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Exploring Agriculture In The Age Of Drones: A Comprehensive Review

Jui Ray[1], Pabitra Kumar Ghosh[2*], Sagar Banik[3], Swarnali Duary[4], Madhusri Pramanik[5], Soumik Dey Roy[6], Sourav Roy[7]

[1]Department of Genetics Plant Breeding and Seed Science & Technology, Centurion University of Technology and Management, Paralakhemundi, Gajapati (Odisha), India
[2*,3,4,5,6,7]Department of Agriculture, Brainware University, Barasat, Kolkata-700125, West Bengal, India

*Corresponding author: Pabitra Kumar Ghosh
*Department of Agriculture, Brainware University, Barasat, Kolkata-700125, West Bengal, India
Email : pkgalivesince1995@gmail.com/ pabitrakr609@gmail.com

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Abstract
The incorporation of drone technology into contemporary farming has brought about a fundamental change, fundamentally altering traditional agricultural methods and significantly affecting how farming is conducted. Drones, also known as Unmanned Aerial Vehicles (UAVs), present a flexible and effective means for overseeing and managing crops, livestock, and overall farm activities. A significant advantage of drone technology in agriculture is its capability to deliver real-time, high-resolution aerial images. Drones equipped with sophisticated sensors and cameras enable precise monitoring of crop health, soil conditions, and pest outbreaks. This detailed data empowers farmers to make well-informed decisions, optimizing the allocation of resources and improving crop yields. Moreover, timely identification of potential issues allows for proactive measures, reducing dependence on chemical inputs and lessening environmental impact. Additionally, drones facilitate precision agriculture by enabling targeted applications of fertilizers, pesticides, and water. This not only improves resource efficiency but also cuts production costs and minimizes environmental risks. By automating repetitive tasks like crop scouting and surveying large areas of farmland, drones enhance operational efficiency, enabling farmers to focus on strategic decision-making. Furthermore, the impact of drone technology extends beyond crop management to encompass livestock monitoring, infrastructure inspection, and crop mapping. As the technology progresses, the agriculture sector stands to benefit from further advancements in data analytics and machine learning, unlocking new opportunities for optimizing farming practices. In conclusion, the integration of drone technology into modern agriculture has proven to be a transformative influence, providing farmers with unparalleled insights, enhanced efficiency, and sustainable practices. With ongoing advancements, this technology is poised to have an even greater positive impact on agriculture, fostering resilience and productivity in the agricultural sector.

Keywords: Drone Technology, Environmental risks, Precision agriculture, Sustainable practices, Unmanned Aerial Vehicles (UAVs).

Introduction

In today's agricultural landscape, farmers grapple with a multitude of challenges. The modern farming sector stands at a crucial juncture due to heightened demands for food production and consumption, resulting in a global surplus of supply and historically low commodity prices. Climate change exacerbates these issues, significantly impacting food security. According to Pathak et al., (2020), over 815 million individuals suffer from chronic hunger, with a majority residing in Asia. Moreover, climate change introduces additional complexities to the agricultural industry, particularly concerning supply chain security. In response to these challenges, drones are gaining popularity as a valuable tool in agriculture. They are integral to sustainable agricultural management strategies, aiding farmers, agronomists, and agricultural engineers in optimizing operations. By leveraging powerful data analytics, stakeholders can gain deep insights into their crops, enabling informed decision-making and enhancing overall efficiency. Despite India's heavy reliance on agriculture, the country lags in adopting cutting-edge technologies to enhance farm productivity. Farmers predominantly employ conventional methods for tasks such as pesticide application, composting, and seed planting (Rolle et al., 2015). These traditional practices are time-consuming and less efficient, highlighting the urgent need for technological advancements in this sector. However, the COVID-19 pandemic has exacerbated challenges for conventional farmers, particularly in monitoring crops and conducting tasks like fertilizer and pesticide spraying (Varshney et al., 2020).

In contrast, developed nations have already embraced the use of unmanned aerial vehicles (UAVs) for various agricultural purposes, including remote sensing, photogrammetry, and precision agriculture (Aditya and Kulkarni, 2016; Zhang and Kovacs, 2012; Everaerts, 2008; Colomina and Molina, 2014). Equipped with sensors, cameras, and sprayers, UAVs enable efficient monitoring of crops and precise application of pesticides. For a considerable duration, drones were viewed as expensive gadgets, often perceived as mere recreational items. Surprisingly, the agriculture sector has largely overlooked drones, potentially to its detriment. An in-depth examination of UAVs in precision agriculture involves assessing their suitability for various agricultural tasks such as crop monitoring (Bending et al., 2012), estimating crop height (Anthony et al., 2014), and pesticide spraying (Huang et al., 2009). Consequently, aerial remote sensing emerges as a critical component of Precision Agriculture (PA) and intelligent farming. The evolution of Unmanned Aerial Vehicle (UAV) technologies and the reduction in equipment weight have notably transformed crop remote sensing.

Nevertheless, challenges such as the high cost of drones, regulatory policies, and the scarcity of technically skilled pilots pose significant barriers to the development of the drone market in India. Similar to initiatives like the custom hiring of farm machinery, there's a suggestion that farmers should undergo training in drone operation and be encouraged to establish collective enterprises to own drones. The reluctance of small and medium-scale farmers to adopt drones stems from the substantial investment required. This article delves into the potential applications of drones in agriculture, along with the associated possibilities and limitations.

Application of drone in agriculture

Crop health monitoring

Employing drones for crop monitoring throughout the growing season facilitates timely and customized responses. By analyzing reflection patterns across various wavelengths, diverse multispectral indices can be computed using visible, near-infrared, and thermal infrared sensors. These indices enable the assessment of crop conditions including water stress, nutrient deficiencies, pest infestations, diseases, and more. UAVs have the capacity to cover vast hectares of fields in a single flight, eliminating the need for farmers to conduct physical crop inspections. This technology enables farmers to remotely monitor crops in horticultural areas or other remote locations like mountainous regions. Moreover, it allows for effective monitoring of trees and tall crops, which are challenging for farmers to survey manually.

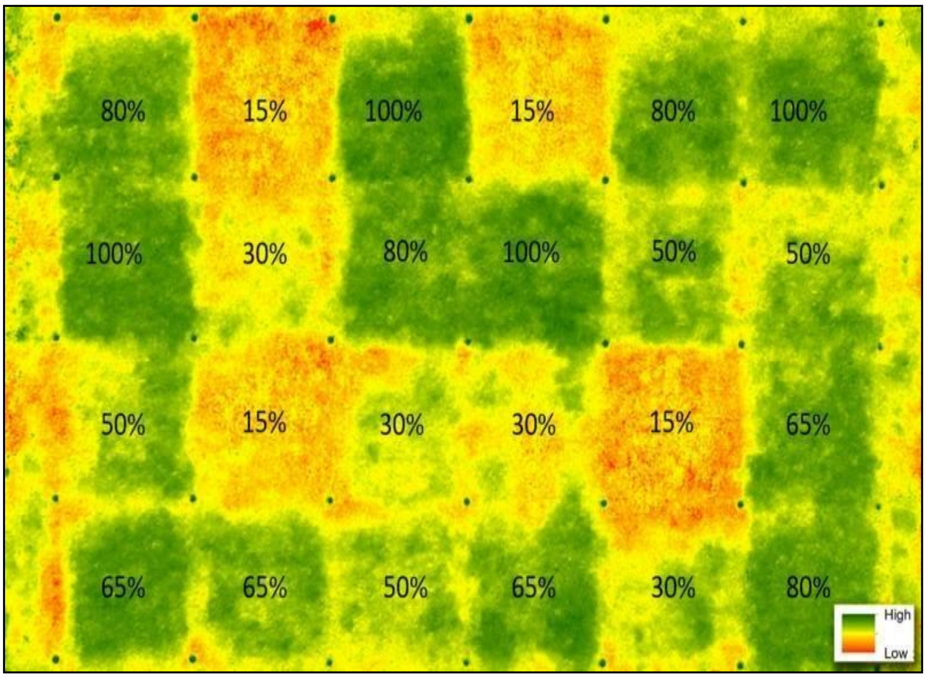

Figure. 1: Application of drone for crop health monitoring (source: https://www.usga.org/course-care/turfgrass-and-environmental-research/research-updates/small-unmanned-aircraft-systems-detect-turfgrass-drought.html)

Water stress monitoring

Assessing water stress in crops is a complex endeavour due to the multifaceted nature of drought's impacts, as noted by Espinoza et al., (2017). Variables extracted from thermal imagery often rely on subtle temperature fluctuations to identify stress and related phenomena. For instance, disparate genotypes of the same crop may exhibit markedly different canopy temperatures under identical conditions due to inherent variations in stomatal conductance and transpiration rates (Berni et al., 2009). Vegetation indices such as NDVI and GNDVI, as referenced in works by Zarco-Tejada et al., (2012) and Espinoza et al., (2017), and the utilization of multispectral or hyperspectral images are the result of spectral manipulations designed to emphasize specific vegetation characteristics. While RGB images are infrequently utilized, they are typically paired with multispectral or thermal images to compute hybrid variables like the Water Deficit Index (WDI), as observed in the study by Hoffmann et al., (2016).

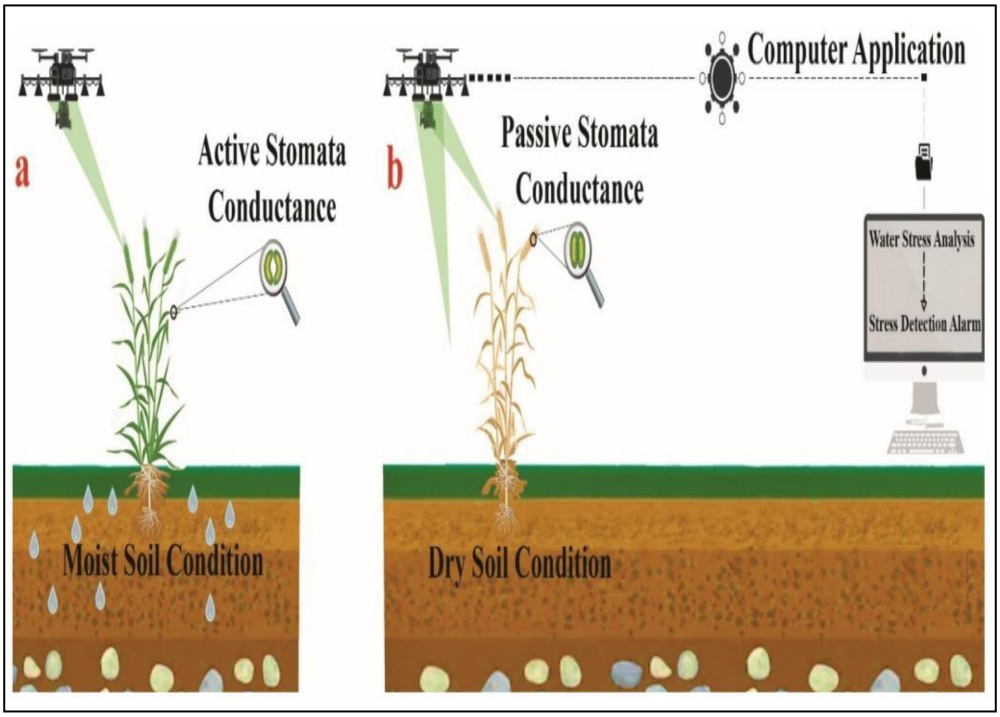

Figure. 2: Application of drone for water stress monitoring (Ahmad et al., 2021)

Nutrient status monitoring

Remote sensing in agriculture holds significant promise for identifying symptoms arising from both biotic and abiotic stressors on plants, such as nutrient deficiencies, pest pressure, and adverse environmental conditions. Numerous studies have demonstrated successful monitoring of plant nutrition using remote sensing techniques (Cilia et al., 2014; Maresma et al., 2018; Corti et al., 2019; Berger et al., 2020). Monitoring both nutrient deficiency and toxicity symptoms is vital across various crops. Utilizing Unmanned Aerial Systems (UAS) for remote monitoring of crop nutrient status offers real-time, detailed spatial data, which can enhance crop productivity and reduce excessive fertilizer usage when integrated with existing precision agriculture technologies employed on commercial farm machinery. Sensors can detect plant nutrient deficiencies by analyzing changes in spectral reflectance, allowing for non-invasive diagnosis. Vegetation indices like the Normalized Difference Vegetation Index (NDVI), measured using broad-band multispectral sensors, are widely used in agriculture research due to their strong correlation with crop health (Stroppiana et al., 2015; Severtson et al., 2016; Stanton et al., 2017). In a recent study by Montgomerry et al. (2020) on flue-cured tobacco, spectral data analysis was conducted to monitor crop health remotely. This study explored the relationship between crop health and 3D canopy structure using low-cost UAS equipped with consumer-grade RGB cameras. It was suggested that there is a significant link between relative canopy shape and crop health, potentially enhancing the effectiveness of low-cost UAS for precision agriculture.

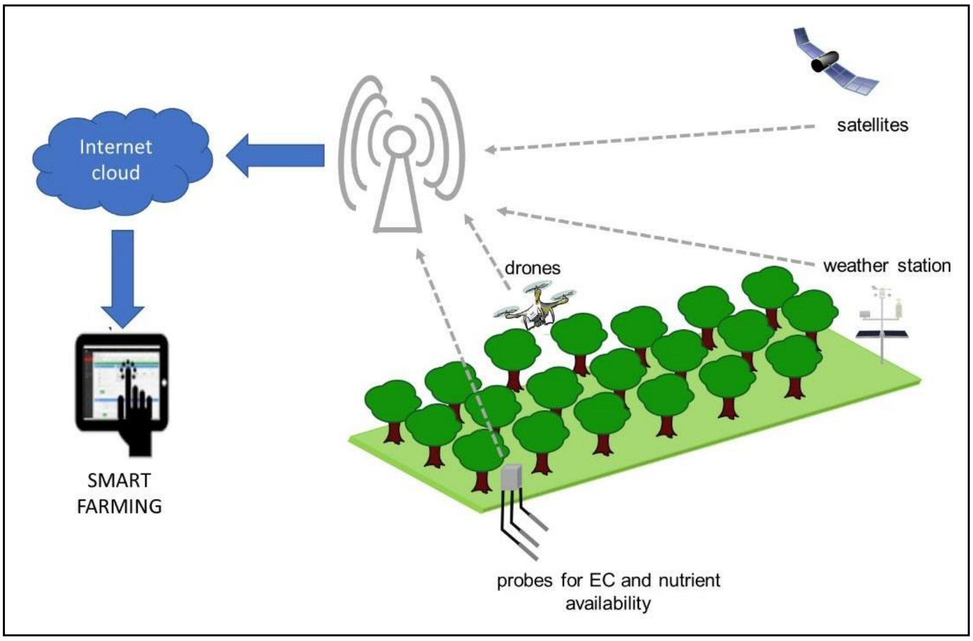

Figure. 3: Drone and sensor technology for sustainable nutrient management (Toselli et al., 2023)

Disease monitoring

Crop diseases, whether fungal, bacterial, or viral, pose significant threats to global food security by causing substantial yield losses (Ning et al., 2017). Effective prevention of crop damage hinges on timely and cost-efficient detection methods to accurately identify the disease's causative agents (Singh et al., 2018). Conventional disease identification approaches were often time-consuming, subjective, and relied solely on human observation. Additionally, human scouting for diseases incurred high costs and was often impractical due to the possibility of human error and the presence of subtle symptoms that are easily missed (Qin et al., 2021). Hence, addressing these challenges at a reasonable cost with minimal environmental impact necessitates a technology-driven agricultural revolution.

Drones equipped with advanced visual systems for aerial remote sensing, also known as unmanned aerial vehicles (UAVs) or unmanned aerial systems (UAS), offer a promising and affordable solution for identifying crop and plant diseases across various agricultural settings, from small greenhouses to large farms (Ge, 2011; Mahlein et al., 2016; Herrmann et al., 2020). Researchers are actively developing methods to differentiate between infected and uninfected leaves and classify disease severity levels based on visual cues, even before symptoms become apparent (De Jong et al., 2004). An example of drone technology's efficacy in disease detection is demonstrated by farmers at the University of North Dakota, USA, who initially used remote sensing data to validate the effectiveness of fungicide treatments against plant diseases in sugar beet crops (Seelan et al., 2003). Subsequently, multispectral imagery was utilized to assess varying degrees of rice sheath blight disease in field plots with an accuracy exceeding 60% (Martinelli et al., 2015). The study revealed that drones equipped with digital and multispectral cameras are the most effective method for field-based rice sheath blight disease detection. In another instance, drone footage was employed to conduct a multispectral detection analysis of fungal infections in barley. This facilitated mapping and comparison with ground truth data, enabling the monitoring of fungicide intensity to prevent environmental damage from fungicide misuse (Dunning et al., 2017). The utilization of drones for plant disease assessment offers efficient monitoring and detection capabilities for smart agriculture, providing enhanced accessibility, broader coverage, and rapid data collection, ultimately enabling timely disease detection.

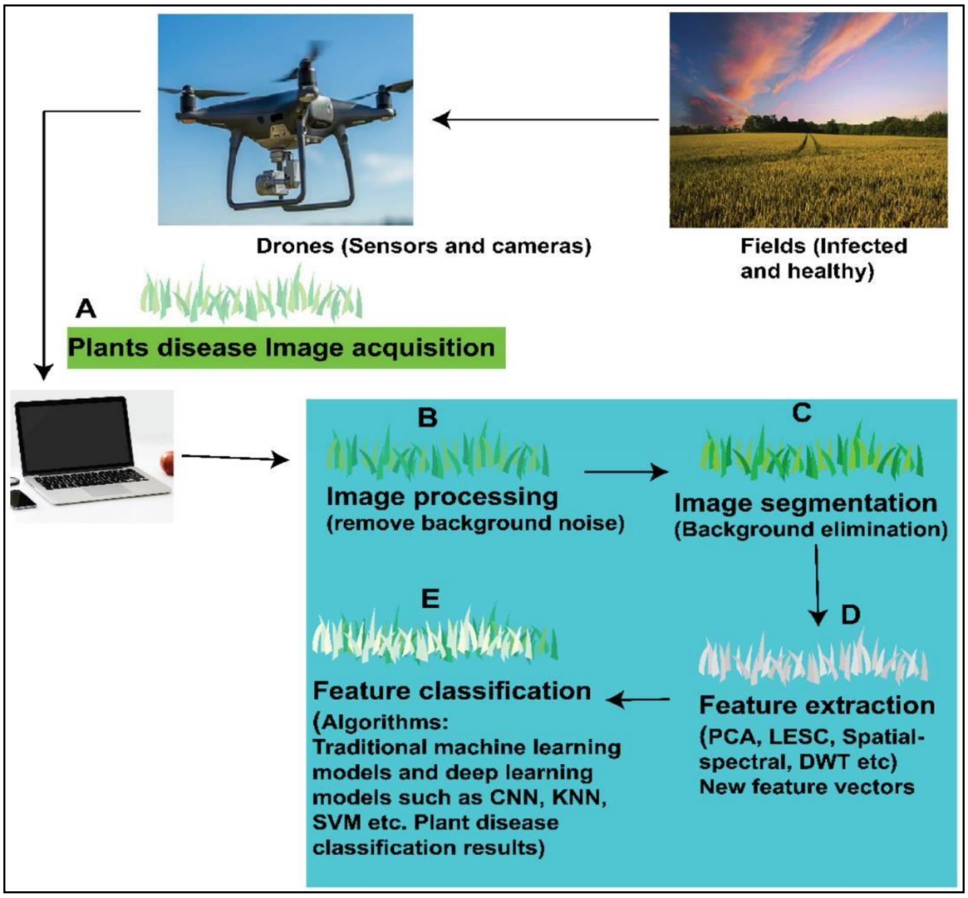

Figure. 4: Application of drone for disease monitoring (Abbas et al., 2023)

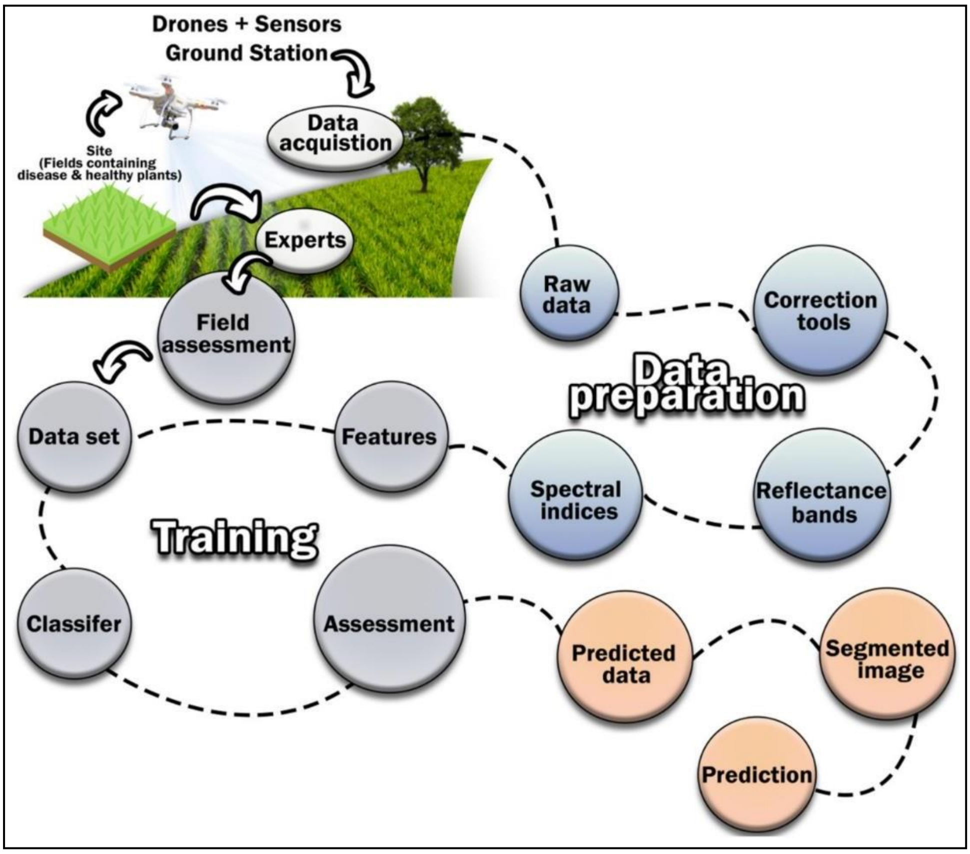

Figure. 5: Data preparation and scaling of disease using drone (Abbas et al., 2023)

Weed control

As laborers in agriculture increasingly transition to non-agricultural sectors (Srivastava et al., 2020), the agricultural workforce is declining by 30.7 million workers, leading to a 12% decrease, and subsequently, a 9.3% rise in labor wages (Vaishnavi and Manisankar, 2022). Thus, the advancement of drone technologies becomes crucial for efficiently managing limited resources while ensuring profitable energy, yield, and returns. Although traditional hand weeding is effective in weed elimination, it demands extensive labor and energy, often proving economically inefficient. Chemical weed management, as suggested by Pratap et al. (2021), emerges as a viable alternative to manual weeding. However, the selection of herbicides must be wise to ensure effective weed management. Typically, knapsack sprayers are utilized for chemical application in agricultural tasks, but they come with several drawbacks, including a shortage of skilled labor and considerable herbicide exposure risk (Cao et al., 2017). Moreover, applying herbicides with conventional sprayers requires additional labor, energy, water, time, and effort. Drones offer an alternative method for herbicide application in resource-scarce settings, minimizing resource misuse. Paul et al. (2023) demonstrated that drone application of pre-emergence pretilachlor followed by post-emergence bispyribac sodium significantly reduced weed density and dry weight, while also recording the highest grain and straw yield in Direct Seeded Rice (DSR). However, the overuse of herbicides may lead to the development of herbicide-resistant weeds, impacting crop growth and yield and posing environmental pollution risks. Site-specific weed control aims to address these issues by ensuring precise herbicide spraying based on accurate weed cover maps. Detailed weed cover maps, created using data and images collected by drones across the entire field, are essential for accurate herbicide spraying. Hunter et al. (2019) highlighted that integrating UAVs for weed mapping and site-specific management (UAV-IS) offers an efficient alternative to conventional broadcast weed management practices, potentially reducing pesticide use. Nevertheless, the efficacy of weed control with UAV-IS depends on weed distribution and morphology. Furthermore, UAV-IS can be utilized for detecting and mapping weed escapes to direct UAV sprayers to control them before seed production occurs, eliminating potential herbicide-resistant individuals (Niu et al., 2020).

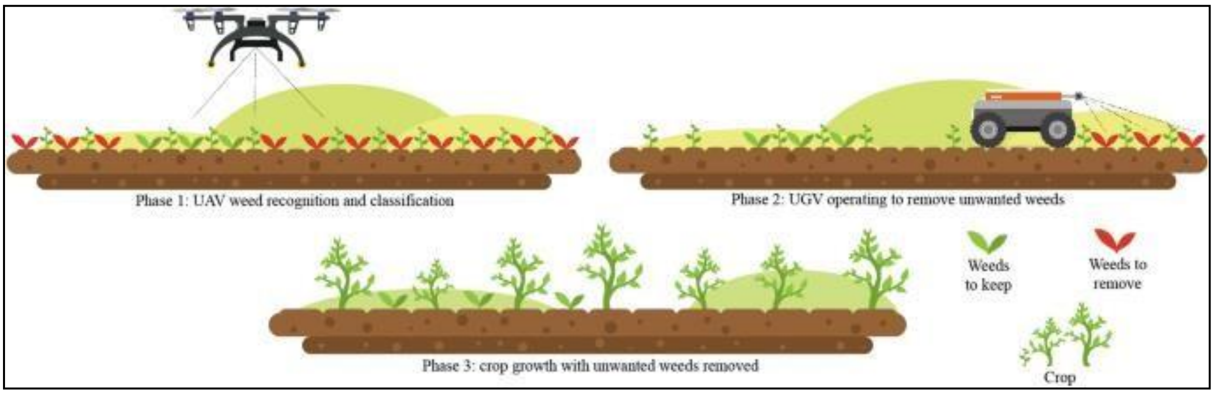

Figure. 6: Drone and sensor technology for sustainable weed management (Esposito et al., 2021)

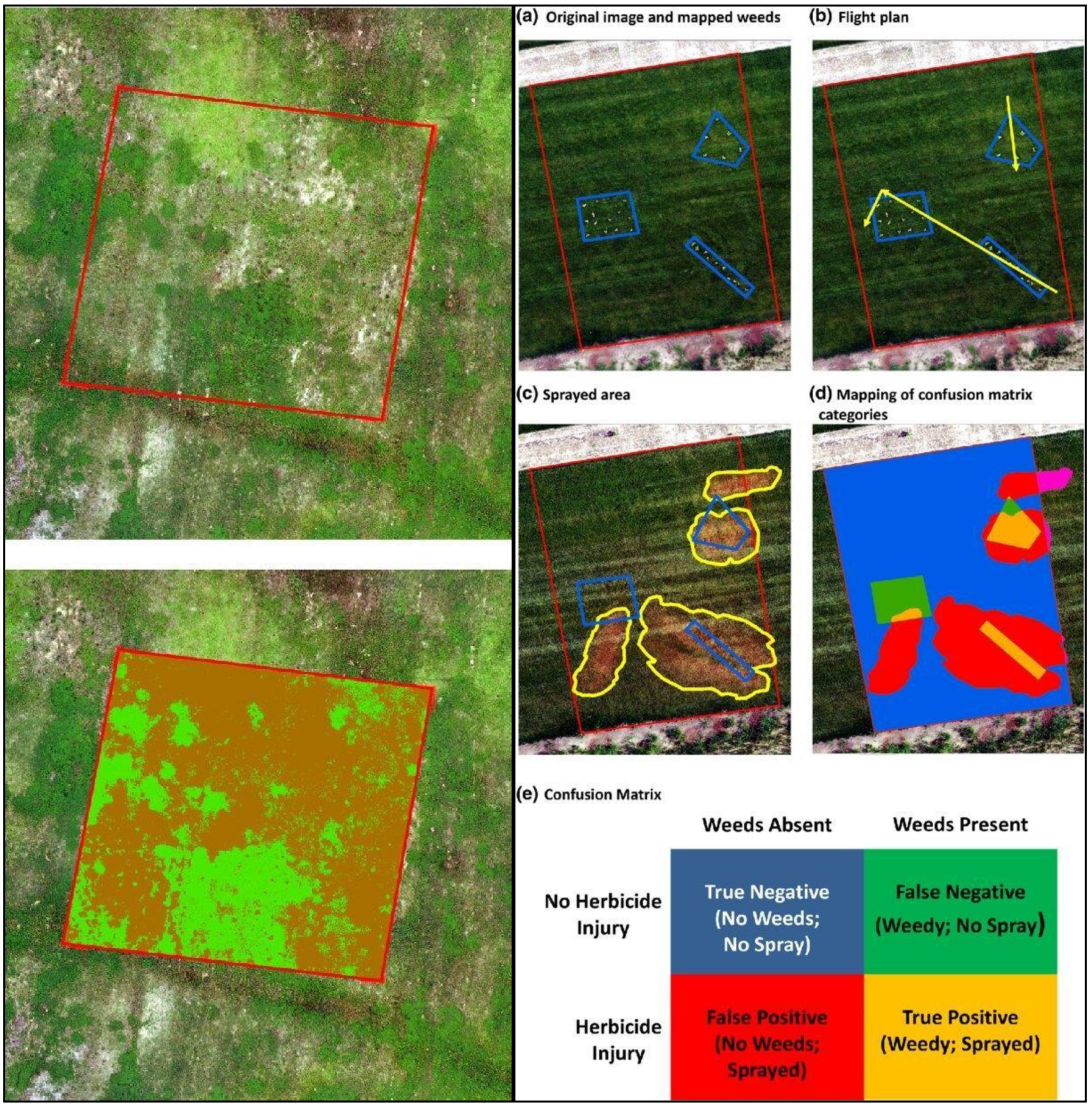

Figure. 7: Application of drone technology in identifying the weed infestation in crop fields and steps for integrating UAV weed mapping and UAV herbicide application (Hunter et al., 2019)

Evapotranspiration estimation

Evapotranspiration, or ET, refers to the process of transferring water from the land to the atmosphere through plant transpiration and soil evaporation. This phenomenon holds significant importance in hydrology, agriculture, and water management, with experts relying on estimates of potential ET. Given the growing concerns over water scarcity, increasing population, and the impacts of climate change, evapotranspiration estimation has emerged as a crucial focus area in agricultural research. Various types of unmanned aerial vehicles (UAVs) are utilized for different research objectives in estimating ET. These UAV platforms include fixed-wing aircraft, quadcopters, and airplanes. Utah State University has developed an airborne digital system capable of collecting multispectral and thermal images for evapotranspiration estimation (Xia et al., 2016). Compared to satellite-based remote sensing methods, UAV platforms equipped with lightweight sensors offer superior image quality, higher spatial resolution, and increased temporal resolution.

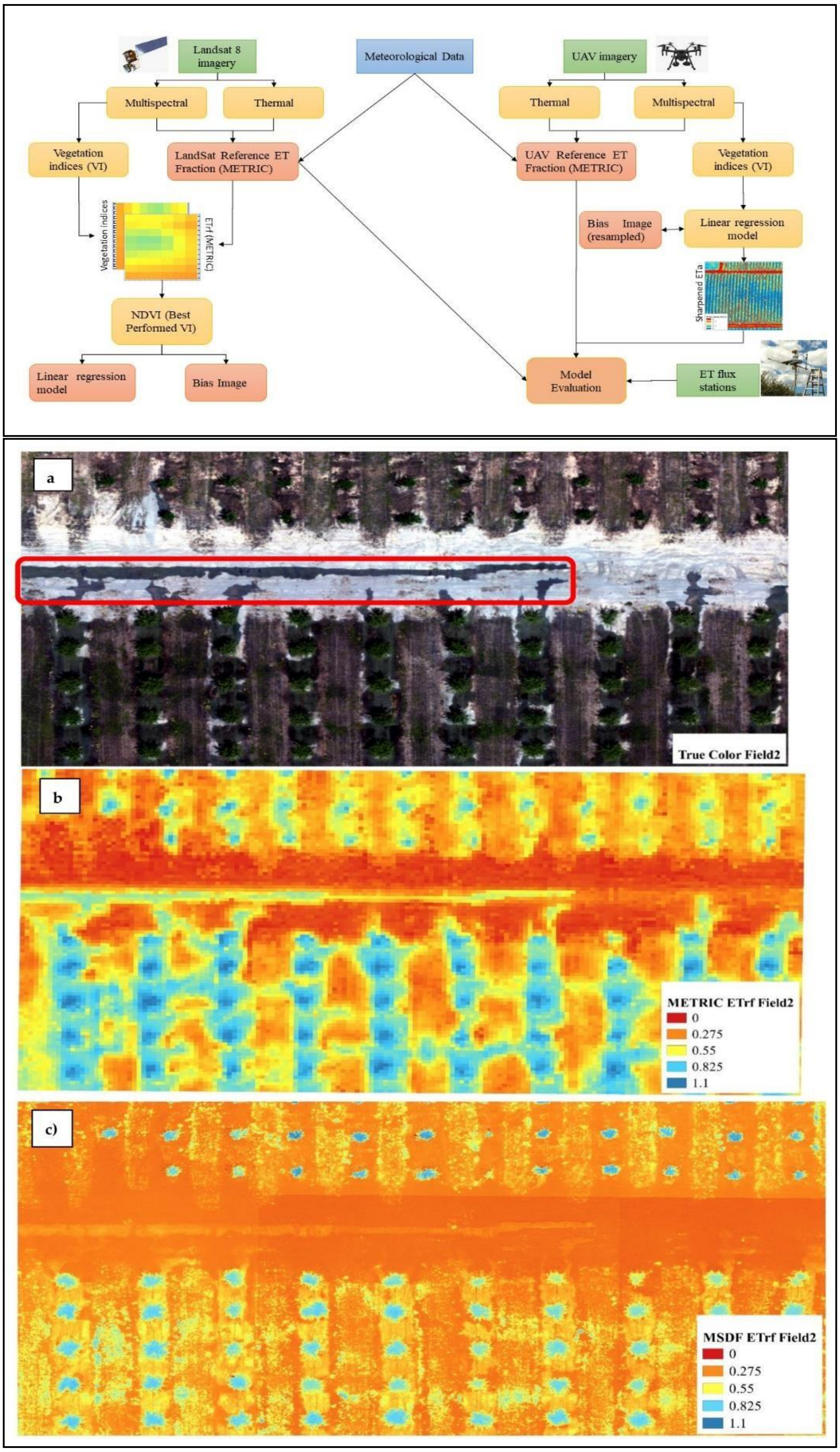

Figure. 8: Application of drone for determining Actual Evapotranspiration from UAV Images (Mokhtari et al., 2021)

Spraying

To achieve high levels of productivity in Indian agriculture, there is a constant need for production and protection materials. Fertilizers and chemicals play a crucial role in eradicating pests and promoting crop growth. Drones offer a promising solution for spraying these chemicals, allowing for precise application tailored to the specific spatial variability of fields and crops. Depending on factors such as crop conditions or the severity of pest attacks, the quantity of chemicals sprayed can be adjusted accordingly. The integration of UAV technology with sprayer systems provides a platform for vector control and pest management, offering precise application even in large crop fields. The efficiency of pesticide application is further enhanced through the use of a PWM controller (Huang et al., 2009; Zhu et al., 2010). Various innovative drone-based sprayers have been developed, such as the blimp-integrated quadcopter aerial automated pesticide sprayer (AAPS), which operates based on GPS coordinates in lower altitude environments (Vardhan et al., 2014). The utilization of drone-mounted sprayers has improved coverage capabilities, increased chemical effectiveness, and streamlined the spraying process, making it faster and easier. Modern drones can carry large pesticide tanks, some up to 40 liters, and follow pre-mapped routes to spray crops according to specific requirements. Drones are particularly beneficial for covering fields with difficult access for tractors or conventional aircraft. Researchers have proposed advanced systems for optimizing pesticide spraying tasks, such as a genetic algorithm-based multi-UAV system (He Luo et al., 2017). Additionally, various drone models, like Freyr and Aero Drone, have been developed specifically for uniform spraying applications and field monitoring (Spoorthi et al., 2017; B. Balaji et al., 2018; Kislaya and Goutam, 2019). Moreover, efforts have been made to address payload limitations in aerial pesticide spraying systems (Martinez-Guanter et al., 2019).

Figure. 9: Application of drone for spraying (Hanif et al., 2022)

Conclusion

Significant advancements have been observed in drone technology for precision agriculture post-2017, particularly in terms of modifications to drone design, the development of specialized sensors for data collection, innovative applications in pesticide delivery, and the integration of deep learning and artificial intelligence for remote agricultural monitoring. This surge in drone applications is attributed to the reduction in UAV weight, cost, and cargo capacity, making drones more accessible and versatile. Multi-copter and fixed-wing drones are the predominant types used for crop health monitoring and livestock detection, with ongoing trends toward smaller and more affordable models. Unmanned helicopters, due to their substantial payload capacity, are primarily utilized for fertilizer and pesticide spraying, although the use of multi-copters for this purpose is steadily increasing, particularly for spot spraying, benefiting from their enhanced flying stability. The evolution of drone cameras, marked by changes in weight, size, and resolution, has seen a transition from RGB to multispectral cameras, which are preferred for their enhanced feature extraction capabilities. Advancements in drone controls have progressed from basic microcontrollers to AI-capable boards like Arduino Uno and Raspberry Pi, enabling more sophisticated operations. With ongoing research in embedded systems, data transmission, and processing, drone technologies are evolving from semi-controlled to fully automated systems, incorporating machine learning to enhance user-friendliness. Despite these advancements, several challenges remain in the widespread adoption of drone technology in agriculture, including high equipment costs, limited battery life, line-of-sight limitations, user technology literacy, and deficiencies in image processing and data analysis. Addressing these obstacles is essential to accelerate the integration of drones into agricultural practices.

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Declaration of Competing Interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Code availability: Not applicable

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