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A SYSTEMATIC REVIEW OF THE IMPACT OF CLIMATE CHANGE ON AGRICULTURE AND FUTURE ADAPTATION STRATEGIES FOR NORTH MACEDONIA

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Abstract

Climate change poses significant challenges to agriculture worldwide, with implications for food security, livelihoods, and ecosystems. This review paper examines the impact of climate change on agriculture and explores adaptation strategies for North Macedonia. The paper synthesizes existing literature on the subject, drawing from peer-reviewed articles, academic papers, and reports. The introduction provides an overview of the interconnectedness between climate change and agriculture, emphasizing the vulnerability of the agricultural sector to changing climatic conditions. The materials and methods section outlines the methodology employed, including a systematic literature search, source selection criteria, data extraction, analysis, and synthesis. Results and discussion focus on five key areas: crop adaptation, water management, pests and diseases in crops, biodiversity, and agroforestry. Each subsection discusses the challenges posed by climate change in these areas and explores potential adaptation measures tailored to North Macedonian context. The conclusion highlights the urgency of addressing climate change impacts on agriculture and emphasizes the importance of adopting climate-smart agricultural practices. It underscores the need for collaborative efforts between stakeholders to promote knowledge exchange, capacity building, and policy interventions. This paper highlights the importance of adapting agricultural practices to mitigate the adverse effects of climate change on food production and rural livelihoods in North Macedonia. By embracing adaptation strategies, policymakers, farmers, and other stakeholders can enhance resilience and ensure sustainable agricultural development in the face of a changing climate.

Key words: *Climate change, Agriculture, Adaptation strategies, North Macedonia.*

Introduction

Climate change poses significant challenges to global ecosystems and agricultural systems worldwide. In the face of escalating environmental degradation and the proliferation of greenhouse gas emissions, agriculture stands as both a contributor to climate change and one of its most vulnerable sectors (Piguet, 2022). This intersection underscores the urgency of understanding the multifaceted impacts of climate change on agricultural productivity, food security, and rural livelihoods.

While agricultural systems have historically shaped landscapes and sustained human societies, modern food production practices have increasingly strained natural resources and exacerbated environmental degradation (Redden et al., 2014). With approximately 70% of the global population reliant on agriculture for their livelihoods, the repercussions of climate change reverberate across regions already grappling with distinct shifts in climatic patterns (IPCC, 2021).

The escalating atmospheric concentrations of greenhouse gases, including methane, carbon dioxide, and nitrous oxide, highlight the unprecedented nature of the current climate crisis

(Usman et al., 2021). The consequences of these changes manifest in extreme weather events and environmental disruptions, from devastating bushfires in Australia and the United States to the accelerated melting of polar ice sheets and rising sea levels (Canadell et al., 2021; Perkins, 2022).

Amidst these global challenges, North Macedonia stands particularly vulnerable to the impacts of climate change on its agricultural sector. Characterized by a dry climate, changing rainfall patterns, and rising temperatures, the country faces mounting pressures on its agricultural productivity and food security (MAFWE, 2022). Agriculture, comprising 7.9% of the nation's GDP, occupies a critical role in sustaining rural livelihoods and supporting approximately 193,000 family farms.

Projections from the World Bank indicate a looming future of heightened climatic instability in North Macedonia, with anticipated increases in temperature and precipitation deficits exacerbating existing challenges (MOEPP, 2020). In this context, it is imperative to explore adaptation strategies tailored to the unique socio-environmental landscape of North Macedonia.

This review aims to provide a comprehensive overview of the current state of climate change impacts on global ecosystems and elucidate potential adaptation strategies tailored to North Macedonia's agricultural sector. By focusing on adaptation measures aimed at mitigating climate change impacts, this review seeks to contribute to ongoing efforts to safeguard agricultural sustainability and rural livelihoods in North Macedonia.

Materials and Methods

Objective Statement:

The aim of this review paper was to comprehensively explore existing research and literature on the impact of climate change on agriculture, with a focus on North Macedonia. The objective was to outline the necessary adaptation measures and strategies to address these impacts.

Systematic Literature Search:

A systematic literature search was conducted in September-October 2023 to identify relevant peer-reviewed articles, academic papers, reports, and publications related to the impact of climate change on agriculture. Search terms included "climate change" and "agricultural adaptation measures," and databases searched included Google Scholar, Web of Science, Scopus, Emerald, Elsevier Science Direct, and the World Bank's Climate Change Information Portal. Additionally, official data published in The Annual Reports of the Ministry of Agriculture, Forestry and Water Economy were consulted.

Source Selection Criteria:

A total of 60 studies were identified and deemed appropriate for review based on their relevance to the subject matter. Selection criteria included the significance of the articles to the topic of climate change in agriculture and adaptation measures. Irrelevant or duplicated articles were excluded from the review.

Data Extraction and Analysis:

Essential insights were extracted and structured from the selected sources, focusing on challenges related to climate change impacts on agriculture and proposed adaptation solutions. This involved identifying recurring themes, emerging trends, and patterns in the literature. The selected articles were then analyzed to distill key findings, methodologies, and recommendations.

Synthesis of Information:

The synthesized information provides a structured overview of the challenges faced by agriculture due to climate change, along with corresponding adaptation actions. Insights from

the chosen articles were categorized into specific themes, including Crop Adaptation, Water Management, Pests and Diseases in Crops, Biodiversity, and Agroforestry. These themes serve as the basis for the discussion section of this paper.

Results and discussion

The impacts of climate change on agriculture in North Macedonia are multifaceted, affecting various aspects of crop production, water management, pest and disease control, biodiversity, and agroforestry. This section summarized in Table 1 discusses the key challenges identified in these areas and explores the potential adaptation measures tailored to the specific context of North Macedonia.

Table 1. Challenges and adaptation measures for agriculture in North Macedonia facing climate change

Key area	Challenges	Adaptation measures
Crop adaptation	Drought and heat stress	Crop rotation to optimize soil moisture retention and improve soil health
	Disruption of crucial stages of plant development	Adopting heat-resistant crop varieties
	Flower drop and reduced yield	Implementing precision agriculture techniques
Water management	Reduced water supplies due to climate change	Water-saving techniques like mulching, shading nets, and micro-irrigation systems
	Inefficient irrigation methods	Transition to modern irrigation systems like micro-irrigation and fertigation
	Soil erosion and yield loss	Extensive animal husbandry in water-scarce regions
Pests and diseases in crops	Heavy reliance on pesticides	Implementing integrated pest management (IPM) practices
	Misuse of pesticides	Using biological pest control methods
	Abiotic and biotic plant diseases	Developing disease-resistant crop varieties
Biodiversity	Decline in farmland biodiversity	Enhancing biodiversity monitoring and establishing protected areas that consider climate impacts
	Loss of ecosystem services	Promoting ex situ conservation efforts
	Impact on pollinators and soil biodiversity	Implementing sustainable land management practices
Agroforestry	Climate change threats to forests	Integration of trees or shrubs with crops to enhance resilience and offer biophysical and socioeconomic benefits
	Soil erosion and reduced soil health	Promoting awareness, capacity building, and policy support for agroforestry practices
	Loss of ecosystem services	Strategic tree planting and management to create microclimates and buffer crops against adverse climatic conditions

Crop Adaptation

Abiotic stressors, such as drought and heat stress, significantly impact crop development and morphology worldwide (Reidsma et al., 2009). Several studies indicate that these stressors, exacerbated by climate change, are likely to negatively affect crop yields in North Macedonia (Hristov, 2018). The country's diverse agro-ecological zones, including alpine, Mediterranean, and continental regions, exhibit variations in response to changing climatic conditions.

While higher temperatures may initially promote plant growth and shorten growing seasons, they can also disrupt crucial stages of plant development, leading to phenomena like flower drop and ultimately reducing yield (Demirevska et al., 2009; Jahanzad et al., 2020). This underscores the urgent need for adaptation strategies to mitigate the adverse effects of climate change on agricultural production.

Crop rotation emerges as a vital adaptation measure to optimize soil moisture retention and minimize water loss through evaporation and surface runoff (Yu et al., 2022). By enhancing soil structure, nutrient cycling, and resistance to erosion, crop rotation promotes soil health and resilience to extreme weather events such as floods and droughts. Additionally, it fosters microbial activity in the soil, contributing to disease suppression and overall plant health (Yu et al., 2022).

The planned strategy for agriculture and rural development in North Macedonia emphasizes the importance of ensuring consistent food production, stable farmer incomes, and sustainable rural development (MAFWE, 2022). This policy framework supports the cultivation of grain and vegetables, enabling continued production despite challenges posed by fluctuating rainfall and temperatures, as well as rising agricultural input costs.

Water Management

Water plays a pivotal role in agriculture, with factors like elevation and drought significantly influencing its quality and availability. Climate change-induced shifts, including reduced water supplies due to snowmelt, evaporation, and other climatic alterations, pose challenges for the agricultural sector and food security. Consequently, there is a pressing need for rational water management practices in agricultural production.

In North Macedonia, excessive irrigation practices can exacerbate water shortages for fellow farmers, compromise crop health, and increase susceptibility to diseases and pests. Moreover, inefficient irrigation methods contribute to soil erosion, yield loss, and elevated production costs. To address these challenges, farmers are increasingly adopting water-saving techniques such as mulching, shading nets, and micro-irrigation systems. These technologies help minimize water loss from soil evaporation and enhance water use efficiency by plants.

Transitioning from traditional irrigation practices to modern systems, such as micro-irrigation and fertigation, is crucial for optimizing water resources and mitigating climate change impacts. Proper management practices aim to improve the allocation and efficiency of irrigation water, taking into account factors like pricing, technology type, environmental conditions, and watering schedules (Hillel, 1997). Emphasizing the adoption of these advanced irrigation technologies and practices through farmer training programs is essential to enhance water conservation and resilience in agricultural systems.

In regions facing acute water scarcity, promoting extensive animal husbandry as an alternative to water-intensive crop cultivation can be economically viable and environmentally sustainable. By diversifying agricultural activities, farmers can reduce reliance on water-intensive crops and adapt to changing climate conditions more effectively.

Climate change poses significant challenges to water resources in North Macedonia, with smallholder farms being particularly vulnerable to increased heatwaves, severe droughts, and floods. Effective water management strategies are imperative to safeguard agricultural livelihoods and ensure sustainable food production amidst changing climatic conditions.

Pests and Diseases in Crops

Pesticides play a crucial role in modern agriculture, offering farmers labor savings and higher yields by effectively combating pests and diseases. While some small-scale farmers may opt for minimal pesticide use, large-scale crop producers often rely heavily on these chemicals to safeguard their crops. For instance, wheat farmers may apply weed killers to expedite drying and prevent losses from wet weather, while fruit and vegetable growers frequently employ pesticides to protect delicate varieties like strawberries.

However, the widespread use of pesticides comes with both economic benefits and environmental concerns. In the EU, pesticides account for approximately 7-8% of total agricultural production costs, highlighting their significant financial impact (Popp et al., 2013). Nonetheless, misuse of pesticides can lead to socio-economic and environmental repercussions, underscoring the importance of adopting alternative pest control methods, such as Organic Agriculture production, to reduce reliance on artificial fertilizers and pesticides.

Plant diseases pose a significant threat to crop production, necessitating effective preventive measures. Diseases can be categorized as abiotic (non-infectious) or biotic (infectious), with adverse environmental conditions often serving as catalysts for their development. Examples include extreme temperatures, moisture imbalances, air pollutants, soil contaminants, and toxins released by certain plants and fungi (Vicente and Holub, 2013; Koza et al., 2022).

Among the most common infectious agents in agriculture are bacteria, pathogenic fungi, viruses, and parasites. Preventive measures against bacterial infections include the use of pathogen-free seeds, seed treatment with hot water, soil solarization, and application of germicidal compounds (Vicente and Holub, 2013). Similarly, control strategies for fungi involve destroying infected plant matter, using healthy seeds, implementing regular crop rotation, and employing chemical and biological fungicides.

Viruses and viroids pose unique challenges due to their small size and ability to spread rapidly through the soil. Control measures include cultivating resistant crops, conducting indexing to determine virus presence, and implementing quarantine protocols to contain outbreaks (Fontdevila Pareta et al., 2023). Additionally, parasites are effectively managed through herbicide application on resistant crops, manual weeding, and crop rotation.

In cases of severe infection, farmers may need to resort to drastic measures such as destroying infected crops and implementing quarantine to salvage remaining yields (Almeida et al., 2019). Despite the challenges posed by pests and diseases, sustainable agriculture practices not only protect the environment but also contribute to long-term profitability in the agricultural sector.

Biodiversity

Biodiversity serves as a cornerstone of natural ecosystems and is essential for sustaining food resources worldwide. However, there is alarming evidence of global declines in farmland biodiversity, particularly observed in plants, pollinating birds, and insects, predominantly in regions like North America and Europe. Agricultural intensification processes, characterized by practices such as fertilization, tillage, and pesticide use, are recognized as the primary drivers of biodiversity loss and ecosystem degradation (ECA, 2020).

Over the past five decades, arable land has witnessed a significant decline in biodiversity, leading to biotic homogenization and species extinctions, particularly in Europe (Outhwaite et al., 2022; Maxwell et al., 2016). This trend is exacerbated by the intensification of agricultural practices and the removal of landscape features that support biodiversity (Czucz et al., 2022). The decline in biodiversity poses risks to essential ecosystem services vital for agriculture, including pollination and soil health.

Pollinators, such as bees and butterflies, play a crucial role in sustaining agricultural production by pollinating three-quarters of the world's most cultivated crops, thereby

contributing to the production of fruits, vegetables, and seeds. Similarly, soil biodiversity, encompassing bacteria, fungi, and worms, enhances water and nitrogen use efficiency, while insects serve as biological control agents, regulating pest populations.
The intensification of agricultural activities and expansion of agricultural frontiers contribute to dwindling biodiversity, with pesticide use emerging as a key factor in altering farmland ecosystems, particularly impacting farmland bird populations. Excessive pesticide application can disrupt biological diversity and compromise habitat quality for diverse species.
As global demand for crops and food continues to rise, driven by population growth, biodiversity in both farmland and natural areas faces escalating risks. To address these challenges, adaptation strategies in North Macedonia must prioritize collecting climate impact data on biodiversity, especially in mountain ecosystems, enhancing biodiversity monitoring efforts, establishing functional systems of protected areas that consider climate impacts, and promoting ex situ conservation efforts (MOEPP, 2023).

Agroforestry

Recent Intergovernmental Panel on Climate Change (IPCC) report have underscored the significance of agroforestry in the context of climate change adaptation, prompting a growing recognition of its importance in national adaptation plans (IPCC, 2022; Meybeck et al., 2020). Agroforestry, characterized by the intentional integration of trees or shrubs with crops within plots, farms, or landscapes, emerges as a promising climate change adaptation strategy to enhance the resilience of farmers and agricultural systems, offering a multitude of biophysical and socioeconomic benefits (Rosenstock et al., 2019).
In response to climate change threats, the agricultural community must assess the long-term impacts on forests and devise restoration strategies to mitigate risks. Research highlights two key adaptation approaches: increasing tree diversity to accommodate heightened climate variability and implementing targeted interventions to address projected climate trends (Catacutan et al., 2017).
Agroforestry systems not only contribute to climate change mitigation by sequestering carbon dioxide but also offer multiple adaptation benefits, including improved soil health, enhanced water retention, and diversified income sources for farmers (Jose, 2009). By integrating trees or shrubs into agricultural landscapes, farmers can mitigate the impacts of extreme weather events, such as floods and droughts, while simultaneously enhancing biodiversity and ecosystem services (Rolo et al., 2023).
Furthermore, agroforestry practices promote sustainable land management by reducing soil erosion, conserving water resources, and enhancing agroecosystem resilience to climate variability (Ruiz et al. 2020). Through strategic tree planting and management, farmers can create microclimates that buffer crops against adverse climatic conditions, fostering greater agricultural productivity and food security in the face of changing climate patterns (Torquebiau, 2000).
To realize the full potential of agroforestry as a climate change adaptation strategy, concerted efforts are needed to promote awareness, capacity building, and policy support for its widespread adoption. Collaborative initiatives between governments, research institutions, and local communities can facilitate the implementation of agroforestry practices, fostering sustainable agricultural development and climate resilience in North Macedonia and beyond.

Conclusion

Climate change poses unprecedented challenges to agriculture worldwide, threatening food security, livelihoods, and ecosystems. This review paper has explored the impact of climate change on agriculture and outlined potential adaptation strategies for North Macedonia.

The findings highlight the urgency of addressing climate change impacts on agriculture, given its profound implications for global food production and rural livelihoods. From shifts in temperature and precipitation patterns to increased frequency of extreme weather events, climate change poses multifaceted risks to agricultural systems.

In North Macedonia, where agriculture plays a vital role in the economy and sustenance of rural communities, the effects of climate change are particularly pronounced. Changing rainfall patterns, rising temperatures, and water scarcity pose significant challenges to crop yields, soil health, and biodiversity.

However, amidst these challenges lie opportunities for adaptation and resilience-building. Through the adoption of innovative agricultural practices such as crop rotation, water management techniques, pest and disease control measures, agroforestry, and biodiversity conservation efforts, farmers can enhance their capacity to withstand climate variability and change.

Furthermore, strategic policy interventions and investments are crucial to support climate-smart agriculture initiatives and facilitate the transition towards more sustainable and resilient farming systems. Collaborative efforts involving government agencies, research institutions, civil society organizations, and local communities are essential to promote knowledge exchange, capacity building, and the adoption of climate-resilient agricultural practices.

In conclusion, addressing the impacts of climate change on agriculture requires concerted action at all levels. By embracing adaptation strategies tailored to local contexts and leveraging the potential of nature-based solutions, North Macedonia can mitigate the adverse effects of climate change on its agricultural sector and ensure food security, environmental sustainability, and prosperity for future generations.

References

Almeida, F., Rodrigues, M.L., Coelho, C. (2019). The still underestimated problem of fungal diseases worldwide, Frontiers in Microbiology 10:214

Canadell, J.G., Meyer, C.P., Cook, G.D., et al. (2021). Multi-decadal increase of forest burned area in Australia is linked to climate change, Nature Communications, 12, 6921

Catacutan, D.C., Hai, N.T., Mercado, A.R., Van Noordwijk, M., Öborn, I. (2017). Agroforestry: contribution to food security and climate-change adaptation and mitigation in Southeast Asia. White Paper, World Agroforestry Center (ICRAF) Southeast Asia Regional Program, Bogor

Demirevska, K., Zasheva, D., Dimitrov, R., Simova-Stoilova, L., Stamenova, M., Feller, U. (2009) Drought stress effects on Rubisco in wheat: Changes in the Rubisco large subunit, Acta Physiologiae Plantarum, 31(6), 1129

European court of auditors (2020). Biodiversity on Farmland: CAP Contribution has not halted the decline Special Report. Available from: https://www.eca.europa.eu/Lists/ECADocuments/SR20_13/SR_Biodiversity_on_farmland_EN.pdf

Fontdevila Pareta, N., Khalili, M., Maachi, A., Rivarez, M. P. S., Rollin, J., Salavert, F., Temple, C., Aranda, M. A., Boonham, N., Botermans, M., Candresse, T., Fox, A., Hernando, Y., Kutnjak, D., Marais, A., Petter, F., Ravnikar, M., Selmi, I., Tahzima, R., Trontin, C., Wetzel, T., Massart, S. (2023). Managing the deluge of newly discovered

plant viruses and viroids: an optimized scientific and regulatory framework for their characterization and risk analysis. Frontiers in microbiology, 14, 1181562.
Hillel D. (1997). Small-scale irrigation for arid zones: Principles and options. FAO Technical Paper 2, Rome, Italy
Hristov, J. (2018). "An Exploratory Analysis of the Impact of Climate Change on Macedonian Agriculture, Environments, 5, no.1:3
IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change[Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA
IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp
Jahanzad, E., Holtz, B.A., Zuber, C.A., Doll, D., Brewer, K.M., Hogan, S., Gaudin, A.C. (2020). Orchard recycling improves climate change adaptation and mitigation potential of almond production systems, PLoS ONE, 15(3):e0229588
Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits: an overview, Agroforestry Systems, 76, 1–10
Koza, N. A., Adedayo, A. A., Babalola, O. O., & Kappo, A. P. (2022). Microorganisms in Plant Growth and Development: Roles in Abiotic Stress Tolerance and Secondary Metabolites Secretion, Microorganisms, 10(8), 1528
Maxwell, S.L., Fuller, R.A., Brooks, T.M., Watson, J.E.M. (2016). Biodiversity: the ravages of guns, nets and bulldozers, Nature, 536 , 143-145
Meybeck, A., Gitz, V., Wolf, J. and Wong, T. (2020). Addressing forestry and agroforestry in National Adaptation Plans – Supplementary guidelines. Bogor/Rome. FAO and CIFOR
MAFWE, Ministry of Agriculture, Forestry and Water Economy (2022) Annual Agriculture Report. Available from: https://www.mzsv.gov.mk/
Ministry of Environment and Physical Planning (2020) Macedonian third biennial update report on climate change Available from: https://unfccc.int/sites/default/files/resource/1%20TBUR_EN_f.pdf
MOEPP, Ministry of Environment and Spatial Planning (2023) 4th Climate change communication Available from: https://api.klimatskipromeni.mk/data/rest/file/download/15644574e26d61c276c5899e7ccfca8c191f7207b5393d352d6ca2ba51e91406.pdf
Outhwaite, C., McCann, P., Newbold, T. (2022). Agriculture and climate change are reshaping insect biodiversity worldwide, Nature, 605, 97-102
Perkins, S. (2022). How much of the Earth's ice is melting? New and old techniques combine to paint a sobering picture, Proceedings of the National Academy of Sciences of the United States of America, 119(37), e2213762119
Piguet, E. (2022). Linking climate change, environmental degradation, and migration: An update after 10 years, Wiley Interdisciplinary Reviews: Climate Change, (13), e746
Popp, J., Peto, K. & Nagy, J. (2013). Pesticide productivity and food security. A review, Agronomy for sustainable development, 33, 243–255
Redden, B., Yadav, S.S., and Hatfield, J.L. (2014). Global climate change and food security, Chapter 8. In "Temperature and Plant Development". Eds K.A. Franklin, P.A. Wigge.

Wiley Blackwell & Sons, Inc. Ames Iowa, USA), 181–202.Reidsma, P., Ewert, F., Boogaard, H., van Diepen, K. (2009). Regional crop modeling in Europe: the influence of climatic conditions and farm characteristics on maize yields, Agricultural Systems, 100(1–3):51–60

Rolo, V., Rivest, D., Maillard, E., & Moreno, G. (2023). Agroforestry potential for adaptation to climate change: A soil-based perspective, Soil Use and Management, 39, 1006–1032

Rosenstock, T.S., Wilkes, A., Jallo, C., Namai, N., Bulusu, M., Suber, M., Mbai, D., Mulia, R., Simelton, E., Richards, M., Gurwick, N., Wallenberg, E. (2019). Making trees count measurement and reporting of agroforestry in UNFCCC national communications of non-Annex I countries, Agriculture, Ecosystems & Environment, 284:106569

Ruiz, I., Almagro, M., García de Jalon, S., del Mar Sola, M., Jose Sanz, M. (2020). Assessment of sustainable land management practices in Mediterranean rural regions, Journal of Environmental Management, 276, 111293

Torquebiau E. F. (2000). A renewed perspective on agroforestry concepts and classification. Comptes rendus de l'Academie des sciences. Serie III, Sciences de la vie, 323(11), 1009–1017

Usman, M., Makhdum, M.S.A. (2021). What abates ecological footprint in BRICS-T region? Exploring the influence of renewable energy, non-renewable energy, agriculture, forest area and financial development, Renewable Energy, 179:12–28

Vicente, J. G., & Holub, E. B. (2013). Xanthomonas campestris pv. campestris (cause of black rot of crucifers) in the genomic era is still a worldwide threat to brassica crops, Molecular plant pathology, 14(1), 2–18

Yu, T., Mahe, L., Li, Y., Wei, X., Deng, X., Zhang, D. (2022). Benefits of Crop Rotation on Climate Resilience and Its Prospects in China, Agronomy, 222, 12, 436