. The nexus between climate change, land use and conflicts has been studied [28]. The authors stated that climate change is considered as a threat multiplier increasing food insecurity. They mentioned that land and land-use can be affected by climate change mitigation and adaptation measures. The nexus between climate change and smart agriculture in Korea has been explored [29]. The authors using a mathematical model assessed the trade-offs among water, energy, food, carbon emissions and economic benefits. The nexus between climate change and small-scale agriculture in the eastern Cape province has been examined [30]. The authors analyzing questionnaires from 200 small-scale farmers found that they are fully aware of climate change and they have experienced its negative impacts. They stated that farmers have adopted several adaptation strategies improving agricultural yields and their incomes. The climate change impacts on sustainable agriculture in Armenia have been explored [31]. The authors stated that animal husbandry is vulnerable to climate variability highlighting the need for adaptive strategies to mitigate risks. The impacts of global climate change on agricultural production have been reviewed [32]. The authors stated that climate change has direct and indirect effects on agricultural production while agricultural activities contribute to climate change. They proposed the adoption of intelligent agricultural management techniques to enhance the resilience of agriculture. The

impact of cattle farming on climate change has been studied [33]. The authors stated that livestock is attributed approximately at 9% of global anthropogenic CO₂ emissions, 35%-40% of anthropogenic CH₄ emissions, 65% of anthropogenic N₂O emissions and 64% of anthropogenic NH₃ emissions. They mentioned that apart from GHG emissions cattle farming harms the soil, the water resources and the local ecology. The impact of climate change on livestock production has been reviewed [34]. The authors stated that ruminant livestock such as cattle, sheep and goats contributes the major proportion of total agricultural emissions of CH₄. They mentioned that heat stress adversely affects productive and reproductive performance of livestock. The interactions between climate change and food production have been reviewed [35]. The authors stated that the complexity of the food supply chain suggest a holistic approach to address the many challenges. They mentioned that crop and livestock production is the weakest link in the chain having the highest interaction with climate chain. The nexus among energy, water and climate change in Crete has been examined [36]. The author stated that water, energy and climate change are interlinked and interdependent. He mentioned that water management in Crete requires large quantities of energy while climate change has undesired impacts on water availability. The water demand management in the island of Crete, Greece has been studied [37]. The author stated that agriculture is by far the greatest water consumer in the island having a share around 80% in the total water demand. He also mentioned that water demand management is necessary to avoid water shortages in the future due to climate change.

3. THE AGRICULTURAL SECTOR IN CRETE

Crete, the largest island of Greece, has a long agricultural tradition shaped by its Mediterranean climate, fertile valleys, mountainous landscape and abundant sunshine. Agriculture remains an important part of the island's economy and culture. The main crops cultivated in Crete include olives, grapes, citrus fruits and vegetables. The olive tree is by far one of the most important crops on the island. Olive cultivation has existed in Crete for thousands of years and olive oil is a fundamental part of the local diet and economy. Cretan olive oil is widely known for its quality and is used both domestically and exported to other countries. Grapes are another important crop. Vineyards are found in several parts of Crete, particularly in areas around Heraklion and other central regions. Grapes are used to produce wine and also traditional products such as raisins. Cretan winemaking has a long history and local grape varieties contribute to the island's distinctive wines. Citrus fruits, including oranges, lemons and mandarins, are also widely cultivated, especially in the wetter and more fertile areas of western Crete. The region around Chania is particularly well known for citrus production. In addition, Crete produces a variety of vegetables, such as tomatoes, cucumbers, peppers and potatoes. These crops benefit from the island's mild climate and are grown both for local consumption and for export.

During the last decades avocado is cultivated in the western part of the island. Overall, agriculture in Crete reflects the island’s natural environment and cultural heritage. Olive oil, grapes, fruits and vegetables are not only important agricultural products but also essential elements of the traditional Cretan diet and way of life. The main agricultural crops cultivated in Crete are presented in table 1.

Table 1. Main agricultural crops cultivated in Crete (2021)

Type of crop	Cultivated area (,000 m ²)
Annual crops	138,000
Vineyards	92,000
Several trees (olive trees, oranges trees et cetera)	1,347,000
Greenhouses	15,509
Others (including grassland, pasture, et cetera)	1,754,000

Source: [6]

4. CATTLE BREEDING IN CRETE

Livestock production is an important part of agriculture in Crete and has played a significant role in the island’s economy and traditional way of life for centuries. The mountainous landscape and Mediterranean climate provide suitable conditions for raising animals, particularly sheep and goats. Sheep and goat farming are the most common forms of livestock production in Crete. Many animals are raised in mountainous and semi-mountainous areas, where they can graze on natural vegetation, herbs and grasses. This type of farming is often extensive, with animals spending considerable time outdoors. Sheep and goats provide important products such as milk, meat and wool. Goat and sheep milk are particularly important because they are used to produce traditional Cretan cheeses, including graviera, mizithra and anothotyro. Cattle farming is less widespread because of the island’s limited availability of large areas of flat pasture. Nevertheless, cattle are raised in some parts of Crete, mainly for milk and meat production. Pig and poultry farming are also present and contribute to the supply of pork, eggs and poultry meat for the local market. Livestock farming is closely connected with the traditional Cretan diet and culture. Animal products are important ingredients in many local dishes and are also used in traditional food production. However, livestock farmers face challenges such as high production costs, limited grazing land, water availability and changing market conditions. Overall, livestock production remains an important agricultural activity in Crete. It supports rural communities, contributes to local food production and helps preserve the island’s distinctive agricultural traditions and cultural heritage. The impact of agriculture and cattle breeding nowadays in island’s economy is declining compared to previous decades for several reasons including the rapid development of tourism industry. Table 2 indicates the livestock in Crete in 2023.

Table 2. Livestock in Crete (2023)

Livestock	Number
Cows	1,617
Sheep	2,379,775
Goats	553,066
Pigs	19,638
Poultry	1,120,414
Rabbits	161,061

Source: [6]

5. CLIMATE CHANGE IN CRETE

Crete, the largest island in Greece and one of the most important Mediterranean regions, is particularly vulnerable to the effects of climate change. Its geographical location, Mediterranean climate and dependence on agriculture, tourism and natural resources make changes in temperature and precipitation especially important. Climate change is already affecting the island through increasing temperatures, changing rainfall patterns, droughts, extreme weather events, wildfires and pressure on water resources. These changes are expected to create environmental, economic and social challenges in the coming decades. One of the most visible effects of climate change is the increase in temperature. Crete is experiencing warmer conditions, with particularly high temperatures during the summer months. More frequent and intense heatwaves can affect human health, agriculture, livestock and natural ecosystems. Higher temperatures also increase evaporation, which contributes to soil moisture loss and increases the demand for water for irrigation and other uses. Water scarcity and changing rainfall patterns represent major concerns for Crete. The island already has a relatively dry Mediterranean climate, with most rainfall occurring during the winter and much drier conditions during the summer. Climate change can increase the frequency and duration of drought periods and make rainfall more irregular. Reduced rainfall and higher evaporation can place additional pressure on groundwater, reservoirs and other freshwater resources. This is particularly important because agriculture and tourism are both major users of water. Climate change is also expected to increase the risk of extreme weather events. Intense rainfall over short periods can cause flash floods, soil erosion and damage to infrastructure, while prolonged dry periods increase the risk of drought and wildfires. The combination of high temperatures, dry vegetation and strong winds can create particularly dangerous conditions for forest and agricultural fires. Such events can damage ecosystems, agricultural land, homes and infrastructure and can impose significant economic costs on local communities. Natural ecosystems and biodiversity are also affected. Many plant and animal species depend on specific temperature and water conditions. Changes in climate can alter habitats and the timing of biological processes. Drought, wildfires and increased temperatures can place additional stress on forests, wetlands and coastal ecosystems. Sea-level rise and increasing marine temperatures may also affect coastal environments and marine biodiversity. Therefore, climate

change represents a significant environmental and socioeconomic challenge for Crete. Rising temperatures, water scarcity, changing rainfall, extreme weather events, wildfires and impacts on agriculture and ecosystems are closely interconnected. Effective climate policies, sustainable resource management and adaptation measures will be essential to protect Crete's environment, economy and communities and to increase the island's resilience to future climate change.

6. THE IMPACT OF AGRICULTURE IN CRETE ON CLIMATE CHANGE

Agriculture is an important sector of the economy and landscape of Crete, with olive cultivation, vineyards, citrus fruits, vegetables and other crops being particularly significant. The island's Mediterranean climate provides favorable conditions for agricultural production, but farming practices can also contribute to climate change through greenhouse gas emissions, energy consumption, changes in land use and the management of agricultural residues. One important source of environmental impact is the use of agrochemicals, including synthetic fertilizers, herbicides, fungicides and pesticides. Nitrogen fertilizers are particularly relevant to climate change because their application can result in emissions of nitrous oxide (N₂O), a powerful greenhouse gas. More efficient fertilizer application, integrated pest management and the increased use of organic amendments can therefore reduce both environmental pressures and greenhouse gas emissions. Fossil-fuel consumption is another contributor to the carbon footprint of agriculture in Crete. Agricultural machinery such as tractors, harvesters, pumps and other equipment generally relies on diesel or electricity generated from fossil fuels. Olive harvesting and cultivation, soil preparation, transportation of agricultural products and irrigation can all require significant energy. Irrigation is particularly important in Crete because water availability is limited and farmers may need to pump water from wells or other sources. Land-use changes can also influence the climate impact of agriculture. The expansion or intensification of agricultural land may involve the removal of natural vegetation, which can reduce carbon stored in soils and plants. Conversely, well-managed perennial crops such as olive groves can provide long-term vegetation cover and store carbon in both biomass and soil. Maintaining existing vegetation, preventing soil erosion and improving soil organic matter can therefore increase the capacity of agricultural land to act as a carbon sink. Changes in land management are particularly important in Mediterranean environments, where soil degradation and erosion can become more severe under hotter and drier conditions. Another issue is the burning of agricultural biomass, such as olive pruning, vine cuttings and other crop residues. Open burning releases carbon dioxide and other pollutants into the atmosphere and can also produce particulate matter and other substances harmful to air quality. Although some of the carbon dioxide released originates from recently grown

biomass, burning nevertheless produces immediate emissions and removes an opportunity to use the material in alternative ways. Composting, mulching or processing agricultural residues into useful bioenergy products can provide more sustainable alternatives. Therefore, crop agriculture in Crete has several connections with climate change. The use of agrochemicals, fossil fuels, land-use changes and the open burning of biomass can contribute to greenhouse gas emissions and environmental degradation. However, agriculture can also contribute to climate-change mitigation through carbon storage in soils and perennial crops, use of renewable energy, improved soil management and the recovery of agricultural residues through anaerobic digestion. Table 3 indicates the main impacts of agriculture in Crete on climate change.

Table 3. Main impacts of agriculture in Crete on climate change

1	N ₂ O is mainly formed during the application of fertilizers rich in nitrogen to the fields. It is also emitted from engines burning fossil fuels
2	CO ₂ is emitted during the use of fossil fuels in agricultural machinery
3	Burning residual biomass in the fields emit CO ₂
4	Land-use changes, related to agriculture contributes in CO ₂ emissions taken into account that land acts as a carbon sink

Source: own estimations

7. THE IMPACTS OF CATTLE BREEDING IN CRETE ON CLIMATE CHANGE

Cattle breeding is an important component of livestock agriculture in Crete, although the island is particularly well known for sheep and goat farming. Cattle production contributes to the local food system and rural economy, but it can also have environmental impacts associated with greenhouse gas emissions, feed production, manure management, land use and energy consumption. These impacts are relevant to climate change because livestock systems can release methane, nitrous oxide, ammonia and carbon dioxide, which contribute to the accumulation of greenhouse gases in the atmosphere. One of the most significant climate impacts of cattle breeding is the production of methane (CH₄) through enteric fermentation. Cattle digest plant material through a specialized digestive system and microorganisms in the rumen produce methane as part of this process. The methane is subsequently released mainly through the animals' respiration and belching. Methane has a much stronger warming effect than carbon dioxide over a 100-year period, although it remains in the atmosphere for a considerably shorter time. Manure management is another source of greenhouse gas emissions. When cattle manure is stored or decomposes under conditions with limited oxygen, methane can be produced. Nitrous oxide can also be released during the storage and application of manure to agricultural soils. These emissions depend on

factors such as the type of manure management system, storage conditions, temperature and the way manure is applied to land. Improving manure storage and management can therefore reduce emissions while allowing manure to be used as an organic fertilizer. Cattle breeding also has indirect climate impacts through the production and transportation of animal feed. Feed production can require agricultural land, fertilizers, water, machinery and transportation. The cultivation of feed crops, particularly when synthetic nitrogen fertilizers are used, can result in nitrous oxide emissions. Energy used to process and transport feed can additionally generate carbon dioxide emissions when fossil fuels are involved. Where locally available feed resources are used efficiently, some of these indirect emissions may be reduced. Land use is another important consideration. Grazing and the production of animal feed require land and changes in land management can influence the amount of carbon stored in vegetation and soils. Well-managed grasslands and grazing areas can store carbon in soil, while overgrazing may contribute to vegetation loss, soil erosion and declining soil carbon. In Crete, where water availability is limited and the climate is increasingly characterized by higher temperatures and periods of drought, appropriate management of grazing land is particularly important. Therefore, cattle breeding in Crete contributes to climate change primarily through methane emissions from digestion, greenhouse gases associated with manure management and indirect emissions from feed production, land use and energy consumption. Nevertheless, cattle production can become more climate-efficient through improved feeding, herd management, manure treatment and sustainable land management. Table 4 indicates the main impacts of cattle breeding in Crete on climate change.

Table 4. Main impacts of cattle breeding in Crete on climate change

1	The digestive processes in cattle and similar fermentative processes in manure emit methane (CH ₄)
2	Cattle emit large amounts of nitrous oxide (N ₂ O) and ammonia (NH ₃) through waste
3	Fossil fuels are used in several stages of cattle breeding emitting CO ₂
4	Land-use changes, related to cattle breeding contributes in CO ₂ emissions taken into account that land acts as a carbon sink

Source: own estimations

8. THE IMPACTS OF CLIMATE CHANGE ON AGRICULTURE IN CRETE

Crete has favorable conditions for the production of olives, grapes, vegetables, citrus fruits and other Mediterranean crops. However, climate change is increasingly creating challenges for agricultural production. Rising temperatures, changes in rainfall patterns, prolonged droughts, extreme weather events, soil degradation and the increasing pressure

from pests and diseases can affect both the quantity and quality of agricultural products. These changes may have significant economic and social consequences for farmers and rural communities across Crete. One of the most important impacts of climate change is the increase in temperature. Higher average temperatures and more frequent heatwaves can cause heat stress in crops, particularly during flowering and fruit development. Olive trees, grapevines and vegetables may experience reduced productivity when temperatures become excessively high. Higher temperatures can also increase evaporation from soils and plants, meaning that crops require more water to maintain normal growth. This creates additional pressure on farmers in an island where water resources are already limited. Changes in rainfall and increasing drought represent another major challenge. Mediterranean regions such as Crete are vulnerable to irregular precipitation and extended periods without rainfall. Reduced or unpredictable rainfall can decrease soil moisture and groundwater recharge, increasing farmers' dependence on irrigation. Competition for water between agriculture, tourism, households and the environment may also become more significant. Efficient irrigation systems, rainwater collection and improved water-management practices will therefore become increasingly important for maintaining agricultural production. Climate change can also increase the frequency and severity of extreme weather events. Heavy rainfall can cause flooding, soil erosion and damage to crops and agricultural infrastructure. At the other extreme, prolonged drought can cause crop failure and reduce the availability of water for irrigation. Strong winds and storms can damage trees, vineyards, greenhouses and other agricultural facilities. Such events can cause substantial financial losses, particularly for small farms that may have limited resources to recover from repeated damage. Another concern is the effect of climate change on soil quality. Higher temperatures and prolonged dry periods can accelerate the loss of soil moisture and increase the risk of erosion and desertification. Heavy rainfall following dry periods can further increase erosion by removing fertile topsoil. The degradation of soil reduces its ability to retain water and nutrients and can consequently reduce agricultural productivity. Practices such as maintaining vegetation cover, applying organic matter and reducing unnecessary soil disturbance can help improve soil resilience. Climate change may also influence the distribution and behavior of agricultural pests and diseases. Warmer conditions can allow certain insects and pathogens to survive through periods that were previously too cold for them. Changes in temperature and humidity may also alter the timing of pest outbreaks. Farmers may therefore face increased pressure to protect crops, potentially increasing the use of pesticides and production costs. Therefore, climate change presents significant challenges for agriculture in Crete. Rising temperatures, water scarcity, drought, extreme weather, soil degradation and changing pest pressures can affect crop yields, quality and farm profitability. Nevertheless,

adaptation measures can reduce these risks. More efficient irrigation, drought- and heat-tolerant crop varieties, improved soil management, diversification and better monitoring of pests can help Cretan agriculture adapt to future climatic conditions. Table 5 indicates the main impacts of climate change on agriculture in Crete.

Table 5. Main impacts of climate change on agriculture in Crete

1	Higher temperatures affect agricultural productivity
2	Higher temperatures increase water losses by evaporation
3	Changes in precipitation patterns have significant impacts on agriculture
4	Extreme weather conditions including droughts, floods, storms et cetera have negative impacts on agriculture
5	Climate change increases the negative impacts of pests and diseases on agriculture
6	Water availability in lakes, rivers and reservoirs is affected by climate change having significant impacts on agriculture
7	Sea-level rise affects agriculture in coastal lands
8	Increase in the atmospheric CO ₂ concentration increases plant photosynthesis and transpiration

Source: own estimations

9. THE IMPACTS OF CLIMATE CHANGE ON CATTLE BREEDING IN CRETE

Climate change is increasingly affecting livestock production throughout the Mediterranean region, and cattle breeding in Crete is likely to face significant challenges as temperatures rise and water availability becomes less predictable. Cattle farming depends on suitable temperatures, adequate water supplies, reliable feed resources and healthy animals. Changes in climatic conditions can therefore influence animal welfare, productivity and the economic sustainability of cattle farms. The effects are particularly important in Crete because the island already experiences hot, dry summers and periods of water scarcity. One of the most significant impacts of climate change on cattle is heat stress. Cattle have a relatively limited ability to cope with very high temperatures, particularly when high temperatures are combined with high humidity. During periods of heat stress, animals may reduce their feed intake, increase their water consumption and spend more time seeking shade or reducing physical activity. Prolonged heat stress can affect growth, milk production and reproductive performance. Dairy cattle can be particularly sensitive because milk production generates additional metabolic heat. More frequent and intense heatwaves could therefore reduce productivity and increase the need for cooling and shade facilities. Water availability is another major concern. Cattle require regular access to clean drinking water, and their water requirements increase substantially during hot weather. Climate change may increase the

frequency and duration of droughts in Crete, placing additional pressure on already limited water resources. Farms may therefore face higher costs for supplying and storing water. Competition for water between livestock farming, crop production, households and tourism could also become more significant during periods of drought. Climate change can also affect the availability and quality of animal feed. Higher temperatures and reduced rainfall can decrease the productivity of pastures and forage crops. Drought can reduce the quantity of grass and other vegetation available for grazing, while heat and water stress can reduce crop yields. Farmers in Crete may consequently become more dependent on purchased feed, potentially increasing production costs. Changes in the nutritional quality of available forage may also affect animal productivity and health. Another concern is animal health. Warmer temperatures can influence the distribution and abundance of insects, parasites and disease-carrying organisms. Some diseases that were previously limited by cooler conditions may become more prevalent or extend their geographical range. Heat stress can also weaken animals' ability to cope with disease and may increase susceptibility to health problems. Veterinary monitoring and effective farm management will therefore become increasingly important. Climate change may also affect reproductive performance. Heat stress can reduce fertility in both male and female cattle and can influence conception rates and pregnancy outcomes. Reduced reproductive efficiency can increase the time and resources required to maintain herd numbers and may have economic consequences for farmers. Therefore, climate change presents several challenges for cattle breeding in Crete, particularly through increasing temperatures, heat stress, water scarcity, reduced feed availability, disease risks and reproductive problems. These impacts could affect both animal welfare and farm profitability. However, appropriate adaptation strategies, including improved housing, water management, feeding practices, animal selection and health monitoring, can help Cretan cattle farmers respond to changing climatic conditions and maintain sustainable livestock production. Table 6 indicates the main impacts of climate change on cattle breeding in Crete.

Table 6. Main impacts of climate change on cattle breeding in Crete

1	Rising temperatures and heat stresses affect the health and the production ability of cattle
2	Lower water availability affects cattle which require regular access to clean drinking water
3	Climate change affects the availability and quality of animal feed
4	Climate change influences the presence of insects, parasites and disease-carrying organisms affecting the health of cattle
5	Climate change may also affect reproductive performance of cattle

Source: own estimations

10. DISCUSSION

The interrelation between agriculture, cattle breeding and climate change in Crete has been analyzed. Agriculture and cattle breeding was in the past an important part in island's economy while nowadays its contribution has been decreased. It has been indicated that climate change alters the climate conditions in the island changing the rainfall patterns, increasing the air temperatures and the extreme weather events. However, the quantitative impacts cannot be accurately predicted. Climate change has undesired impacts on agriculture and cattle breeding in the island while agriculture and cattle breeding emit GHGs such as CO₂, CH₄, NH₃ and N₂O which intensify climate change. These impacts are mainly negative although the increase in atmospheric CO₂ concentration increases plants' photosynthesis. Our findings indicate that agriculture and cattle breeding in the island should try to mitigate climate change with various measures including the decrease in GHG emissions. Additionally, several measures should be taken to adapt agriculture and cattle breeding in the island to climate change. Our study describes only the qualitative interrelations between climate change, agriculture and cattle breeding in Crete without estimating the quantitative interlinkages. Future work should be focused in describing the detailed measures that should be taken in Crete for mitigating the impacts of agriculture and cattle breeding to climate change as well as in describing the detailed measures that should be taken for adapting food production in the island to climate change.

11. CONCLUSIONS

The interlinkages and interrelations between climate change, agriculture and cattle breeding in the island of Crete have been explored. The main findings can be summarized as follows:

- a) Several annual and perennial crops including vegetables, olive trees, citrus trees and vines are cultivated in Crete while sheep and goat breeding is developed in the island,
- b) Climate change is predicted to alter the climate conditions in Crete decreasing the rainfalls, increasing the air temperature and the extreme weather events,
- c) Current agricultural practices in Crete increase the emissions of several greenhouse gases including CO₂, N₂O,
- d) Current practices in cattle breeding in Crete result in emission of GHG gases such as CO₂, CH₄, NH₃ and N₂O,
- e) Climate change in Crete affects agriculture increasing the irrigation needs, increasing the pest and diseases damaging the plants, increasing plants' photosynthesis and respiration and increasing the crop damages due to extreme weather events,
- f) Climate change in Crete affects cattle breeding by affecting the availability of animal feed, increasing the heat stress on animals, influencing the presence of pests and diseases and altering the reproductive performance of cattle, and

- g) The mitigation of climate change due to agriculture and cattle breeding in Crete as well as their adaptation to it is urgently necessary to avoid their decline in the future.

The key takeaway from our study is the urgent necessity to develop appropriate policies and measures in agriculture and cattle breeding in Crete towards mitigation and adaptation to climate change which is expected to have undesired and harmful impacts on food production in the island.

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