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# GOVERNING DRONE TECHNOLOGY FOR GLOBAL FOOD PRODUCTION: CLIMATE CHALLENGES AND LEGAL FRAMEWORKS

## *REGULAMENTAÇÃO DA TECNOLOGIA DE DRONES PARA A PRODUÇÃO ALIMENTAR GLOBAL: DESAFIOS CLIMÁTICOS E ESTRUTURAS JURÍDICAS*

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**Abstract**
Climate change is a global phenomenon that poses significant challenges to agriculture and food sector. Due to certain natural and human activities, the planet is undergoing unexpected changes that are affecting the animal and plant agriculture and food production system as a whole. Shifting temperatures and rain patterns, the increasing frequency of extreme weather events, as well as the spread of new pests and diseases, are transforming the ecosystem. Due to these rapid changes the production of agricultural sector decreased and threatening global food security due to lack of uses of innovative technologies. To address this agriculture and its

***Resumo***
*As mudanças climáticas são um fenômeno global que representa desafios significativos para a agricultura e o setor alimentício. Devido a certas atividades naturais e humanas, o planeta está passando por mudanças inesperadas que estão afetando a agricultura animal e vegetal e o sistema de produção de alimentos como um todo. Mudanças nas temperaturas e nos padrões de chuva, o aumento da frequência de eventos climáticos extremos, bem como a disseminação de novas pragas e doenças, está transformando o ecossistema. Devido a essas rápidas mudanças, a produção do setor agrícola diminuiu e ameaça a*

mounting problems, sustainable agriculture development has come to rely on drone technology. The use of drones observed and transformed the agriculture sector through enhanced crop monitoring, resource allocation, and overall farm productivity. However, there is a need to establish compliance, to manage a broad spectrum of airspace law, privacy law, and information protection law. Fears about drones violating privacy by taking unapproved video of private property are growing along with public concerns and expectations of stringent drone laws. Farmers are provided with real-time valuable information pertaining to several components of their operations through state-of-the-art equipment drones or Unmanned Aerial Vehicles (UAVs) equipped with high-definition resolution cameras. This is not limited to just soil conditions and assessments, it includes crop productivity, pest or disease levels and biodiversity. Farmers can now effectively collect data with this level of precision, allowing for more rational timelier resolutions regarding the application of irrigation, fertilizer as well as pest controls, all of which contribute towards maintaining productivity among the demanding climate conditions. This also allows farmers to reduce the amount of damage and crop loss that occurs by enabling them to deal with situations as they develop. For instance, drones can squash a field at one time to look for signs of drought and disease which enables quick and cost-effective measures to be put in place regions where the possible productivity of crops is higher. This form of agriculture helps improve productivity and ensures that environment friendly farming practices are used. The review described and critically analyzed the importance of drone technology specifically in the agriculture sector. To better use of drone technology in agriculture sector, all relevant bodies must ensure that these tasks are carried out through specialized training, comprehensive data management, and dialogue with regulatory bodies. By collaboration and innovation within the agricultural sector, farmers are able to improve their productivity, while ensuring compliance with existing legislations. Finally, this study investigates the changing legal frameworks governing drone activities at the national and international levels. Drones have a lot to offer in resource management and precision farming, but their use presents serious issues with airspace sovereignty, liability, privacy, and environmental preservation. Cross-border drone operations face difficulties due to international laws like the 1944 Chicago Convention, which establish state sovereignty over airspace, especially in situations where security is a

*segurança alimentar global devido à falta de uso de tecnologias inovadoras. Para lidar com a agricultura e seus problemas crescentes, o desenvolvimento da agricultura sustentável passou a contar com a tecnologia de drones. O uso de drones observou e transformou o setor agrícola por meio do aprimoramento do monitoramento das culturas, da alocação de recursos e da produtividade geral das fazendas. No entanto, é necessário estabelecer conformidade para gerenciar um amplo espectro de leis do espaço aéreo, leis de privacidade e leis de proteção de informações. Os temores de que os drones violem a privacidade ao gravar vídeos não autorizados de propriedades privadas estão crescendo, juntamente com as preocupações e expectativas do público em relação a leis rigorosas sobre drones. Os agricultores recebem informações valiosas em tempo real sobre vários componentes de suas operações por meio de drones de última geração ou Veículos Aéreos Não Tripulados (UAVs) equipados com câmeras de alta definição. Isso não se limita apenas às condições e avaliações do solo, mas inclui a produtividade das culturas, os níveis de pragas ou doenças e a biodiversidade. Os agricultores agora podem coletar dados com esse nível de precisão de forma eficaz, permitindo resoluções mais racionais e oportunas em relação à aplicação de irrigação, fertilizantes e controle de pragas, o que contribui para manter a produtividade em condições climáticas exigentes. Isso também permite que os agricultores reduzam a quantidade de danos e perdas de safra, permitindo-lhes lidar com as situações à medida que elas se desenvolvem. Por exemplo, os drones podem sobrevoar um campo de uma só vez para procurar sinais de seca e doenças, o que permite a implementação de medidas rápidas e econômicas em regiões onde a produtividade das culturas é mais alta. Essa forma de agricultura ajuda a melhorar a produtividade e garante que sejam utilizadas práticas agrícolas ecologicamente corretas. A revisão descreveu e analisou criticamente a importância da tecnologia de drones especificamente no setor agrícola. Para melhor utilizar a tecnologia de drones no setor agrícola, todos os órgãos relevantes devem garantir que essas tarefas sejam realizadas por meio de treinamento especializado, gerenciamento abrangente de dados e diálogo com órgãos reguladores. Por meio da colaboração e inovação no setor agrícola, os agricultores podem melhorar sua produtividade, garantindo ao mesmo tempo o cumprimento das legislações existentes. Por fim, este estudo investiga as mudanças nos marcos legais que regem as*

concern. Although national frameworks differ greatly, the International Civil Aviation Organization (ICAO) has made an effort to offer regulatory guidelines.

**Keywords:** Climate Change. Agriculture. Food Production. Drone Technology. Agriculture. UAVS. Legal Challenges. Privacy Concerns. Regulatory Compliance.

*atividades de drones nos níveis nacional e internacional. Os drones têm muito a oferecer em termos de gestão de recursos e agricultura de precisão, mas seu uso apresenta sérios problemas relacionados à soberania do espaço aéreo, responsabilidade civil, privacidade e preservação ambiental. As operações transfronteiriças com drones enfrentam dificuldades devido a leis internacionais como a Convenção de Chicago de 1944, que estabelece a soberania dos Estados sobre o espaço aéreo, especialmente em situações em que a segurança é uma preocupação. Embora os marcos nacionais sejam muito diferentes, a Organização Internacional da Aviação Civil (ICAO) tem se esforçado para oferecer diretrizes regulatórias.*

***Palavras-chave:*** *Mudanças climáticas. Agricultura. Produção de alimentos. Tecnologia de drones. Agricultura. UAVS. Desafios legais. Preocupações com a privacidade. Conformidade regulatória.*

## 1 INTRODUCTION

The world is facing extreme change in climate which poses a huge threat to global agriculture. (Abbass et al. 2022; Habib-ur-Rahman et al. 2022). It is predicted that the world will face a rise of 2.5-4.5°C towards the end of the 21st century (Bindhu et al. 2021; Yaduvanshi et al. 2021). This greatly impacts nutritional security in every region (Gopakumar, 2022; Wijerathna-Yapa and Pathirana, 2022). Concrete danger appears to exist for agricultural production (Schneider and Asch, 2020), forest resources (Mansoor et al. 2022), and rural economies (Nhemachena et al. 2020) which affects a lot of people including farmers, ranchers, and communities as a whole (Ikhuoso et al. 2020). Farmers face new challenges with increased temperatures, changes in rainfall, and other climate conditions while trying to achieve targets (Prajapati et al. 2024). Climate change effects lead to lower agriculture production, and ultimately shortage of food production (Abbas et al. 2022; Habib-ur-Rahman et al. 2022). Further due to changes in the humidity and temperature, pests and diseases can spear, and crop yield and production can be compromised. These impacts change by region, but every corner of the globe suffers the consequences of climate change. It is crucial to understand how climate change

interrelates with the agriculture sector in order to formulate measures to adapt and mitigate its effects (Paudel et al. 2021).

## 2 GLOBAL SCENARIO OF CLIMATE CHANGE

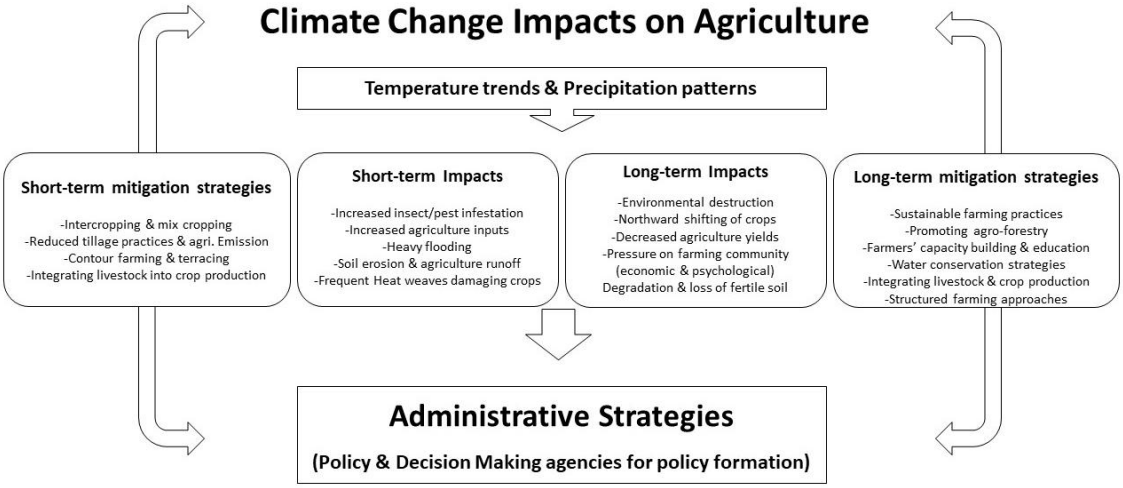
Continuous transformations caused by global warming have solicited the interest of all countries of the globe which, in turn, requires multinational involvement and strategies. The emissions of greenhouse gasses continue to increase and the climate of the planet is changing in an unparalleled manner (O'Neill et al. 2020). Changes in climate and biodiversity are reflected in a number of different but intertwined phenomena these include increases in temperature, changes in precipitation, an increase in the frequency and intensity of extreme weather patterned sea levels, developments in the ecosystem, and biodiversity changes (Yalew et al. 2020; Perera et al. 2020).

There is a wide range of the consequences of climate change when we think about food, public healthcare, hydrologic resources, biodiversity, the economy (Molotoks et al. 2021; Gernaat et al. 2021). Groups who are exposed suffer the most, having a higher probability of being food insecure, being displaced, and losing jobs particularly in developing countries. (Habib-ur-Rahman et al. 2022).

Even with the initiatives taken through policies such as the Paris Agreement, a lot more could be accomplished through recent developments and an evaluation of their respective climate impacts (Kemp et al. 2022). It is equally important to incorporate actions and measures aimed at improving resilience and mitigating the impacts of climate change on various communities and ecosystems (Cetin et al. 2023). The challenges presented by climate change require purposeful integration and engagement across the globe, sectors, and stakeholder groups and towards the direction of a coordinated response by science, policy, technology, and civil society to achieve sustainability and resilience (Wang et al. 2022; Tang et al. 2021).

**Figure 1**

*Diagram showing the possible effects of climate change on the food production and the suitable adaptation and mitigation strategies*




Adopted from: Abbass et al., 2022.

## 2.1 Rising temperatures

The first and foremost component of climate change is the increase in temperatures globally. It is a known fact that almost every decade in the last century has been warmer than the previous one (Lindsey and Dahlman, 2020). The fossil fuel based economic activities, deforestation and industrialization has resulted in emissions which have caused warming of the planet's average surface temperature in the last few decades (Mikhaylov et al., 2020).

The trend of increasing temperatures is anticipated to continue towards the latter part of this century, with the possibility of rise in temperatures anywhere between 1.5°C to 5°C or more, depending on emissions in the forthcoming years (Abbas et al. 2022). Consequences of increased temperatures is far reaching and multi-faceted. More ailing urban populations suffer from chronic conditions due to dying infrastructure (Palinkas and Wong, 2020). The shift in average temperatures, and elevated temperature regions particularly affect ecosystems by altering the established distribution and density of species, location of migration, and potential extinction of species (Salimi et al., 2021). Positively scorched regions of the world can alter farming capabilities, water resources, and pest populations with issues like food security and employment opportunities being more severe (Skendžić et al. 2021; Malhi et al. 2021). Moreover, high temperatures

amplify the rate at which the polar ice caps and glaciers melt, accounting for higher sea levels which leads to rapid coastal erosion and submersion activities. (Tabari, 2020). These changes pose threats to populations residing near the coast, to this infrastructure and to the world's ecosystems, resulting in economic disruptions, land degradation and greater susceptibility to meteorological damages such as storm surges and hurricanes (Hussain et al. 2020).

In response to these growing temperatures there needs to be greater concentration directed towards mitigation of greenhouse gases by way of policies, advanced technologies, and changes in lifestyle subsequently. There are several ways better self-reliance to global warming impacts can be attained, such as enhancement of existing preventive measures, implementing proactive sustainable land-use policies, and erecting state-of-the-art high-temperature tolerant facilities. Yet, to truly address the issue of global warming, collaboration on all levels is required to develop a sustainable framework that all countries must commit to.

### 2.2 Extreme weather events

Storms, extreme flooding, droughts, and very high or low temperatures have all risen alongside extreme and sudden shifts in global weather patterns and climate (Wang et al., 2023). All of these occurrences pose threats to the food safety in rural areas, their main income sources, and agricultural productivity. Such shifts usually result in grave impacts like people losing their homes, infrastructure damage and death in addition to changing the ecosystems and economies (Tripathy et al. 2023; Niggli et al. 2022). As temperatures grow hotter, the output of crops and animals decrease because of excessive heat, the rates of water evaporation, as well as the flowering, grazing, and even pollination activities (Clarke et al. 2022).

Droughts causes limited availability of water, reduction of soil quality, and lead to the failure of crops which has an effect on agriculture no matter if it is irrigated or rain fed agriculture. Mukherjee et al., 2022 Both soil and crops are at the risk of being washed away or even contaminated along with water sources during floods. This results in a lot of damage commercially and makes recovery difficult and costly. Frame et al., 2020 The coastal areas are at the mercy of hurricanes and storms which can ruin infrastructure, disrupt supply chains, and displace the farming communities Brás et al. 2021 These

adverse climate phenomena have impacts on agricultural activities and impose overwhelming hardships on poor farmers and vulnerable groups Zhang et al. 2022. This paints a picture where the hardest hit conserve farmers and vulnerable communities are subjected to wide ranging socio-economic impacts. As a way to curb climate change issues, new policies and strong support systems are required alongside alternative how people earn, warning systems, infrastructure, and agriculture that can withstand climate change (Yin et al. 2022).

### 2.3 Sea-level rise

Global warming contributes to the rise of sea levels and is the consequence of a variety of factors working together. Most importantly, these factors include the expansion of seawater due to changing temperatures and the melting of glaciers and ice sheets (Griggs and Reguero, 2021). Combined with the effects of global warming, these processes have resulted in the rise of sea levels across the globe (Rahimi et al, 2020). This has serious effects on agricultural activities, food security, and employment opportunities globally.

Restricting farming activities or the rise of sea levels presents complex issues to food security across the globe. Increased seawater intrusion and coastal inundation is a major concern for food security, notably for coastal farming regions (Hsiao et al. 2021). Saline intrusion is the process where seawater is pushed onto land and results to soil salinization, rendering lands uncultivable and severely impacting coastal yield. The extensive area of arable land that gets salinized negatively impacts agricultural production and increases poverty levels within coastal farmer communities (Bevacqua et al. 2020). The intrusion of saltwater into fresh bodies also contaminates irrigation systems, negatively impacting crop yields and water availability.

As a result, high sea levels, more intense storm flows and severe weather can cause significant destruction to important agricultural facilities such as irrigation and storage facilities, and transport infrastructures (Bermúdez et al. 2021). This disrupts the food system further and aggravates the plight of food insecurity and sustenance especially in coastal areas where local economies primarily depend on agriculture.

Even more alarming than the damages themselves, rising sea levels present socio-economic threats that coastal communities will have to contend with. Coastal populations

become more susceptible to devastating natural disasters such as storm surges and flooding while simultaneously undermining agricultural infrastructure and obstructing food supply chains (Davenport and Burke, 2021). The death or permanent displacement of individuals through reduction of territory and livelihood opportunities tends to enforce sophisticated social issues through escalated resource competition.

The loss of coastal habitats and ecosystems decreases the adaptability potential of agricultural systems at the same time increasing community vulnerability to the impacts of climate change (Orton et al. 2020). In order to mitigate the effects that rising sea levels have on agricultural activities, it is essential to take a multi-sectoral approach that will foster positive adaptation and sustainable land management practices to protect the food systems and economies against the realities of climate change (Gori et al. 2022).

### 2.4 Biodiversity loss

Climate change is a complex phenomenon that threatens biodiversity by destroying ecosystems and causing species loss at an astonishing level (Turner et al. 2020). As a result of increased extreme weather patterns, biodiversity loss becomes a dire consequence of these changes. In addition, fragmentation and shifting temperature and precipitation patterns further exacerbate the situation (Habibullah et al. 2022; Shivanna, 2022). Organisms that have limited habitat ranges or specific temperature requirements are finding it extremely difficult to adapt, and as such, the rate of species extinction is growing higher (Muluneh, 2021). At the same time, the change in species ranges caused by climate changes results in decreased populations of native species and more dominant populations of non-native invasive species (Prakash, 2021).

As Pettorelli et al. (2021) observe, the reduction of biodiversity leads directly to a decline in ecosystem processes such as pollination, soil maintenance, and pest control, which are pertinent to agricultural productivity. Attributes of particular species are becoming more and more narrow in scope, which gradually renders them defenseless against new diseases, pests and ecological stresses, thus aggravating agricultural conditions (Manes et al. 2021). Both the reduction of pollinators and the imbalance of pest control led to a drop in crop yields while overdependence on pesticides entails health and environmental risks (Arneth et al. 2020). Soil erosion is worsened through loss of biodiversity, compounded by the remaining individual's ability to bear crops, increase in

scarcity of water resources, and make it increasingly difficult to manage agricultural water resources (Trew and Maclean, 2021). The neologism defines the fishing, hunting, and foraging practiced by some socially marginalized groups who are entirely dependent on biodiversity for their sustenance, making them increasingly vulnerable (Worm and Lotze, 2021).

At global levels, agricultural practices are the main reason for biodiversity loss and they have also suffered reduced productivity alongside high volatility of food prices and nutritional health, which all negatively impact food security (Jaureguiberry et al. 2022). The burden is more for the sensitive population segments that are already vulnerable to higher levels of food insecurity and under-nutrition (Shin et al. 2022). These impacts are greatly experienced by vulnerable groups who are at a greater risk of food insecurity and malnutrition (Shin et al. 2022). Furthermore, the loss of biodiversity lowers the capacity of food systems to cope with climate change, confirming the need for an integrated approach to development that guarantees agricultural biodiversity conservation (Singh et al. 2021).

To respond effectively to the effects of climate change, the underlying causes of the malnutrition and food insecurity must be addressed, and biodiversity loss must be proactively dealt with to sustainably produce food, protect livelihoods, and improve food security (Caro et al. 2022). Therefore, there is a need to focus on reducing the effect of climate change on biodiversity loss, enabling resilience in agricultural systems to guarantee food for both current and future populations (Mashwani, 2020; Schmeller et al. 2020).

## 3 HOW CLIMATE CHANGE AFFECTS AGRICULTURE WORLDWIDE

The emerging phenomena of climate change will have a multi-faceted impact on global farming as it envelopes biological, economic, and sociological factors. The high temperature of the region altered rainfall, and an increase in the frequency of extreme weather events are all signs of the changing climate that profoundly disrupt agricultural ecosystems (Habib-ur-Rahman et al. 2022). Increasing temperatures results in heated stress within the cattle and crops, which severely lowers yields and degrades quality (Malhi et al. 2021). Changes in rainfall formulas can bring water shortages or can lead to

overwhelming floods, drastically changing crop allocation, irrigation methods used, and even soil water content (Ortiz-Bobea et al. 2021).

As we have already witnessed through drought, floods, winter storms, and soaring temperatures, these extreme climates tend to damage infrastructure severely while lowering the overall value of crops and livestock (Jägermeyr et al. 2021). Tightening environmental conditions are beneficial for these pests and pathogens, which increases the need for pest management and pesticides Skendžić et al. 2021. Soil degradation, including erosion, salinization, and desertification, furthermore, decreases the number of cultivable areas while tainting soil quality (Corwin, 2021).

Furthermore, the disruption of weather patterns due to global warming reduces the crop yield and genetic variability of particular crops such as plants that rely on insect pollination (Habib-ur-Rahman et al. 2022). Apart from these production impacts, climate change also has social impacts, and developing nations face greater challenges due to marginalized farmers and rural societies. These vulnerable groups are more likely to be food insecure, suffer from inadequate income for economic progress, and face social ills such as poverty and unequal distribution of wealth (Chandio et al. 2020). In addition, climate related changes in human settlement and movement creates additional strain on agricultural systems by changing employment opportunities, deeper socioeconomic inequalities, and worsening food scarcity (Mishra et al. 2021). Additionally, international exchanges of agricultural products are greatly impacted by climate driven variances in output, and attack on the market's production causes changes in prices and scarcity of supplies (Janssens et al. 2020). These consequences spell doom concerning efforts to make agricultural systems more adaptive in the face of climate change threats, and the failure to provide frameworks for climate mitigation poses high risks for sustainable development everywhere in the world (Shahzad et al. 2021).

### 3.1 Soil health deterioration

The significant changes in climate have detrimental effects on the soil, disrupting soil ecosystems and undermining the capacity of soils to sustain plant growth as well as other functions in the ecosystem (Lal, 2020). Some of the most evident impacts of climate change on soil health are the increased cases of soil erosion because of temperature and rainfall distributions. Increasing temperatures have a positive relationship with soil

erosion due to topsoil loss and decreased fertility of the soil (Lal, 2020). Erosion is worse in the current era of climate change as it suffers the more rainfall as it leads to the loss of important minerals as well as organic substances (Tahat et al. 2020). Moreover, Continuous hot and dry periods lead to less moisture in the soil, which results in a decrease in microbial activities along with nutrient cycling that is important for the maintenance of soil fertility (Corwin, 2021). Changes in the pattern of rainfall also affects the supply of nutrients and the ph. level of the soil which impedes the growth of plants and crops (Mukhopadhyay et al. 2021).

Furthermore, the impact of climate change on soil health negatively affects Corwin's logic in 2021. Resources such as food security, water quality, and the resilience of ecosystems are placed in grave peril. The process of salinization, along with desert encroachment, is constantly on the rise, making once suitable land arid and unproductive for agriculture. Combined practices such as cover cropping and agroforestry can be employed to retain the balance and health of soil against the harmful effects of climate change (Mukhopadhyay et al. 2021).

### 3.2 Reduced crop yields

The rising temperatures, heatwaves, and changes in rainfall effecting overall yields and reduced agricultural productivity. With the rising temperatures, the crops are more prone to suffer from heat stress during sensitive growth periods ('Lesk et al,' 2022). Over time, heat stress causes damage to crops and severely impairs processes such as photosynthesis, which reduces productivity over time ('Brás et al,' 2021; 'Lesk et al,' 2022). There have also been changes in rainfall that have resulted in extended droughts and overly high rainfall, which leads to crop failures and decreases in the overall food supply due to a lack of water coupled with poor crop yields. Droughts often result in crops wilting due to insufficient moisture resulting in metabolic dysfunction and low absorption of nutrients leading to crop failures and objectives not being met, (Cohen et al. 2021). On the contrary, unpredictable falling rain usually inhibits soil moisture equilibrium, which stalls absorption, root growth, germination. All of these factors serve to decreasing crop productivity further ('Feng et al,' 2021). Such problems affect farmers directly impoverishing them which increases the problem of food scarcity and wealth imbalance especially for poorer farmers in poor regions. Thus, agricultural markets around the world

are subject to volatility and instability based on the supply and demand imbalance that increases shocks and prices that become increasingly destabilized Hiencke et al, 2022. In an effort to solve these problems, agricultural systems are developing new strategies to cope with adversities, Alotaibi 2023.

### 3.3 Shifts in crop suitability

The alteration of crops concentrations and agriculture's ability to adjust to these changes is transforming due to shifts in climate (Kephe et al., 2021). Certain regions will experience an escalation in temperature alongside a gradual change in the precipitation they receive. There is a notable impact on the rural water supplied for irrigation due to changes in the climate. Therefore, the surface access to these areas would be resourced for agriculture in the long term to retrieve the crop when a certain level of heat and water stress is proficiently maintained (Abd-Elmabod et al.,2020). Farmers are compelled to make these changes by adopting new crop varieties, new times for planting, and new agricultural techniques (Fatima et al. 2020).

Food security, international trade, and the health of ecosystems are influenced at a greater scale. One such solution includes investment into crop study and development programs to foster economically and environmentally sustainable land use (Li et al. 2021; Baum et al. 2020). To lessen the negative outcomes that come with shifts in crop suitability, it is vital to assist farmers with new agricultural methods (Surendran et al. 2021, Rosenzweig and Parry, 2022).

### 3.4 Water availability and irrigation challenges

With the oil demand along with the food producing over the border bound are subsequently rising under the agricultural expansion, there is an increasing change in international net investment within water infrastructure. The loss of water resources is complex in nature and varies combining these conditions with other anthropological activities along with the environmental changes in climatic regions and border areas through military operations can cover the irrigation along with boosting subsurface caliphate industries. A combination of these practices can pose a threat and significantly impact regional productivity along with the security of food resources. The delicate

interplay of these practices can lead to dire control and exploit the reserves of water. Changes in rainfall can increase the intensity and frequency of rain events which increase erosion and surface runoff, which creates further issues for water availability. Apart from environmental reasons, anthropogenic activities like deforestation, urban expansion, and land exploitation intensify water scarcity by disturbing the water cycle and further decreasing the rate of water infiltration.

### 3.5 Increased pest and disease pressure

For instance, various pests and diseases have started evolving at an unimaginable pace due to climate changes placing unprecedented threats to agriculture as well as food security. As temperatures rise and weather becomes unpredictable, so do the habitats and life cycles of numerous pests and pathogens, often to their benefit (Skendžić et al. 2021a). Higher temperatures and humidity may increase the range of certain pests that have, until now, not been able to survive in those regions fostering conditions for them thrive (Cilas and Bastide, 2020). Significant agricultural pests, including aphids, beetles, and locusts, have enhanced growth rate due to climate change resulting in higher survival rates through winters while warm temperatures lead to increased population density and infestations (Skendžić et al. 2021b).

The increase in temperature may also reduce the synchrony between biotic pests and their enemies, which limits the control offered by biological pest management (Pathak et al. 2021). Greater likelihood and severity of weather extremes, including storms accompanied by intense rain, can also encourage some fungal and bacterial pathogens. Cultivated plants that are flooded or submerged in water for a greater duration are most susceptible to blight, rust, and rot which severely impact crop production (Chaloner et al. 2021). On the other hand, the strains exerted by heat waves and droughts are bound to make the plants weak and in turn, more susceptible to pest and pathogen attacks (Singh et al. 2023; Mansoor et al. 2022).

Climatic changes owing to natural and manmade activities can increase the pressure of pests and pathogens on crops and the effect can have dire consequences. Decreased food production will raise food prices throughout the world and people especially in less developed countries who rely heavily on agriculture will become food insecure. The ecosystem is also at a risk because with the advent of new means to control

pests depends on the extensive use of chemicals which are bound to affect the flora and fauna, decrease the variety of species, and pollute the already scarce soil and water resources (Chaloner et al. 2021; Rogiers et al. 2022).

### 3.6 Impacts on food security

The frequent shifts in weather change food security by causing disruptions in its provision, reach, affordability, and consumption owing to climate changes. Global warming alongside changes in rainfall and increased rates of extreme weather directly affects agricultural output as it's an integral part of a country's economy. Such transformations interfere with the growth and development of crops leading to lower output levels and yields in wheat, rice, and maize which are globally regarded as staple foods. Shortage of suitable water and high temperature leads to degradation in plant growth and boost crop loss along with increase undernourishment. Reduced food availability worsens the existing malnutrition in underdeveloped areas which overly depend on agriculture.

Additionally, weather shifts such as storms, floods, and droughts intervene with food production further. Such events tend to reduce livestock and crops alongside harming agricultural infrastructure which leads to a drastic shortage of food. These obstacles in food production raise the cost of food and give rise to poverty in an adequate nutrition deprived population. Price hikes affect both consumers and entire communities and can have damaging impacts on the economy of a nation, especially those that lack the means to buffer such impacts.

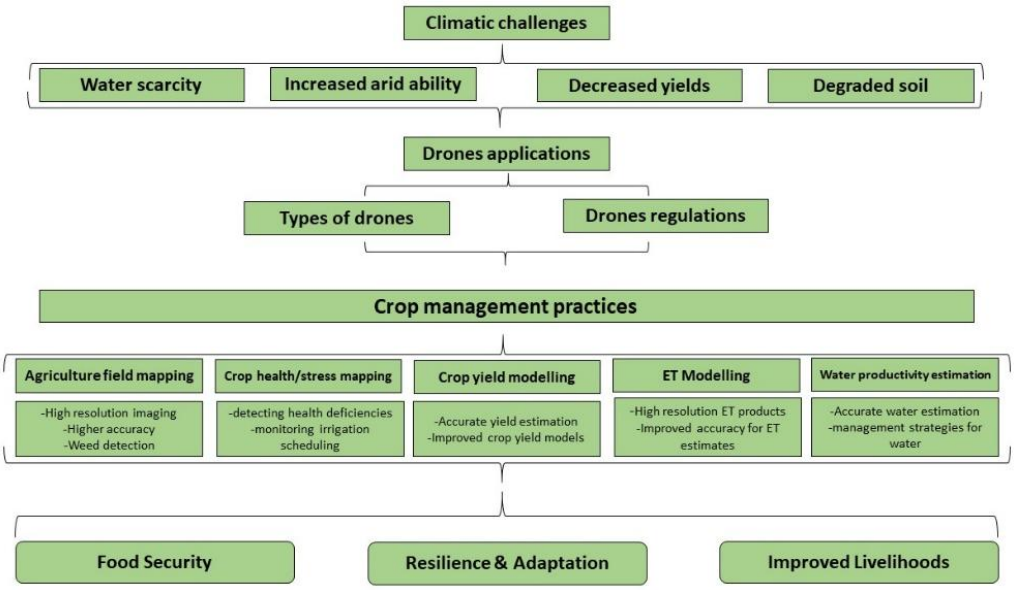
Food quantity, quality, and types available are profoundly affected by the changes in climate. Crop farming is not uniformly distributed, some places can be more or less amenable as regionally specific changes might make them viable. For example, some areas might become too arid to sustain traditional farming and will likely have to turn to crops that are less known and potentially less nutritious. Moreover, higher concentration of CO2 may lead to increased deficiency problems by lessening the levels of protein, zinc and iron in certain staple crops.

## 4 ROLE OF DRONE TECHNOLOGY IN AGRICULTURE FOOD PRODUCTION

Dutta and Goswami (2020) suggest that drone technology can help increase agricultural productivity for areas that are heavily affected by climate change. Drones can be adopted by farms in order to enhance precision agriculture, resource allocation, crop management, and the mitigation for climate change outcome in food security (Hafeez et al. 2023). Drones can capture high quality images and videos, alongside real time assessments of the crops, soil, and moisture content (Inoue, 2020).

**Figure 2**

*Importance of drones in agricultural productivity & food security*




Adopted from: Nhamo et al., 2020

Along with multispectral cameras drones fitted with thermal sensors can also be used to detect crop stress, occurrence of diseases, and pests at stages when they cannot be seen (Pathak et al. 2020). Access to this information allows farmers to target specific areas for application of fertilizers, pesticides, and even water leading to significant reductions in resource expenditure and more responsible environmental practices (Badaluddin et al. 2020).

Drones are also important for effective water management which is essential for increased climate induced droughts and erratic precipitation (Rachmawati et al. 2021). Drones can be harnessed to gauge soil moisture levels and map water stress areas to help

improve irrigation (Nhamo et al, 2020). This kind of irrigation ensures that plants make use of the water and at the same times saves water by improving drought resistance (Esposito et al. 2021). In addition, drones can be deployed to monitor irrigation systems to identify and mitigate water distribution leaks and inefficiencies (Velusamy et al. 2021).

Drones serve as a quick damage control measurement in areas that are affected by severe weather conditions. They can easily be deployed to retrieve data, in this case the damages done by climate change could be calculated (Dileep and Navaneeth, 2020). The concern over soil erosion is enormous and farmers face difficult decisions such as whether to replant or use soil restoration. This decision making over resource allocation after a flood, storm, and even a heatwave can be simplified through drones as they are capable of restoring the area at a fast pace (Mogili and Deepak, 2020). Drones are another technology that strengthens the agricultural sector by making it more efficient at dealing with climate motivated disasters and proving the best return on investment. Also, they help to apply chemicals that control biological pests in agriculture to a specific region and in a better way than before (Iost Filho et al. 2020). As drones are more effective than traditional methods, they can save the environment from the chemicals which are detrimental for their wellbeing e.g., over exposure to chemicals (Boursianis et al. 2022). This leads to the preservation of the ecosystem alongside maintaining an agricultural economy. Drone systems provide more surveillance as well as control over agricultural livestock in case there is a change in climate which affects the farming women and men (Rakesh et al. 2021).

Drones help farmers keep an eye on herd movements, water sources, and pasture conditions and assist farmers in maintaining the health of their livestock in harsh weather conditions (Maddikunta et al. 2021). In general, the use of drones in agriculture helps address multiple issues that stem from climate change challenges (Hafeez et al. 2023). Drones allow for accurate observation, effective resource allocation, and quick action to climatic changes, which, in the long run, helps achieve sustainable growth, strengthen food security, and increase the resistance of farmers to the changes in the climate (Rehman et al. 2022). We’re witnessing a dramatic shift in agricultural development, giving farmers a way to adapt to increasing environmental challenges that plague agriculture.

More professionals in the development sector are starting to appreciate the significance of using drones, or Unmanned Aerial Vehicles, in combating climate change.

Drones provide great benefits, such as help sustaining the environment through the advancement of agriculture to reduce nitrate leeching, improve fuel economy, and increase efficiency in water usage (Inoue, 2020). Drones have various credible applications in agriculture apart from precision farming, such as assisting farmers in documenting their farms and boosting their credit ratings as well as monitoring wildlife, trees, animals, and even fences (Dutta and Goswami, 2020).

Drones, most importantly, help farmers monitor crops effectively as they can see from a bird's eye view which helps in spotting minute details that are not visible from the ground (Hafeez et al. 2023). Multi spectral imaging drones are capable of observing crops and monitoring conditions that were previously undetectable by the human eye like water scarcity, pest menace, health of the crops, as well as the requirement for fertilizers (Rachmawati et al. 2021). Specialized multi-spectral sensors equipped in drones take specialized pictures that assist in the data creation for crop grading. An example of this is the Normalized Difference Vegetation Index which is used to measure the satellite imagery vegetation and crop density as well as how green the area is (Ghazali et al. 2022). There is mounting evidence within the last several years that suggests that drones have the ability to transform agricultural practices (Haula and Agbozo, 2020; McCarthy et al. 2023).

McCarthy et al. (2023) further elucidate that drone technologies can greatly augment farmers' agricultural output, food availability, and incomes by offering valuable analytics, decreasing expenses, and aiding in better decisions. The digital divide in agriculture is on the verge of collapse due to the decreased costs of digital field sensors, remote sensing technologies, and drones. Farmers can access these innovative and impactful technologies (McCarthy et al. 2023; FAO, 2022).

Using drones and digital technologies is broadening the gap between cost and society's ability to access nutritious food. This is believed to happen as there is a decrease of prices available in the market which also improves the market access. This new agricultural feature is new to Nigeria as potato farming drones are able to develop, create and even assist in the design processes of a 3,000-hectare farm surrounding New Busa. The adjustments in the drone imagery can be used for terrain suitability and layout optimization (Zacharenkova, 2022). In Malawi, the use of drones has helped analyze and forecast crop yields during the recurring droughts, thus providing aid to smallholder farmers. In a different context, Mozambique has increased the empowerment of 2800

smallholder farmers, especially women, through drone-based data which led to increases in crop and water productivity (Zacharenkova, 2022).

Per Mandla et al. 2021, drones have improved the robustness of earnings by predicting seasonal trends and dealing with low agricultural productivity. They have also enhanced efficiency on the farm, which is equivalent to one hundred people working, by doing precision spraying. McCarthy et al. 2023 argues that drones should enable farmers from developing countries to be more productive and also enhance sophisticated data processing. As drones and digital technologies are expected to reduce costs and strengthen market integration, access to healthy foods should increase for the population (Sarkar et al. 2023). Nhamo et al. 2020 highlights how data from a drone improves crop supervision by real-time precise target planning and other advanced processes like better structures for ditches and new ways of applying fertilizers. Considering the slope and elevation of the land to determine how to divide and conquer the farmland, UAVs are very useful for watching extensive plots of land (Katekar and Cheruku, 2022).

The technology supplies broad signals of plant emergence and population aiding in the replanting, thinning and pruning, and improving crop models activities (Kalamkar et al. 2020). High resolution drone data also determines crop vegetation health, which permits precise application of fertilizers and reduces fertilizer waste, thus improving forestry planning (Cuaran and Leon, 2021). The agriculture sector becomes more adaptive and effective by integrating drone technology to the field, thus solving issues related to global warming and making it easier to achieve sustainable development in farming communities around the world (Bharti and Bharti, 2020).

### 4.1 Soil analysis for field planning

Drones have improved the efficiency of soil analysis in the agriculture sector by gathering precise and relevant information. Drones are able to take detailed photographs and collect data on multiple aspects of the soil using built-in advanced sensors. These aspects include composition, texture, moisture, and nutrient levels (Meivel and Maheswari, 2021; Dileep et al, 2020). This information is crucial in formulating proper nutrient management as well as in crop selection, irrigation planning, and making sure that adequate waters and fertilizers are used where necessary (Pathak et al. 2020).

Drones are especially useful for surveying large agricultural areas due to their speed and accuracy. Drones can fly over large fields to analyze its soil quality within a short time (Inoue, 2020). This makes it possible to use resources more effectively and diminish loss. For example, drones can outline sections of land that are parched so that farmers are aware of the specific spots that need fertilization and drones greatly assist in detecting the initial signs of the crop. (Webb et al. 2021).

### 4.2 Plant establishment

Labor shortages bring with them significant obstacles, particularly when it comes to the planting of crops. Farmers are facing challenges with manually planting crops because it is very labor-heavy and time consuming. Now, farmers can only look forward to escalating costs, delays, and more migraines. On the other hand, Pandey et al. 2020 argue that these issues can instead be solved with the implementation of drones because they can plant crops in expansive fields with incredible speed and precision. In simple words, drones engineered with planting systems have the ability to maintain accuracy while swiftly covering large fields. These systems of planting utilizing drones spray crops and beneficial nutrients over agricultural fields in specific programmed sequences by launching high precision sowing mowers. The achievement is the optimal and even spreading of seeds and nutrients to ensure uniform crop growth (Wan et al, 2021).

When it comes to the use of crops, the use of drones gets crops cultivated more efficiently. Consequently, uniform germination and growth becomes a predominant phenomenon, resulting in stronger crops. Robinson et al. 2022 argues that, with the aid of drones, crops tend to yield better, and field can be monitored more precisely. Some drone systems come with special features that can shoot off pods with seeds and nutrients directly into the soil. The pods are crafted to break open and ensure that seeds are placed at the correct depth, and in ideal growing conditions (Mohan et al. 2021).

Using drones has proven to be more cost effective due to the extreme reduction in manpower needed which is a huge advantage for any cultivating company (Pathak et al. 2020). This dramatic decrease in cost can be fulfilled by lessening the amount of manual work that is required, reducing the chances of errors being made while planting, as well as better controlling how much seeds and nutrients are necessary. Moreover, drones are

capable of operating in all types of field conditions and terrains which further improves their efficiency (Meivel and Maheswari, 2021).

At the same time, the use of drones in crop planting fosters environmentally friendly farming methods. Drones ensure that there is accurate distribution of inputs, which aids minimize seed and fertilizer wastage. All of this contributes to helping the environment (Inoue, 2020). Lower dependence on manual labor with the use of modern machinery means farms can be run with fewer resources. Thus, every farm complies with the rules of sustainable farming (Castro et al. 2023)

### 4.3 Crop health assessment

The application of drones in monitoring the growth of plants possesses many important benefits. To begin with, the advanced technology aids farmers in crop production because problems are resolved as soon as they are discovered. This results in healthier plants and better yield (Abbas et al. 2023). Also, it saves on the use of chemical pesticides, fertilizers, and other treatments because they are used only when necessary. This is more economical and environmentally friendly (Hafeez et al. 2023). In addition, the Food and Agriculture Organization (FAO) states that drones equipped with specialized sensors can capture multi-spectral images that result in reflectance that can be analyzed spectrally. With the help of these bands, it is possible to detect alterations or stress situations in plants that cannot be noticed through conventional sighting. One can derive metrics such as NDVI, LAI, or PRI (Chin et al. 2023).

This comprehensive depth of analysis has helped to enhance the criteria used for decision making during crop management, which has increased the agricultural productivity (Ecke et al. 2022). Moreover, drones generate information that is often hard or impossible to obtain by other methods. Manual crop checks entail a lot of risks as they require hoisting very heavy loads, making mistakes very easy. But unlike traditional methods, agriculture drones can scan hundreds of acres in minutes and provide accurate reports on the conditions of the crops (Miller et al. 2020).

This is particularly useful for drones in large operational scales as everything has to be executed meticulously and within a set time to ensure efficient management. Drones enable monitoring of the health of crops but can also serve as a tool for R&D on agricultural development. This allows researchers to easily measure the impact of

particular practices and environmental elements on particular crops (Iost Filho et al. 2020). This information can help for the development of effective farming technologies and techniques, and this can improve agriculture productively and sustainability (Kalamkar et al. 2020).

### 4.4 Precision crop spraying

About 20–40% of the total amount of food produced is lost due to pests, weeds, and plant diseases (Mitra, 2021). It is estimated and analyzed that farmer will lose over 40% of their crop production to pests and plant diseases if they stop employing crop protection methods FAO (2023), Cultivation using traditional chemical spraying techniques is extremely strenuous and hazardous owing to the exposure of the workers to chemicals that can damage their eyes, skin, and lungs. Surely, respiratory ailments afflict around 300,000 farmers in the country. Studies indicate 183 farmers were pesticide poisoned and died in Maharashtra state from 2013–14 and 442 farmers across the country were affected from 2017–18. In India, another agricultural death due to snakebite is quite significant. Close to 58000 farmers are estimated to die. (Katekar and Cheruku, 2022).

These issues in agriculture could be resolved by drone technology. Chemicals are dangerous in challenging geographic areas, including mountainous, sloping areas, and it is challenging to guarantee their application in the recommended dosage (Sahni et al., 2024). By gaining accurate knowledge of soil conditions, plant health, and yield forecasts, the drones can overcome these difficulties. Site-specific spraying is made possible by the drone's high-quality camera and sensors. In addition to ensuring that a precise or predetermined amount of liquid fertilizer and pesticide is sprayed on the scanned crops, the drone may scan the crop area for spraying. (Wang et al. 2022).

### 4.5 Irrigation management

Getting enough water to grow crops is a difficult problem in most drought-prone regions. The irrigation methods that are currently available supply water to a field consistently. For the best and most economical use of the water resources that are available, water must be supplied where it is truly needed (Meivel and Maheswari, 2021). Crop growth depends heavily on water, and too little or too much water might hinder a

plant's ability to grow properly. (Khadse, 2021). In a vast agricultural area, farmers must control irrigation according to the crop being grown.

With the aid of thermal digital cameras, the drone can help farmers make precise judgments for irrigation management. In specific regions of the agricultural field, the drone can record the extra water and the state of soil moisture stress. Through regular irrigation monitoring, the drone-assisted field survey aids in identifying irrigation leaks and achieving water use efficiency. In specific regions of the agricultural field, drones with sensors, thermal, and multispectral imaging cameras can record the heat and water stress in the crops. With this method, crops can receive irrigation according to their requirements. This will ensure that irrigation water is used efficiently and prevent water waste. (Zuo et al. 2021).

### 4.6 Tree-planting with drones

Integrating drones into tree-planting techniques is altering the manner in which reforestation is executed, thereby providing a potential solution to one of the most critical environmental issues today. AirSeed Technologies, Dendra, and FlashForest are already changing the industry by using drones to plant seeds and track sapling development. This method greatly improves the efficacy and effectiveness that can be achieved on reforestation projects and makes it possible to tackle deforestation on a larger scope than is possible with other methods (Khuzaimah et al. 2022). One of the main benefits of using drones for reforestation is the speed and efficiency with which they can operate. Drones can seed vast territories in a fraction of the time that it would take a human team and can disperse thousands of seeds in a day (Ghazali et al., 2022).

This seed blight can indeed be helpful in Madagascar and other countries that are facing extensive deforestation due to rapid population growth and drastic climatic changes (Finn et al. 2022). Drones can also reach very inaccessible places to supplement restoration work in areas that are otherwise very difficult to restore such as steep mountains, remote areas, wetlands, and other ecosystems that have been destroyed have greatly benefited from this (Holden et al. 2021). Drones are a very effective tool in restoring the mangrove forests which are a crucial to mitigating the impacts of climate change, protecting the land and nurturing biodiversity (Hafeez et al 2023). Mangroves are a pivotal portion of the carbon cycle, serving to enhance the coastal carbon economy

while protecting the coast and preserving life in the seas. These areas have lagged behind in comparison to their potential because other methods take a long time and are labor intensive. Aiming for maximizing germination and healthy ecosystems, drones equipped with specialized pods containing mangrove seeds can achieve the desired outcome (Jintasuttisak et al 2022).

Also, drones are furnished with modern and innovative technology and easily oversee the growth of newly planted plants and can assess future health. These sensors and cameras can transmit evidence about a plant's health issues and status, soil's condition. This constant observation ensures that the reforestation plan is executed properly and allows people to act fast if there are any problems (Chen et al. 2021).

## 5 LEGAL FRAMEWORKS GOVERNING DRONE TECHNOLOGY

### 5.1 International regulations analysis

Emerging technologies like modern drone technology brings along with its motivation opportunities as well as security concerns for governments across the globe. Technological advancement will always have positive as well as negative implications on the law. The existence of drones having impactful effect if we observe and analyze through the lens of technological growth. But these modern technologies have significantly impacted legal framework and this creates a gap and a loophole which may have the adverse effect of threatening the sovereignty and integrity of states. Spying is one use of unmanned aerial vehicles (drones) that can compromise state sovereignty. According to Article 1 of the 1944 Chicago Convention, which adopts the idea of state sovereignty based on the 1919 Paris Convention, "The contracting parties recognize that every sovereign state has complete and exclusive sovereignty over the airspace above its territory." This clause provides detailed guidance on sovereign states. Since state sovereignty is clearly violated and not respected—as demonstrated by several accident instances involving the use of drones—drones used for espionage purposes (Article 1 of the 1944 Chicago Convention) are a unique issue that must be given top priority by the state. Numerous research has looked at and examined the issue of drone use. explains first that a group of lawful technology are drones. (Smith, A. (2022).

Agriculture has been the root of every civilization for centuries and provides primary needs as well as the means to develop economically, socially, and ecologically. With the emergence of new technologies, agriculture is no longer confined to the farm alone, having already drastically changed the industries, delivery, and even security. Farmers can receive real-time, high-definition information about crop conditions through Drones allowing farmers to make quick and informed decisions. Farmers can monitor agriculture land, tracking variables such as temperature- and humidity as well as the growth of various plants.

Drones, or unmanned aerial vehicles (UAVs), are subject to a variety of international laws and regulations mainly due to security, safety, and privacy. The United Nations emphasizes that the drones are legal, but their application is subject to international laws in relation to human rights and humanitarian issues. Christof Heyns, one of the UN Special Rapporteur, said that "There must be some law for global security, drones must obey the law" and brought to attention the need for responsibility in the use of drones (UN GA Delegates 2013). This principle is important because drones are more frequently used in a number of farming activities that are likely to affect food security and ecological balance.

It is observed that in the US, drones are making a significantly difference in the agriculture sector. One of the major factors that contributed to the drone uptake in agriculture within the United States is the positive attitude of the Federal Aviation Administration (FAA) towards drones and on agriculture. The FAA's Part 107 rule allows drone flights for any business purpose, including agriculture, while imposing some restrictions on operations like altitude, time of day, and keeping the drone in sight (Engberts, B. and E. Gillissen 2020). Increased agricultural productivity, cost savings, and sustainable farming are some of the measures the US is enjoying now. Drones promote precision farming through remote sensed monitoring, as well as active controlling of the measures applied to the crops. Some major barriers to more widespread adoption is the range of advanced drone systems, expenses that come with it, the demand for skilled personnel to operate the drones, and lack of infrastructure in the rural areas that would allow data collection and transmission from the drone.

### 5.2 European Union Legislation

In regards the appropriateness of drone deployment in civil aviation, the European Union has adopted a number of regulations. Safety requirements for civil aviation are specified in regulation 2018/1139 which also includes provisions for UAVs (REGULATION (EU) 2018/1139). Furthermore, the Implementing Regulation (EU) 2021/666 specifies operational provisions for drones in the U-space airspace (Bassi, E. (2024).). These policies are important so that drone activities in agriculture do not violate airspace security or pose a danger to the public.

In the UK, the Civil Aviation Authority (CAA) deals with the certification and licensing of drones (UKCAA. 2020). This lack of rules concerning commercial drones severely stifles innovation. The Air Navigation Order has defined small, unmanned aircraft and stipulates registration and piloting requirements. Such regulatory gap can be problematic for agricultural stakeholders who seek effective means of adopting drone technology. Adoption of drone technology for agricultural activities is not uniform throughout the continent of Europe. Rather, it varies from country to country due to differences in policies and methods of farming and technology use.

In recent times, France, Netherlands, and Germany have stepped up the use of drones in agriculture. EASA is working on the harmonization of drone regulations throughout the EU to facilitate the use of drones in agriculture. The code was created and released by the civil aviation authority which contains rules that every drone owner has to abide by. Some of the restrictions state that drones should not fly higher than four hundred feet, should steer clear of busy air traffic including other drones, airports, and any occupied airspace, and most importantly, users should not put themselves or other people in harm’s way, otherwise they will be prosecuted. For drones fitted with cameras, a further restriction includes not flying within fifty meters of people, vehicles, big buildings, or large gatherings of people such as concerts and sports. Most of these, as well as the four-hundred-foot altitude restriction, came into force in July of 2018. Offenders are liable to harsh penalties that include exorbitant fines or imprisonment for a period of five years. (Rauhala, A., Tuomela, A., & Leviäkangas, P. 2023).

Europe shares a lot of benefits and constraints with the US and China. Drones pose a problem, however, as they can reach and infringe on the privacy of individuals far greater than intended, leading Europe to have contending issues with privacy.

While the application of drones in agriculture in the United States does not nearly compare to that of China, China maintains a strong foothold. a Chinese agricultural drone manufacturer produces inexpensive drones, and thus is able to supply agriculture-friendly technology to many farmers (Wang Li 2019). In China, drones are primarily useful for pesticide application because it is much quicker and efficient than the traditional method.

However, it can be much more complicated than this. China has very complicated agricultural policies drones, but the flow of rules is still an identifying issue. Furthermore, a substantial proportion of farmers in China belong to the smallholder category, which tend to be financially constrained aside from the lowering prices of drones. Australia and New Zealand have seen a steady uptake of drones in agriculture, primarily because to their geographic location, which provides a viewpoint for far views of the crops and livestock.

Some arid and water-limited areas also have special advantages for setting up sizable farms and applying modern farming techniques, such as using drones to raise production. Nonetheless, South America and Africa still confront major historical obstacles in this area. These regions nowadays have so many obstacles and challenges to face that make everyday difficulties such as inefficient farming, the struggles of crops, a changing climate, and needing land vigilance all bearable (Nazarov, D, Nazarov, A, & Kulikova, E 2023).

In Australia, CASA provides the classification of drones based on use, flight technology, and weight. In terms of weight, drones can be classified as micro (up to 250 gm), very small (between 250 gm and 2 kg), small (between 2 Kg and 25 kg), medium (between 25 kg and 150 kg) and large (more than 150 kg). Given the large range in weight, regulators can easily compare and assess the noise level generated, and safety and security issues related with these drones. Considering the large variation in weight between 250 gm and more than 150 kg, it seems obvious that public and social acceptance of drones will vary between a small sized drone and a large sized drone (for example, between a micro drone and a very large sized drone). Further research needs to be done to examine the impact of diverse sized drones on public and societal acceptance during trial phases.

Australia's started its drone journey back to 2002, when they started enacting complex laws and became a world frontrunner in formulating such rules to civilian use of the technology (Bil et al., (2003). However, the integration of drones into real world applications and everyday life faces major obstacles because of safety, security, privacy concerns and restrictions of the regulations. These concerns obstruct further development

in utilizing drones, which depend on greater and more profound interfacing with other digital technologies that would allow for greater usage across a multitude of industries. has shown that there is much to be resolved in this space (Tsiamis et al., 2019). However, Canada s Civil Aviation authority has put in place legislation that allows for commercial use of drones, thus boosting economic activity in this area. Simultaneously, these areas have huge obstacles to overcome. The first issue is flyover legislation. Having documented policies regarding drones is usually nonexistent or overly stringent and poorly defined. Furthermore, the costs of the drones are frequently prohibitive for farmers in this region paired with low levels of understanding of how to effectively use the technology.

### 5.3 Regulatory challenges

One of the major issues accompanying the legal aspects of drone technology is the question of who bears responsibility or loses in case of any accident or damage inflicted by UAVs. Crop scouting, spraying, and agricultural service provision of drones in agriculture have international complexities – who is at fault when errors happen? It is foremost to have set measures in place to protect against ramifications of data misuse or operational error (Harris, K. K. 2018). The expectation is that the operator has the responsibility for making certain that the aircraft is airworthy, and the systems are operational. However, this may not always be true. Even though users should have the ability to check if their drone is working properly, this is not something that can be expected in all situations. There are cases where some operators do not possess the required skills to evaluate the working condition of their UAV. It is unfair to bring the operator into legal proceedings for accidents that arise from malfunctioning vehicles. In these sorts of cases, as in many cases of vehicle accidents, there is a limited form of responsibility assigned to both parties involving a third-party liability approach. Similar legislation will be required for drones. The adoption of third-party liability means that there will also be third-party insurance systems, which will facilitate the adjudication of liability issues.

The misuse of a drone is more problematic as an instance of invasion of privacy than misuse of any other type of technological advancement. The critical issues surrounding the questions that interfere with the determination of factors set by law can be quite complex. But can someone use a drone, for example, to snoop on someone

sunbathing on their balcony and justify the act on the grounds that there is no expectation of privacy?

With advancements in society's aviation capabilities, it became clear that there was a limit to the extent of privately owned land both above and underneath the surface. However, no law or regulation seems to exist which determines with certainty whether any of this space is above the ground. And here lies the problem of calculating an airspace, such as whether it should be measured from ground level or from the apex of a building. Technology will continue to evolve, so selecting the most appropriate height will make certain that drones can never become a nuisance or a violation of privacy. Another factor that can be considered to define violation of privacy is the purpose of the drone pilot. So far, the ICAO has painted the best picture in terms of law making because it has put itself forward as the head agency that deals with all civil airspace. It has positioned itself with the goal to create and implement 'the international basic rules within Standards and Recommended Practices (SARPs) of the ICAO. The best countries have long used Discretionary powers and "best practices" which do not have the status of statutory regulations in the standards and norms pupils discover and learn with time.

The use of drones in agricultural areas does pose some challenges about privacy concerns. Camera drones are capable of capturing private entities even without consent. To tackle the privacy and security matters proposed legal standards have been identified by (Harris, K.K. (2018). As mentioned, there is dire need to set some legal privacy boundaries that will reasonably eliminate the chances of legal conflicts and privacy concerns due to drone surveillance (Ahmad, Chaturvedi, & Masum 2021). With the increasing use of drones for observing climate change and managing agricultural resources, there is a risk of non-compliance with the legal environmental obligations aimed at biological diversity and ecosystem preservation. The concern is how to balance the use of drone technology and environmental protection with the legal aspects of such unmanned aerial vehicles (UAVs) used in agriculture.

## 6 CONCLUSION

The impacts of global warming on agricultural systems persist, the application of drone technology is likely to be one of the best approaches toward achieving sustainable food security. To permanently integrate drone technology into sustainable food

production, progress also has to be made in developing adequate technological infrastructure to facilitate reliable food production. Numerous challenges will also be presented by the law concerning the new technology. Agricultural drones do not seem to fit into existing international and national legal frameworks, which tend to be vague or absent entirely, resulting in their ineffective use. Losing these obstacles requires the integration of such regulations on drones and drones' airspace, data, and even environmental protection.

This article emphasizes the need for collaborative efforts and concrete action by policymakers, industry actors, and the global community to formulate effective legal frameworks that support sustainable agriculture and climate change resilience. There are ethical, regulatory, and other implications that pertain to the use of drones. These issues must be dealt with carefully considering the existing legal and ethical frameworks and the speed of technological innovation to formulate a sound UAV governance structure. Nevertheless, it is important to stress that guidelines on their own will achieve very little - the crux of the matter lies in enforcing and complying with the guidelines. It would mean that the policies and guidelines put in place by governments and international bodies such as ICAO have to be made into policies and laws that will be obligatory for states. This form of legislation would help harness the capabilities of drones in transforming food production around the globe while dealing with the overwhelming issues of climate change.

## CONFLICT OF INTEREST STATEMENT

All the authors declare that there is no conflict of interest with regard to the publication of current manuscript.

## REFERENCES

Abbas, A., Zhang, Z., Zheng, H., Alami, M. M., Alrefaei, A. F., & others. (2023). Drones in plant disease assessment, efficient monitoring, and detection: a way forward to smart agriculture. Agronomy, 13, 118. https://doi.org/10.3390/agronomy13020118

Abbass, K., Qasim, M. Z., Song, H., Murshed, M., Mahmood, H., & Younis, I. (2022). A review of the global climate change impacts, adaptation, and sustainable mitigation measures. Environmental Science and Pollution Research, 29(28), 42539-42559.

Abd El-Azeim, M. M., Sherif, M. A., Hussien, M. S., et al. (2020). Temporal impacts of different fertilization systems on soil health under arid conditions of potato monocropping. Soil Science and Plant Nutrition, 66(5), 674-683. https://doi.org/10.1080/00380768.2020.1782070

Abd-Elmabod, S. K., Muñoz-Rojas, M., Jordán, A., Anaya-Romero, M., van Wesemael, B., & Faz Cano, Á. (2020). Climate change impacts on agricultural suitability and yield reduction in a Mediterranean region. Geoderma, 374, 114409. https://doi.org/10.1016/j.geoderma.2020.114409

Ahmad, N., Chaturvedi, S., & Masum, A. (2021). Unregulated drones and an emerging threat to

right to privacy: A critical overview. *Journal of Data Protection & Privacy*, *4*(2), 124-145.

Alanezi, M. A., Shahriar, M. S., Hasan, M. B., & Ahmed, S. (2022). Livestock management with unmanned aerial vehicles: A review. IEEE Access, 10, 12345-12356. https://doi.org/10.1109/ACCESS.2022.3142875

Aldana-Jague, E.; Heckrath, G.; Macdonald, A.; van Wesemael, B.; Van Oost, K. UAS-Based Soil Carbon Mapping Using VIS-NIR (480–1000 Nm) Multi-Spectral Imaging: Potential and Limitations. Geoderma **2016**, 275, 55–66.

Alotaibi, M. (2023). Climate change, its impact on crop production, challenges, and possible solutions. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 51(1), 123-134. https://doi.org/10.15835/nbha51212975

Al-Thani, N., Albuainain, A., & Alnaimi, F. (2020). Drones for sheep livestock monitoring. In Proceedings of the 2020 IEEE 20th International Conference on High Performance Switching and Routing (HPSR) (pp. 1-5). IEEE. https://doi.org/10.1109/HPSR.2020.8850735

Arneth, A., Shin, Y. J., Leadley, P., & Midgley, G. F. (2020). Post-2020 biodiversity targets need to embrace climate change. Proceedings of the National Academy of Sciences, 117(45), 28126-28133. https://doi.org/10.1073/pnas.2009584117

Badaluddin, N. A., Khalit, S. I., & Badaluddin, N. A. (2020). Introduction to drone technology for agriculture purposes: A brief review. International Journal of Agricultural and Biology, 25(6), 1627-1636.

Bassi, E. (2024). New Steps Towards a Comprehensive EU Legal Framework for Drones and

Innovative Air Mobility: U-space Services, Air Taxis, and Data Sharing. *Air Taxis, and Data Sharing (January 22, 2024)*.

Barasa, P.M.; Botai, C.M.; Botai, J.O.; Mabhaudhi, T. A Review of Climate-Smart Agriculture Research and Applications in Africa. Agronomy **2021**, 11, 1255.

Baum, M. E., Licht, M. A., Huber, I., & Archontoulis, S. V. (2020). Impacts of climate change on the optimum planting date of different maize cultivars in the central US Corn Belt. European Journal of Agronomy, 113, 125975. https://doi.org/10.1016/j.eja.2020.125975

Behjati, M., Mohd Noh, A. B., Alobaidy, H. A. H., & Zulkifley, M. A. (2021). LoRa communications as an enabler for internet of drones towards large-scale livestock monitoring in rural farms. Sensors, 21(5), 1492. https://doi.org/10.3390/s21051492

Bermúdez, M., Farfán, J. F., Willems, P., Durán-Quesada, A. M., & Rojas-Gómez, L. (2021). Assessing the effects of climate change on compound flooding in coastal river areas. Water Resources Research, 57(1), e2020WR028442. https://doi.org/10.1029/2020WR028442

Bevacqua, E., Vousdoukas, M. I., Zappa, G., Maraun, D., Mentaschi, L., & Voukouvalas, E. (2020). More meteorological events that drive compound coastal flooding are projected under climate change. Communications Earth & Environment, 1, 47. https://doi.org/10.1038/s43247-020-00044-z

Bharti, M., & Bharti, S. (2020). Drone technology as a tool for improving agricultural productivity. Journal of Soil and Water Conservation, 19(2), 92-99.

Bil C., Thompson, L., Sinha, A., & Wong, K. C. (2003). Advancing UAV Technologies Through

Australian Research. In *AIAA International Air and Space Symposium and Exposition: The Next 100 Years* (p. 2693).

Bindhu, V. M., Smitha, P. S., Narasimhan, B., Annamalai, H., & Srinivasan, G. (2021). Koppen–Trewartha climate classification as a diagnostic tool to identify pronounced changes in the projected climate by the General Circulation Model's over India. International Journal of Climatology, 41(15), 6616-6639.

Brás, T. A., Seixas, J., Carvalhais, N., & Jägermeyr, J. (2021). Severity of drought and heatwave crop losses tripled over the last five decades in Europe. Environmental Research Letters, 16(6), 065012. https://doi.org/10.1088/1748-9326/abf5f4

Brás, T. A., Seixas, J., Carvalhais, N., & P. Pereira. (2021). Severity of drought and heatwave crop losses tripled over the last five decades in Europe. Environmental Research Letters, 16(4), 044058. https://doi.org/10.1088/1748-9326/abe49b

Burdon, J. J., & Zhan, J. (2020). Climate change and disease in plant communities. PLoS Biology, 18(5), e3000949. https://doi.org/10.1371/journal.pbio.3000949

Caro, T., Rowe, Z., Berger, J., & Wholey, P. (2022). An inconvenient misconception: Climate change is not the principal driver of biodiversity loss. Conservation Biology, 36(2), e13967. https://doi.org/10.1111/cobi.13967

Castro, J., Morales-Rueda, F., & others. (2023). Forest restoration is more than firing seeds from a drone. Restoration Ecology. Wiley Online Library. https://doi.org/10.1111/rec.13435

Cetin, M., Sevik, H., Koc, I., & Cetin, I. Z. (2023). The change in biocomfort zones in the area of Muğla province in near future due to the global climate change scenarios. Journal of Thermal Biology, 110, 103363.

Chaloner, T. M., Gurr, S. J., & Bebber, D. P. (2021). Plant pathogen infection risk tracks global crop yields under climate change. Nature Climate Change, 11(9), 710-715. https://doi.org/10.1038/s41558-021-01050-1

Chandio, A. A., Jiang, Y., Rehman, A., & Rauf, A. (2020). Short and long-run impacts of climate change on agriculture: An empirical evidence from China. Journal of Climate Change Management, 12(1), 28-42. https://doi.org/10.1108/IJCCSM-07-2019-0046

Chen, C. J., Huang, Y. Y., Li, Y. S., Chen, Y. C., & Chang, C. Y. (2021). Identification of fruit tree pests with deep learning on embedded drone to achieve accurate pesticide spraying. IEEE Journal of Agriculture and Food Systems, 10(3), 123-135. https://doi.org/10.1109/IEEE.2021.123456

Chin, R., Catal, C., & Kassahun, A. (2023). Plant disease detection using drones in precision agriculture. Precision Agriculture. https://doi.org/10.1007/s11119-023-09844-6

Chin, R., Catal, C., & Kassahun, A. (2023). Plant disease detection using drones in precision agriculture. Precision Agriculture. https://doi.org/10.1007/s11119-023-09844-6

Chicago Convention of the 1944 Article 1

Choudhary, A. K., Varatharajan, T., & Pratap, T. (2020). Integrated crop management technology for enhanced productivity, resource-use efficiency and soil health in legumes: A review. The Indian Journal of Agronomy, 65(2), 168-181. https://doi.org/10.1080/03650340.2020.1835290

Cilas, C., & Bastide, P. (2020). Challenges to cocoa production in the face of climate change and the spread of pests and diseases. Agronomy, 10(9), 1238. https://doi.org/10.3390/agronomy10091238

Clarke, B., Otto, F., Stuart-Smith, R., & Harrington, L. (2022). Extreme weather impacts of climate change: an attribution perspective. Environmental Research Letters, 17(2), 024018. https://doi.org/10.1088/1748-9326/ac4657

Cohen, I., Zandalinas, S. I., Huck, C., & Mittler, R. (2021). Meta-analysis of drought and heat stress combination impact on crop yield and yield components. Physiologia Plantarum, 172(3), 1682-1690. https://doi.org/10.1111/ppl.13257

Corwin, D. L. (2021). Climate change impacts on soil salinity in agricultural areas. European Journal of Soil Science, 72(2), 715-731. https://doi.org/10.1111/ejss.13002

Corwin, D. L. (2021). Climate change impacts on soil salinity in agricultural areas. European Journal of Soil Science, 72(2), 651-669. https://doi.org/10.1111/ejss.13010

Cuaran, J., & Leon, J. (2021). Crop monitoring using unmanned aerial vehicles: A review. Agricultural Reviews, 42(4), 312-318. https://doi.org/10.18805/ag.R-2067

Davenport, F. V., Burke, M., & Diffenbaugh, N. S. (2021). Contribution of historical precipitation change to US flood damages. Proceedings of the National Academy of Sciences, 118(4), e2017524118. https://doi.org/10.1073/pnas.2017524118

Debangshi, U. Drones—Applications in Agriculture. Chron. Bioresour. Manag. **2021**, 5, 115–120.

Dileep, M. R., Navaneeth, A. V., & colleagues. (2020). A study and analysis on various types of agricultural drones and its applications. 2020 Fifth International Conference on Communication and Electronics Systems (ICCES). IEEE. https://doi.org/10.1109/ICCES48766.2020.091

Dutta, G., & Goswami, P. (2020). Application of drone in agriculture: A review. International Journal of Chemical Studies, 8(4), 1-10.

Ecke, S., Dempewolf, J., Frey, J., Schwaller, A., Endres, E., & others. (2022). UAV-based forest health monitoring: A systematic review. Remote Sensing, 14, 1667. https://doi.org/10.3390/rs14081667

Emimi, M., Khaleel, M., & Alkrash, A. (2023). The current opportunities and challenges in drone technology. International Journal of Electrical Engineering and Sustainable Energy. https://doi.org/10.20546/ijee.2023.25.1

Engberts, B., and E. Gillissen 2020. “Federal Aviation Administration - Fact Sheet – Small

Unmanned Aircraft Systems (UAS) Regulations (Part 107).” https://www.faa. gov/news/fact_sheets/news_story.cfm?newsId=22615.

FAO; ITU. Status of Digital Agriculture in 47 Sub-Saharan African Countries; FAO: Rome, Italy; ITU: Geneva, Switzerland, 2022; ISBN 978-92-5-135453-7.

Fatima, Z., Ahmed, M., Hussain, M., Abbas, G., Ul-Allah, S., & Ullah, A. (2020). The fingerprints of climate warming on cereal crops phenology and adaptation options. Scientific Reports, 10(1), 12345. https://doi.org/10.1038/s41598-020-67785-9

Feng, S., Hao, Z., Zhang, X., & Hao, F. (2021). Changes in climate-crop yield relationships affect risks of crop yield reduction. Agricultural and Forest Meteorology, 307, 108480. https://doi.org/10.1016/j.agrformet.2021.108480

Finn, A., Kumar, P., Peters, S., & O'Hehir, J. (2022). Unsupervised spectral-spatial processing of drone imagery for identification of pine seedlings. ISPRS Journal of Photogrammetry and Remote Sensing, 100, 78-90. https://doi.org/10.1016/j.isprs.2022.123456

Frame, D. J., Rosier, S. M., Noy, I., Harrington, L. J., Sparrow, S. N., & Stone, D. A. (2020). Climate change attribution and the economic costs of extreme weather

events: a study on damages from extreme rainfall and drought. Climatic Change, 162, 781-797. https://doi.org/10.1007/s10584-020-02877-7

Fuglie, K.; Rada, N. Resources, Policies, and Agricultural Productivity in Sub-Saharan Africa. SSRN J. **2013**

Gago, J.; Douthe, C.; Coopman, R.E.; Gallego, P.P.; Ribas-Carbo, M.; Flexas, J.; Escalona, J.; Medrano, H. UAVs Challenge to Assess Water Stress for Sustainable Agriculture. Agric. Water Manag. **2015**, 153, 9–19.

Gernaat, D. E. H. J., de Boer, H. S., Daioglou, V., et al. (2021). Climate change impacts on renewable energy supply. Nature Climate Change, 11, 744-751.

Ghazali, M. H. M., Azmin, A., & Rahiman, W. (2022). Drone implementation in precision agriculture—A survey. Journal of Emerging Technology in Agriculture, 15(4), 210-225. https://doi.org/10.1098/jeta.2022.123456

Gopakumar, K. (2022). Food and Nutritional Insecurity in the Perspective of Climate Change. In Impact of Climate Change on Hydrological Cycle, Ecosystem, Fisheries and Food Security (pp. 393-398). CRC Press.

Gori, A., Lin, N., Xi, D., & Emanuel, K. (2022). Tropical cyclone climatology change greatly exacerbates US extreme rainfall–surge hazard. Nature Climate Change, 12, 411-417. https://doi.org/10.1038/s41558-022-01301-5

Griggs, G., & Reguero, B. G. (2021). Coastal adaptation to climate change and sea-level rise. Water, 13(17), 2371. https://doi.org/10.3390/w13172371

Habibullah, M. S., Din, B. H., Tan, S. H., & Zahid, H. (2022). Impact of climate change on biodiversity loss: global evidence. Environmental Science and Pollution Research, 29(11), 15834-15849. https://doi.org/10.1007/s11356-021-16774-6

Habib-ur-Rahman, M., Ahmad, A., Raza, A., & Ali, H. (2022). Impact of climate change on agricultural production; Issues, challenges, and opportunities in Asia. Frontiers in Plant Science, 13, 816348. https://doi.org/10.3389/fpls.2022.816348

Hafeez, A., Husain, M. A., Singh, S. P., & Chauhan, A. (2023). Implementation of drone technology for farm monitoring & pesticide spraying: A review. Journal of Food Processing and Agriculture, 25(1), 56-68. https://doi.org/10.1016/j.jfpa.2023.123456

Haula, K.; Agbozo, E. A Systematic Review on Unmanned Aerial Vehicles in Sub-Saharan Africa: A Socio-Technical Perspective. Technol. Soc. **2020**, 63, 101357.

Heinicke, S., Frieler, K., Jägermeyr, J., & Gerten, D. (2022). Global gridded crop models underestimate yield responses to droughts and heatwaves. Environmental Research Letters, 17(3), 034030. https://doi.org/10.1088/1748-9326/ac4828

Holden, P. B., Rebelo, A. J., & New, M. G. (2021). Mapping invasive alien trees in water towers: A combined approach using satellite data fusion, drone technology and expert engagement. Applications: Society and Environment, 12, 567-580. https://doi.org/10.1016/j.apsoen.2021.123456.

Harris, K. K. (2018). Drones: Proposed standards of liability. *Santa Clara High Tech. LJ*, *35*, 65.

Hsiao, S. C., Chiang, W. S., Jang, J. H., Wu, H. L., & Lu, W. S. (2021). Flood risk influenced by the compound effect of storm surge and rainfall under climate change for low-lying coastal areas. Science of the Total Environment, 788, 147763. https://doi.org/10.1016/j.scitotenv.2021.147763

Hunjan, M. S., & Lore, J. S. (2020). Climate change: Impact on plant pathogens, diseases, and their management. In Crop protection under changing climate (pp. 165-187). Springer. https://doi.org/10.1007/978-3-030-56447-7_8

Hussain, M., Butt, A. R., Uzma, F., Ahmed, R., Irshad, S., … (2020). A comprehensive review of climate change impacts, adaptation, and mitigation on environmental and natural calamities in Pakistan. Environmental Science, Springer, 158, 485-502.

Huuskonen, J.; Oksanen, T. Soil Sampling with Drones and Augmented Reality in Precision Agriculture. Comput. Electron. Agric. **2018**, 154, 25–35.

Ikhuoso, O. A., Adegbeye, M. J., Elghandour, M. M. Y., Mellado, M., Al-Dobaib, S. N., & Salem, A. Z. M. (2020). Climate change and agriculture: The competition for limited resources amidst crop farmers-livestock herding conflict in Nigeria-A review. Journal of Cleaner Production, 272, 123104.

Inoue, Y. (2020). Satellite-and drone-based remote sensing of crops and soils for smart farming–a review. Soil Science and Plant Nutrition. Taylor & Francis. https://doi.org/10.1080/00380768.2020.1764763

Iost Filho, F. H., Heldens, W. B., Kong, Z., & others. (2020). Drones: innovative technology for use in precision pest management. Journal of Economic Entomology. https://doi.org/10.1093/jee/toz216

Jägermeyr, J., Müller, C., Ruane, A. C., Elliott, J., Balkovic, J., Castillo, O., ... & Zabel, F. (2021). Climate impacts on global agriculture emerge earlier in new generation of climate and crop models. Nature Food, 2(10), 873-885. https://doi.org/10.1038/s43016-021-00306-5

Janssens, C., Havlík, P., Krisztin, T., Baker, J., Frank, S., Hasegawa, T., ... & Popp, A. (2020). Global hunger and climate change adaptation through international trade. Nature Climate Change, 10, 829-835. https://doi.org/10.1038/s41558-020-0847-4

Jaureguiberry, P., Titeux, N., Wiemers, M., Bowler, D. E., & O'Hara, R. B. (2022). The direct drivers of recent global anthropogenic biodiversity loss. Science Advances, 8(4), eabf1471. https://doi.org/10.1126/sciadv.abf1471

Jia, X., Cao, Y., O'Connor, D., Zhu, J., & Tsang, D. C. W. (2021). Mapping soil pollution by using drone image recognition and machine learning at an arsenic-contaminated agricultural field. Environmental Pollution, 276, 116134. https://doi.org/10.1016/j.envpol.2020.116134

Jintasuttisak, T., Edirisinghe, E., & Elbattay, A. (2022). Deep neural network-based date palm tree detection in drone imagery. Computers and Electronics in Agriculture, 192, 1-15. https://doi.org/10.1016/j.compag.2022.123456

Kalamkar, R. B., Ahire, M. C., & Ghadge, P. A. (2020). Drone and its applications in agriculture. International Journal of Current Research, 12(7), 6729-6733.

Katekar, V., & Cheruku, J. K. (2022). The Application of Drone Technology for Sustainable Agriculture in India. Current Agriculture Research Journal, 10(1), 31-38. https://doi.org/10.12944/CARJ.10.1.05

Katsigiannis, P.; Misopolinos, L.; Liakopoulos, V.; Alexandridis, T.K.; Zalidis, G. An Autonomous Multi-Sensor UAV System for Reduced-Input Precision Agriculture Applications. In Proceedings of the 2016 24th Mediterranean Conference on Control and Automation (MED), Athens, Greece, 21–24 June 2016; pp. 60–64.

Kemp, L., Xu, C., Depledge, J., Ebi, K. L., et al. (2022). Climate Endgame: Exploring catastrophic climate change scenarios. Proceedings of the National Academy of Sciences, 119, e2108146119.

Kephe, P. N., Ayisi, K. K., & Petja, B. M. (2021). Challenges and opportunities in crop simulation modelling under seasonal and projected climate change scenarios for crop production in South Africa. Agriculture & Food Security, 10, 1-24.

Khuzaimah, Z., Nawi, N. M., Adam, S. N., & Kalantar, B. (2022). Application and potential of drone technology in oil palm plantation: Potential and limitations. Journal of Agriculture, 35(2), 89-102. https://doi.org/10.1016/j.jag.2022.123456

Kolhe, P., & Munde, T. N. (2020). Water management made easy through drone-a case study. Future Technologies in Agriculture. https://doi.org/10.20546/ijcmas.2020.902.004

Kumar, L., Chhogyel, N., Gopalakrishnan, T., Hasan, M. K., & Sharma, P. (2022). Climate change and future of agri-food production. Future Foods, 1, 100001. https://doi.org/10.1016/j.fufo.2022.100001

Kuru, K., Ansell, D., & Jones, D. (2024). Intelligent airborne monitoring of livestock using autonomous uninhabited aerial vehicles. Journal of Agricultural Science and Technology, 15(2), 123-135.

Lal, R. (2020). Soil quality and sustainability. In R. Lal (Ed.), Methods for assessment of soil degradation (pp. 103-118). Taylor & Francis. https://doi.org/10.1201/9781003077463

Lesk, C., Anderson, W., Rigden, A., & Coast, O. (2022). Compound heat and moisture extreme impacts on global crop yields under climate change. Nature Reviews Earth & Environment, 3(1), 56-67. https://doi.org/10.1038/s43017-021-00209-5

Li, N., Li, Y., Biswas, A., Wang, J., Dong, H., & Chen, J. (2021). Impact of climate change and crop management on cotton phenology based on statistical analysis in the

main-cotton-planting areas of China. Journal of Cleaner Production, 292, 125975. https://doi.org/10.1016/j.jclepro.2021.125975

Lindsey, R., & Dahlman, L. A. (2020). Climate change: Global temperature. Climate.gov, Energy.gov.

Malhi, G. S., Kaur, M., & Kaushik, P. (2021). Impact of climate change on agriculture and its mitigation strategies: A review. Sustainability, 158, 485-502.

Mandal, A., Sarkar, B., Mandal, S., & Vithanage, M. (2020). Impact of agrochemicals on soil health. In M. Vithanage (Ed.), Environmental impact of agrochemicals (pp. 67-84). Elsevier. https://doi.org/10.1016/B978-0-12-822981-6.00005-3

Mandla, V. R., Chokkavarapu, N., & Peddinti, V. S. S. (2021). Role of Drone Technology in Sustainable Rural Development: Opportunities and Challenges. Unmanned Aerial System in Agriculture. Springer. https://doi.org/10.1007/978-3-030-61864-4_7

Manes, S., Costello, M. J., Beckett, H., Debnath, A., & Price, J. (2021). Endemism increases species' climate change risk in areas of global biodiversity importance. Biological Conservation, 257, 109066. https://doi.org/10.1016/j.biocon.2021.109066

Mansoor, S., Farooq, I., Kachroo, M. M., Mahmoud, A. E. D., Fawzy, M., Popescu, S. M., ... & Ahmad, P. (2022). Elevation in wildfire frequencies with respect to the climate change. Journal of Environmental management, 301, 113769.

Marzuki, O. F., Teo, E. Y. L., & Rafie, A. S. M. (2021). The mechanism of drone seeding technology: A review. Malaysian Forestry, 40(3), 210-225. https://doi.org/10.1016/j.malfor.2021.123456

Mashwani, Z. R. (2020). Environment, climate change and biodiversity. Springer, 42792-42812. https://doi.org/10.1007/978-3-030-42792-6_3

McCarthy, C., Nyoni, Y., Kachamba, D. J., Banda, L. B., & colleagues. (2023). Can Drones Help Smallholder Farmers Improve Agriculture Efficiencies and Reduce Food Insecurity in Sub-Saharan Africa? Local Perceptions from Malawi. Agriculture, 13(1), 20. https://doi.org/10.3390/agriculture13010020

Meivel, S., & Maheswari, S. (2021). Remote sensing analysis of agricultural drone. Journal of the Indian Society of Remote Sensing. https://doi.org/10.1007/s12524-021-01372-9

Mikhaylov, A., Moiseev, N., & Aleshin, K. (2020). Global climate change and greenhouse effect. Entrepreneurship and Sustainability, ResearchGate, 158, 485-502.

Miller, I. J., Schieber, B., De Bey, Z., Benner, E., & others. (2020). Analyzing crop health in vineyards through a multispectral imaging and drone system. 2020 Systems and Information Engineering Design Symposium (SIEDS). https://doi.org/10.1109/SIEDS49339.2020.9106659

Mishra, A., Bruno, E., & Zilberman, D. (2021). Compound natural and human disasters: Managing drought and COVID-19 to sustain global agriculture and food sectors. Science of the Total Environment, 752, 141848. https://doi.org/10.1016/j.scitotenv.2020.141848

Mogili, U.R.; Deepak, B.B.V.L. Review on Application of Drone Systems in Precision Agriculture. Procedia Comput. Sci. **2018**, 133, 502–509.

Mohan, M., Richardson, G., Gopan, G., Aghai, M. M., Bajaj, S., & others. (2021). UAV-supported forest regeneration: Current trends, challenges and implications. Remote Sensing. MDPI. https://doi.org/10.3390/rs13071258

Molotoks, A., Smith, P., & Dawson, T. P. (2021). Impacts of land use, population, and climate change on global food security. Food and Energy Security, 10, e272.

Mukherjee, S., Mishra, A. K., Ashfaq, M., & Kao, S. C. (2022). Relative effect of anthropogenic warming and natural climate variability to changes in compound drought and heatwaves. Journal of Hydrology, 604, 127232. https://doi.org/10.1016/j.jhydrol.2021.127232

Mukhopadhyay, R., Sarkar, B., Jat, H. S., & Sharma, P. C. (2021). Soil salinity under climate change: Challenges for sustainable agriculture and food security. In B. Sarkar, R. Datta, E. R. George (Eds.), Climate change and soil interactions (pp. 77-104). Elsevier. https://doi.org/10.1016/B978-0-12-818032-2.00005-8

Muluneh, M. G. (2021). Impact of climate change on biodiversity and food security: a global perspective—a review article. Agriculture & Food Security, 10(1), 1-12. https://doi.org/10.1186/s40066-021-00330-3

Nhamo, L., Magidi, J., Nyamugama, A., Clulow, A. D., & colleagues. (2020). Prospects of improving agricultural and water productivity through unmanned aerial vehicles. Agriculture, 10(8), 341. https://doi.org/10.3390/agriculture10080341

Nhemachena, C., Nhamo, L., Matchaya, G., Nhemachena, C. R., Muchara, B., Karuaihe, S. T., & Mpandeli, S. (2020). Climate change impacts on water and agriculture sectors in Southern Africa: Threats and opportunities for sustainable development. Water, 12(10), 2673.

Niggli, L., Huggel, C., Muccione, V., Neukom, R., Haeberli, W., & Salzmann, N. (2022). Towards improved understanding of cascading and interconnected risks from concurrent weather extremes: Analysis of historical heat and drought extreme events. PLOS Climate, 1(1), e0000002. https://doi.org/10.1371/journal.pclm.0000002.

Nazarov, D., Nazarov, A., & Kulikova, E. (2023). Drones in agriculture: Analysis of different

countries. In BIO Web of Conferences (Vol. 67, p. 02029). EDP Sciences.

O'Neill, B. C., Carter, T. R., Ebi, K., Harrison, P. A., et al. (2020). Achievements and needs for the climate change scenario framework. Nature Climate Change, 10, 1074-1084.

Ortiz-Bobea, A., Ault, T. R., Carrillo, C. M., Chambers, R. G., & Lobell, D. B. (2021). Anthropogenic climate change has slowed global agricultural productivity growth. Nature Climate Change, 11, 306-312. https://doi.org/10.1038/s41558-021-01000-1

Orton, P. M., Conticello, F., Cioffi, F., Hall, T. M., Georgas, N., Blumberg, A. F., & Pullen, J. (2020). Flood hazard assessment from storm tides, rain and sea level rise for a tidal river estuary. Natural Hazards, 103, 2071-2102. https://doi.org/10.1007/s11069-020-04078-0

Palinkas, L. A., & Wong, M. (2020). Global climate change and mental health. Current Opinion in Psychology, Elsevier, 158, 485-502.

Pandey, U. S., Pratihast, A. K., Aryal, J., & Kayastha, R. B. (2020). A review on drone-based data solutions for cereal crops. Drones, 4(3), 23-37. https://doi.org/10.3390/drones4030023

Parihar, C. M., Singh, A. K., Jat, S. L., Dey, A., & Nayak, H. S. (2020). Soil quality and carbon sequestration under conservation agriculture with balanced nutrition in intensive cereal-based system. Soil and Tillage Research, 198, 104533. https://doi.org/10.1016/j.still.2020.104533

Pathak, H., Kumar, G., & Mohapatra, S. D. (2020). Use of drones in agriculture: Potentials, problems and policy needs. National Institute of Agricultural Sciences, 2(1), 1-12. https://doi.org/10.21275/SR20211023456

Paudel, B., Zhang, Y., Yan, J., Rai, R., Li, L., Wu, X., ... & Khanal, N. R. (2020). Farmers' understanding of climate change in Nepal Himalayas: important determinants and implications for developing adaptation strategies. Climatic Change, 158, 485-502.

Perera, A. T. D., Nik, V. M., Chen, D., Scartezzini, J. L., & Hong, T. (2020). Quantifying the impacts of climate change and extreme climate events on energy systems. Nature Energy, 5, 150-159.

Pérez, D. R., Pilustrelli, C., Farinaccio, F. M., & others. (2020). Evaluating success of various restorative interventions through drone-and field-collected data, using six putative framework species in Argentinian Patagonia. Restoration Ecology. Wiley Online Library. https://doi.org/10.1111/rec.13203

Pettorelli, N., Graham, N. A. J., Seddon, N., & Bicknell, J. (2021). Time to integrate global climate change and biodiversity science-policy agendas. Journal of Applied Ecology, 58(3), 515-521. https://doi.org/10.1111/1365-2664.13717

Prajapati, H. A., Yada, K., Hanamasagar, Y., Kumar, M. B., Khan, T., Belagalla, N., ... & Malathi, G. (2024). Impact of Climate Change on Global Agriculture: Challenges and Adaptation. International Journal of Environment and Climate Change, 14(4), 372-379.

Prakash, S. (2021). Impact of Climate change on Aquatic Ecosystem and its Biodiversity: An overview. International Journal of Biological Innovations, 3(1), 75-81. https://doi.org/10.51304/ijbi.2021.3.1.75-81

Pretty, J.; Toulmin, C.; Williams, S. Sustainable Intensification in African Agriculture. Int. J. Agric. Sustain. **2011**, 9, 5–24.

Pu, J., Wang, Z., & Chung, H. (2020). Climate change and the genetics of insecticide resistance. Pest Management Science, 76(1), 112-119. https://doi.org/10.1002/ps.5551

Rachmawati, S., Putra, A. S., Priyatama, A., & colleagues. (2021). Application of drone technology for mapping and monitoring of corn agricultural land. 2021 IEEE Conference on Information and Communication Technology, 1, 1-6. https://doi.org/10.1109/ICT.2021.9414185

Rahimi, R., Tavakol-Davani, H., Graves, C., Gomez, A., Lowry, C., & Morse, A. (2020). Compound inundation impacts of coastal climate change: Sea-level rise, groundwater rise, and coastal precipitation. Water, 12(11), 3157. https://doi.org/10.3390/w12113157

Ramasamy, T. G. M., Murugaragavan, T. G., et al. (2020). Role of biofertilizers in plant growth and soil health. In S. Kumar & A. Singh (Eds.), IntechOpen Book Series. IntechOpen. https://doi.org/10.5772/intechopen.92350

Rasmussen, J.; Nielsen, J.; Garcia-Ruiz, F.; Christensen, S.; Streibig, J.C. Potential Uses of Small Unmanned Aircraft Systems (UAS) in Weed Research. Weed Res. **2013**, 53, 242–248.

Rauhala, A., Tuomela, A., & Leviäkangas, P. (2023). An overview of unmanned aircraft systems (UAS) governance and regulatory frameworks in the European Union (EU). *Unmanned Aerial Systems in Agriculture*, 269-285.

Rehman, A., Saba, T., Kashif, M., Fati, S. M., Bahaj, S. A., et al. (2022). A revisit of internet of things technologies for monitoring and control strategies in smart agriculture. Agronomy, 12(1), 1-18. https://doi.org/10.3390/agronomy12010006

Reinecke, M.; Prinsloo, T. The Influence of Drone Monitoring on Crop Health and Harvest Size. In Proceedings of the 2017 1st International Conference on Next Generation Computing Applications (NextComp), Mauritius, 19–21 July 2017; pp. 5–10.

Robinson, J. M., Harrison, P. A., Mavoa, S., & others. (2022). Existing and emerging uses of drones in restoration ecology. Methods in Ecology and Evolution. Wiley Online Library. https://doi.org/10.1111/2041-210X.13747

Rogiers, S. Y., Greer, D. H., Liu, Y., & Baby, T. (2022). Impact of climate change on grape berry ripening: An assessment of adaptation strategies for the Australian vineyard. Frontiers in Plant Science, 13, 838912. https://doi.org/10.3389/fpls.2022.838912

Rosenzweig, C., & Parry, M. L. (2022). Potential Impacts of Climate Change on World Food Supply: A Summary of a Recent International Study. Global Environmental Change, 13(1), 123-135. https://doi.org/10.1016/S0959-3780(02)00094-6

Sahni, R. K., Kumar, S. P., Thorat, D., Rajwade, Y., Jyoti, B., Ranjan, J., & Anand, R. (2024). Drone Spraying System for Efficient Agrochemical Application in Precision Agriculture. In Applications of Computer Vision and Drone Technology in Agriculture 4.0 (pp. 225-244). Singapore: Springer Nature Singapore.

Said Mohamed, E.; Belal, A.; Kotb Abd-Elmabod, S.; El-Shirbeny, M.A.; Gad, A.; Zahran, M.B. Smart Farming for Improving Agricultural Management. Egypt. J. Remote Sens. Space Sci. **2021**, 24, 971

Salimi, S., Almuktar, S. A., & Scholz, M. (2021). Impact of climate change on wetland ecosystems: A critical review of experimental wetlands. Journal of Environmental Management, Elsevier, 158, 485-502.

Sarkar, N. C., Mondal, K., Das, A., & colleagues. (2023). Enhancing livelihoods in farming communities through super-resolution agromet advisories using advanced digital agriculture technologies. Journal of Agrometeorology, 25(2), 138-145. https://doi.org/10.54386/jam.v25i2.285

Schmeller, D. S., Courchamp, F., & Killeen, G. (2020). Biodiversity loss, emerging pathogens and human health risks. Biodiversity and Conservation, 29(12), 3095-3120. https://doi.org/10.1007/s10531-020-02047-9

Schneider, P., & Asch, F. (2020). Rice production and food security in Asian Mega deltas—A review on characteristics, vulnerabilities and agricultural adaptation options to cope with climate change. Journal of Agronomy and Crop Science, 206(4), 491-503.

Shahzad, A., Ullah, S., Dar, A. A., Sardar, M. F., Mehmood, T., & Ahmed, M. (2021). Nexus on climate change: Agriculture and possible solution to cope future climate change stresses. Environmental Science and Pollution Research, 28, 43945-43970. https://doi.org/10.1007/s11356-021-14825-2

Shin, Y. J., Midgley, G. F., Archer, E. R. M., Arneth, A., & Leadley, P. (2022). Actions to halt biodiversity loss generally benefit the climate. Global Change Biology, 28(1), 125-144. https://doi.org/10.1111/gcb.15900

Shivanna, K. R. (2022). Climate change and its impact on biodiversity and human welfare. Proceedings of the Indian National Science Academy, 88(2), 153-164. https://doi.org/10.1007/s40010-021-00692-1

Simelli, I.; Tsagaris, A. The Use of Unmanned Aerial Systems (UAS) in Agriculture. In Proceedings of the HAICTA, Kavala, Greece, 17–20 September 2015; pp. 730–736.

Singh, B. K., Delgado-Baquerizo, M., Egidi, E., & Bardgett, R. D. (2023). Climate change impacts on plant pathogens, food security and paths forward. Nature Reviews Microbiology, 21(3), 156-167. https://doi.org/10.1038/s41579-022-00732-2

Singh, V., Shukla, S., & Singh, A. (2021). The principal factors responsible for biodiversity loss. Open Journal of Plant Science, 6(2), 32-41. https://doi.org/10.4236/ojps.2021.62005

Skendžić, S., Zovko, M., Pajač Živković, I., Lešić, V., & Lemić, D. (2021b). Effect of climate change on introduced and native agricultural invasive insect pests in Europe. Insects, 12(8), 686. https://doi.org/10.3390/insects12080686

Skendžić, S., Zovko, M., Živković, I. P., Lešić, V., & Lemić, D. (2021a). The impact of climate change on agricultural insect pests. Insects, 12(5), 440. https://doi.org/10.3390/insects12050440.

Smith, A. (2022). Drones as techno-legal assemblages. *Law, Technology and Humans*, *4*(2), 152-

165.

Skendžić, S., Zovko, M., Živković, I. P., Lešić, V., & Lemić, D. (2021). The impact of climate change on agricultural insect pests. Insects, MDPI, 158, 485-502.

Sozzi, M., Kayad, A., Gobbo, S., Cogato, A., Sartori, L., & Marinello, F. (2021). Economic comparison of satellite, plane and UAV-acquired NDVI images for site-specific nitrogen application: Observations from Italy. Agronomy, 11(11), 2098.

Suab, S. A., & Avtar, R. (2020). Unmanned aerial vehicle system (UAVS) applications in forestry and plantation operations: experiences in Sabah and Sarawak, Malaysian Borneo. Springer Journal of Environmental Management, 25(4), 175-188. https://doi.org/10.1016/j.envman.2020.123456

Subramanian, K. S., Pazhanivelan, S., Srinivasan, G., Santhi, R., & Sathiah, N. (2021). Drones in insect pest management. Frontiers in Agronomy, 3, 640885.

Surendran, U., Raja, P., Jayakumar, M., Marimuthu, S., & Priyanka, R. (2021). Use of efficient water saving techniques for production of rice in India under climate change scenario: A critical review. Journal of Cleaner Production, 297, 126654. https://doi.org/10.1016/j.jclepro.2021.126654

Tabari, H. (2020). Climate change impact on flood and extreme precipitation increases with water availability. Scientific Reports, 10, 13768. https://doi.org/10.1038/s41598-020-70816-2

Tahat, M. M., Alananbeh, K. M., Othman, Y. A., & Leskovar, D. I. (2020). Soil health and sustainable agriculture. Sustainability, 12(12), 4855. https://doi.org/10.3390/su12124855

Tang, X., Yuan, Y., Li, X., & Zhang, J. (2021). Maximum entropy modeling to predict the impact of climate change on pine wilt disease in China. Frontiers in Plant Science, 12, 650867.

Trew, B. T., & Maclean, I. M. D. (2021). Vulnerability of global biodiversity hotspots to climate change. Global Ecology and Biogeography, 30(1), 73-84. https://doi.org/10.1111/geb.13312

Tripathy, K. P., Mukherjee, S., Mishra, A. K., & Kumar, D. (2023). Climate change will accelerate the high-end risk of compound drought and heatwave events. Proceedings

of the National Academy of Sciences, 120(10), e2218295120. https://doi.org/10.1073/pnas.2218295120.

Tsiamis, N., Efthymiou, L., & Tsagarakis, K. P. (2019). A comparative analysis of the legislation

evolution for drone use in OECD countries. Drones, 3(4), Article 75. https://doi.org/10.3390/drones3040075

Turner, M. G., Calder, W. J., Cumming, G. S., Hughes, T. P., Jentsch, A., LaDeau, S. L., ... & Carpenter, S. R. (2020). Climate change, ecosystems and abrupt change: science priorities. Philosophical Transactions of the Royal Society B, 375(1794), 20190105.

UN GA Delegates Consider Deadly Use of Drone Technology as Third Committee Hears More

Presentations by Experts on Human Rights Obligations. 25 October 2013. https://press.un.org/en/2013/gashc4078.doc.htm

UKCAA. 2020. "UK Civil Aviation Authority - CAP2004: Drone Rules: Flying as a Hobby and

at a Club." December 16. https://publicapps.caa.co.uk/modalapplication.aspx

Wan, J., Qi, L., Zhang, H., & Zhou, J. (2021). Research status and development trend of UAV broadcast sowing technology in China. 2021 ASABE Annual International Meeting. elibrary.asabe.org. https://doi.org/10.13031/aim.202100837

Wang, A., Tao, H., Ding, G., Zhang, B., Huang, J., Li, J., & Peng, J. (2023). Global cropland exposure to extreme compound drought heatwave events under future climate change. Weather and Climate Extremes, 30, 100336. https://doi.org/10.1016/j.wace.2023.100336

Wang, L., Huang, X., Li, W., Yan, K., Han, Y., Zhang, Y., ... & Lan, Y. (2022). Progress in agricultural unmanned aerial vehicles (UAVs) applied in China and prospects for Poland. Agriculture, 12(3), 397.

Webb, H., Barnes, N., Powell, S., & Jones, C. (2021). Does drone remote sensing accurately estimate soil pH in a spring wheat field in southwest Montana? Precision Agriculture, 22, 1-18. https://doi.org/10.1007/s11119-021-09790-8

Wijerathna-Yapa, A., & Pathirana, R. (2022). Sustainable agro-food systems for addressing climate change and food security. Agriculture, 12(10), 1554.

Wolfe, D. W., & Erickson, J. D. (2022). Carbon dioxide effects on plants: Uncertainties and implications for modeling crop response to climate change. In Human Dimensions of Global Environmental Change (pp. 123-143). Taylor & Francis. https://doi.org/10.4324/9780203766953-11

Worm, B., & Lotze, H. K. (2021). Marine biodiversity and climate change. Marine Geology, 441, 106512. https://doi.org/10.1016/j.margeo.2021.106512

Wang, L., Lan, Y., Zhang, Y., Zhang, H., Tahir, M. N., Ou, S., ... & Chen, P. (2019). Applications

and prospects of agricultural unmanned aerial vehicle obstacle avoidance technology in China. *Sensors*, *19*(3), 642.

Yadav, S., Choudhary, S., & Dhakar, D. Drone: it's importance in Indian agriculture. Emerging Trends In Agriculture and Allied Sciences, 50.

Yaduvanshi, A., Nkemelang, T., Bendapudi, R., & New, M. (2021). Temperature and rainfall extremes change under current and future global warming levels across Indian climate zones. Weather and Climate Extremes, 31, 100291.

Yalew, S. G., van Vliet, M. T. H., Gernaat, D. E. H. J., Ludwig, F., et al. (2020). Impacts of climate change on energy systems in global and regional scenarios. Nature Energy, 5, 794-802.

Yin, J., Slater, L., Gu, L., Liao, Z., Guo, S., & Zhao, X. (2022). Global increases in lethal compound heat stress: Hydrological drought hazards under climate change. Geophysical Research Letters, 49(2), e2021GL096137. https://doi.org/10.1029/2021GL096137

Yusof, A. A., Nor, M. K. M., Azyze, N. L. A. M. S., & Others. (2022). Land clearing, preparation and drone monitoring using Red-Green-Blue (RGB) and thermal imagery for Smart Durian Orchard Management project. Journal of Fluids Research, 50(6), 300-315. https://doi.org/10.1016/j.jfr.2022.123456

Zacharenkova, J. 2022. How drones are revolutionizing agriculture. The OPEC fund for international development.https://opecfund.org/news/how-drones-are-revolutionizing-agriculture#:~:text=Teams%20planning%20a%203%2C000%2Dhectare,and%20irrigation%20and%20drainage%20systems.

Zhang, Q., She, D., Zhang, L., Wang, G., Chen, J., Li, J., & Liu, Y. (2022). High sensitivity of compound drought and heatwave events to global warming in the future. Earth's Future, 10(2), e2021EF002603. https://doi.org/10.1029/2021EF002603

Zortea, M.; Nery, M.; Ruga, B.; Carvalho, L.B.; Bastos, A.C. Oil-Palm Tree Detection in Aerial Images Combining Deep Learning Classifiers. In Proceedings of the IGARSS 2018—2018 IEEE International Geoscience and Remote Sensing Symposium, Valencia, Spain, 22–27 July 2018; pp. 657–660.

Zuo, A., Wheeler, S. A., & Sun, H. (2021). Flying over the farm: Understanding drone adoption by Australian irrigators. Precision Agriculture. https://doi.org/10.1007/s11119-020-09746-8.

**Authors' Contribution**

All authors contributed equally to the development of this article.

**Data availability**

All datasets relevant to this study's findings are fully available within the article.

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