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A role of drones and satellite images in agricultural extension: A review

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Abstract

Extension services in agriculture are responsible for the transmission of knowledge, technology, and innovations to farmers, which finally leads to enhancing agricultural productivity and sustainability. Utilization of the latest technologies like drones and satellite imaging has revolutionized contemporary agriculture by increasing precision agriculture, tracking crop health, optimizing resource usage, and lowering environmental footprints. These technologies are capable of supplying real-time high-resolution data that allows extension agents and farmers to make the best decisions. Also, drones and satellite imaging can aid in disaster response, soil analysis, and effective farm management. This review discusses the contributions of these technologies to agricultural extension, emphasizing their benefits, shortcomings, and possibilities for sustainable technology-based agriculture.

Keywords: Drone, satellite image, tracking crop health, extension agent

Introduction

Extension services for agriculture are needed to enhance the productivity, sustainability, and livelihood of farmers (Joshi *et al.*, 2019) [49]. Extension services encompass the delivery of information, best practices, and innovations to farmers to enable them to embrace enhanced agricultural practices (Mapiye *et al.*, 2021) [61]. Extension services had traditionally depended on field visits, on-farm demonstrations, training programs for farmers, and published materials (Phanith *et al.*, 2023) [82]. Yet, these mechanisms were subject to accessibility, scalability, and punctuality of the delivery of information (Isubikalu, 2007) [47].

Drone highly efficient and find useful applications, the biggest weakness of these systems is that they are task-calibrated (like distinguishing between different vegetation types, water bodies, urban land use, and exposed soil) with no ability to present a whole picture of farming processes (Glendenning *et al.*, 2010) [37]. It raises the level of human workload because the operator has to switch output data from one system manually to another. To meet these challenges, studies are being carried out on software modules, drones, and other hardware to engineer a standardized information middleware and application interface (Nouacer *et al.*, 2010) [74]. The aim is to reduce repetitive and time-consuming operations (Abdelmaboud, 2021) [2].

In order to do this, farming needs to incorporate automation, robotics, and advanced information services by bringing technologies like big data, the Internet of Things (IoT), robotics, artificial intelligence (AI), and information and communication technologies (ICT) together. Smart agriculture is the new field changing the future landscape (Misra *et al.*, 2020) [65]. The flagship technology of change here is that of agricultural robots, specifically drones or unmanned aerial vehicles (UAVs), which have caught on globally (AlZubi *et al.*, 2023) [10].

With the digital revolution, extension in agriculture has come a long way, providing a platform for more effective and data-based decision-making in farming (Kosior, 2017)

[54]. The most promising of the new developments is the use of drones and satellite imagery, providing accurate, timely, and at-scale agricultural data collection (Liu *et al.*, 2021) [58]. Such technologies enable useful observations about crop conditions, soil type, water, and climate regimes, thus facilitating farmers and extension agents to act accordingly and take decisions in advance. In addition, they make agriculture sustainable as it maximizes resource use efficiency, reduces the waste of inputs, and raises overall farm yield (Lybbert *et al.*, 2010) [59]. Through the use of drones and satellite imagery in agricultural extension services, extension officers can close the knowledge gap between research and field application, enabling speedy technology uptake among farmers (Singh *et al.*, 2025) [96]. This review emphasizes the importance of these technologies in contemporary agricultural extension, outlining their uses, benefits, and limitations as well as looking into future potential for further development and integration in precision agriculture (Abozar, and Choudhary, 2021) [6].

Drones are revolutionizing agriculture by quickly and effectively gathering large amounts of data. Their use in contemporary farming encompasses numerous advantages (Yadav, and Sidana, 2023) [111]. For example, drones provide an efficient method for pesticide spraying, substituting conventional labor-intensive and dangerous approaches, particularly in difficult terrain such as hilly areas (Iqbal, 2024) [45]. The convergence of machine learning and artificial intelligence with NDVI (Normalized Difference Vegetation Index) imaging means that highly detailed images can be taken by drones to analyze soil health, detect plant stress, and forecast yields (Guebsi, *et al.*, 2024) [39]. Image processing software makes it possible to identify and quantify stressed individual plants (Emimi *et al.* 2023) [32].

This research analyzes current trends, emerging technologies, and numerous applications of UAVs in agriculture (Velusamy *et al.*, 2021) [106]. It also identifies potential future opportunities, challenges, and resolutions for enhancing the efficiency of drones in agriculture. In general, drones offer farmers an important tool to improve productivity, achieve sustainable incomes, and enhance resilience in contemporary agriculture (Rejeb *et al.*, 2022) [89]. With advances in sensor technology, communication systems, and automation, the use of drones in agriculture will continue to grow more, driving innovation and enhancing the efficiency of food production (Abdullahi *et al.*, 2015) [5].

Drone photography and ground sensor data are expected to be a crucial component of precision agriculture, providing immense potential for scientific study and development (Mukherjee *et al.*, 2019) [71]. Other metrological considerations also need to be taken into account when developing such platforms, such as the sensors they incorporate, and the instrumentation and calibration processes necessary for their testing (Daponte, 2019) [25].

UAVs have cut down labor hours substantially while improving the stability of operations, accuracy of measurements, and overall productivity (Mohsan *et al.*, 2023) [69]. They are not only cheaper than most conventional farming machines but are also easy to use. Their uses range over a number of agricultural practices, such as insecticide and fertilizer spraying, seed sowing, weed detection, soil fertility mapping, field mapping, and forecasting crop yields (Mohsan, *et al.*, 2022) [68].

Different sensors and data collection tools have been developed for agricultural use, including yield monitors, weed sensors, and underground and aboveground sensors that monitor temperature and humidity (Omia *et al.*, 2023) [76]. Of these, imaging sensors are a key component of precision agriculture (Salazar Loor *et al.*, 2018) [94]. Historically, aerial imagery was only available through aircraft or satellites, like those in the Landsat program. Satellite and aerial images captured using multispectral and hyperspectral cameras help generate different vegetation indices, which reveal field variations (Candiago *et al.*, 2015) [23]. For example, the Normalized Difference Vegetation Index (NDVI) compares light intensities reflected from plant canopies in the near-infrared (NIR) and visible spectrum to assess vegetation health (Pettorelli, 2013) [81].

Technologies such as precision positioning, navigation systems, imaging methods, battery technology, circuits, and motors are critical for UAV efficiency (Elmeseiry *et al.*, 2021) [30]. The technology selected-such as nozzle control systems, big data analysis, and equipment modernization-varies with the intended UAV application and agricultural requirements (Mohsan, *et al.*, 2022) [68]. Nevertheless, making full information available on UAV technology is still complex. Similar to other sectors, agriculture is adapting to innovation by embracing technological convergence, with the UAV playing an important role (El Alaoui *et al.*, 2024) [29].

In spite of their strengths, agricultural UAVs have various technical limitations, such as low battery life, short flight times, limited communication range, and payload capacity (Elmeseiry *et al.*, 2021) [30]. These limitations must be overcome to create the future generation of agricultural UAV solutions (Mozaffari *et al.*, 2-19). Therefore, prior to large-scale deployment of drone-based systems, it is imperative to research the most recent technological developments, precision equipment, and diversification options (Toscano *et al.*, 2024) [102].

Table 1: Different type Agriculture Drone

one Type	Description	Key Features	Applications in Agriculture	Advantages	Limitations
Fixed-Wing UAV	UAVs with stationary aerofoil-shaped wings that generate lift at a certain speed.	Longer flight duration	Large-scale field mapping	Covers large areas quickly	Needs open space for landing
		High-speed coverage	Crop monitoring	More efficient for extensive farms	Higher cost
		Requires a runway for takeoff and landing	Soil analysis		
Helicopter UAV	Single set of horizontally rotating blades attached to a central pole.	Vertical takeoff and landing	Targeted pesticide spraying	Can operate in crowded or remote locations	Higher maintenance cost
		Ability to hover and maneuver in confined spaces	Crop surveillance in inaccessible areas	High maneuverability	Shorter flight time than fixed-wing drones
Multi-Copter UAV	UAVs with multiple rotors (usually 4-8) that provide lift and control.	Highly stable	Crop health assessment	Easy to deploy	Shorter battery life
		Can hover precisely	Fertilizer & pesticide application	Operates in small and uneven fields	Limited payload capacity
		AI-integrated semi-controlled operation	Irrigation monitoring		
AI-Integrated Drones	Drones that use AI for autonomous decision-making based on sensor data.	Real-time data analysis	Spatial variability mapping	Enhances farm productivity	Requires prior AI training
		Decision-making based on prior training	Soil health monitoring	Reduces manual labor	Expensive to implement
		Improved efficiency	Precision agriculture		
GPS-Based Autonomous Drones	Unmanned aerial vehicles controlled via GPS instead of manual radio control.	Automated flight paths	Remote crop monitoring	Less need for human intervention	Initial setup cost is high
		Customizable camera and sensor integration	High-precision mapping	Improved accuracy	Dependent on satellite signals
			Variable rate application (VRA)		

Fig 1: Image of a helicopter drone used in Agriculture

Grounded on such understanding, farmers are able to undertake preventative actions to manage disease propagation among crops (Rossi *et al.*, 2012) [91]. The timely interventions also reduce losses due to biotic factors like pests and diseases, maximize the use of fertilizers (Palti, 2012) [77], optimize irrigation practices, and reduce impacts of climate change and unstable weather through data analysis from drones and satellite remote sensing (Meivel *et al.*, 2021) [62].

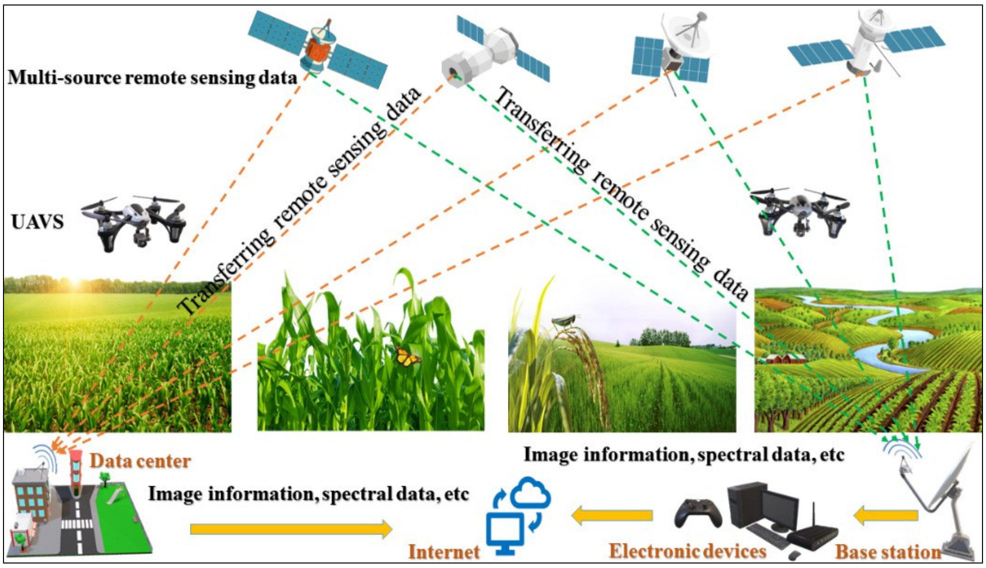
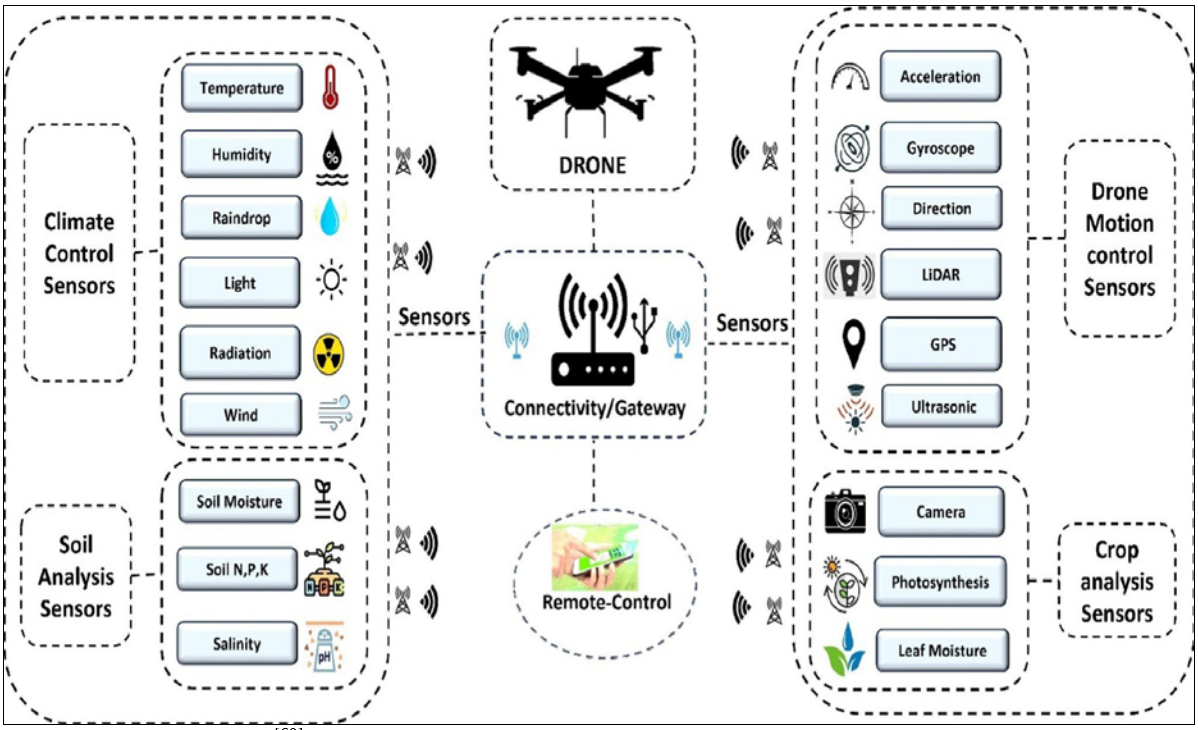


Fig 2: Role of remote sensing in Agriculture crop cultivation helpful for Agriculture extension

Drones' Role in Agricultural Extension

Drones or Unmanned Aerial Vehicles (UAVs) have proven to be priceless assets in contemporary agricultural extension as they are capable of capturing high-resolution, real-time data with little or no human input (Wang *et al.*, 2022) [107]. These aerial devices fill the gap between extension officers and farmers by offering quick, precise, and affordable remedies for numerous agricultural problems (Balyan *et al.*, 2024) [17]. As technology advances rapidly in drones, their extensive use in extension has improved precision agriculture, sustainability, and farm productivity overall (Abdullahi *et al.*, 2015) [5].



Source: Makam *et al.*, 2024 [60]

Fig 3: Diagram of drone by employing various sensors

Drones present a flexible and scalable means to address various applications in agriculture. Utilizing cutting-edge imaging technology, sensors, and machine learning-based analytics, they bring invaluable information regarding the health of crops, fertility of soil, and conditions in the environment (Nahiyoon *et al.*, 2024) [72]. Automation by drones makes it possible to collect large-scale agricultural data in a methodical manner, cutting down the reliance on traditional manual surveys, as well as optimizing the impact of extension services (Ahmad *et al.*, 2024) [9]. Apart from gathering data, drones allow for on-the-spot intervention through the delivery of specific inputs such as water, fertilizers, and pesticides, hence limiting wastage and increasing farm effectiveness (Kar, and Chowdhury, 2024) [50].

Table 2: Application of Various Types of Drones in Agricultural Operations

Types of Drones	Components Attached	Applications	Data Measured	Output	References
Fixed-wing drone	Spray tank, spray gun, water stress sensors	Pesticide, fertilizer, and herbicide spot spraying	Detects areas with low crop moisture and disease zones for precise spraying	Reduces manual labor by 50% and pesticide usage by 30%, increasing profit margins	(Huang *et al.*, 2014) [41]
Multi-copter drone (quad/hexa)	Multispectral, thermal, RGB cameras	Crop health monitoring, disease detection, weed detection	Captures thermal and multispectral images to assess crop health and detect diseases using VIBGYOR reflections	Enables early detection of disease, pest infestation, and water stress with over 90% accuracy, improving crop health and yield	(Hunt ER *et al.*, 2010) [42]
Multi-copter drone (quad/hexa)	GPS, GIS	Land survey and field mapping	Captures high-resolution multispectral images to create detailed maps of crop health and vegetation levels	Increases fertilizer efficiency by 20% and crop yields by 15%, showcasing benefits of GPS and GIS integration	(Cunliffe *et al.*, 2020) [24]
Fixed-wing, multi-copter drone	Rotary blades, gimbal cameras, DC motors	Horticulture and orchard crop harvesting	Captures fruit position and health; cutting blades harvest based on predetermined positions	Reduces harvesting time by 30%, increases crop yield by 10%, and reduces crop wastage by 20%	(Cunliffe *et al.*, 2020) [24]
Fixed-wing, single rotor drone	Seed dispensers, seed box, robotic arms	Planting and seeding	Monitors fields using high-resolution aerial imagery to assess germination rates and plant distribution	Improves germination rate by 20%, reduces seed wastage by 25%, increases crop yield by 15%, and speeds up planting by 30%	(Zhang *et al.*, 2012 [113], Mogili *et al.*, 2018) [66]
Fixed-wing, multi-copter drone	Robotic arms, soil NPK, pH, organic matter sensors	Soil analysis	Collects soil samples at various depths and locations for nutrient, pH, and organic matter analysis	Reduces fertilizer use by 25%, leading to cost savings and environmental benefits; increases crop yield by 15%	(Nawaz *et al.*, 2019) [73]

Source: Makam *et al.*, 2024 [60]

In addition, drones are essential to the response to climate challenges. They offer rapid surveys of drought, flood, and pest disaster areas to allow for timely decision-making in disaster management and recovery (Bosmans *et al.*, 2022) [21]. In precision agriculture, drones improve variable-rate application methods, allowing resources to be applied optimally to maximize yields (Taseer, and Han, 2024) [100]. They also facilitate digital extension platforms by obtaining high-resolution images and video for remote training of farmers, knowledge dissemination, and campaigns (Fabregas *et al.*, 2022) [34]. Their principal uses are:

Crop Health and Monitoring Assessment

Multispectral, hyperspectral, and thermal cameras on drones can identify early stress, disease, and nutrient deficiency in crops by measuring changes in light reflectance and temperature (Kaushik, *et al.*, 2021) [52]. These cutting-edge imaging technologies allow for accurate monitoring of vegetation indices like NDVI (Normalized Difference Vegetation Index), which assists in the evaluation of plant vigor and the identification of trouble spots before the onset of visible symptoms (Sahoo, 2022) [93]. With real-time and actionable information, drones enable precision intervention, minimizing yield loss and maximizing potential yields (Getahun *et al.*, 2024) [36].

Precision Agriculture

UAVs enable precision farming through the application of fertilizers, pesticides, and water exactly where required based on real-time analysis of data (Yadav, and Sidana, 2023) [111]. With the help of sophisticated sensors and AI-based analytics, drones can chart variability in soil fertility, plant health, and moisture levels and apply inputs site-specifically (Tsouros *et al.*, 2019) [103]. This precise application reduces wastage of inputs, increases crop yield, decreases environmental pollution, and reduces production costs. UAVs also allow farmers to track application efficacy and make adjustments as required to maximize field performance (Radoglou-Grammatikis *et al.*, 2020) [85].

Table 3: Different Types of aerial imaging system used in precision agriculture

Types of Aerial platform	Commercial agriculture drones	Price range	Applications in agriculture	Advantage	Disadvantage
Pilot aircraft (40) Single Rotor	M-18 Dromader PZL-106AR Kruk Yamaha RMAXR22-	Very high High	Crop scouting Fertilizer and pesticide spraying for larger area Drought monitoring Security, and surveillance Large area pesticide spraying in	1- High speed 2- High Flight Time 3- Higher payload Weight 4- Can cover well over hundreds of hectares of crop fields in a short period 1- High Payload	1- High operating cost 2- High altitude Flight 3- Problem in inspection of isolated small fields -Heavier 2-Costly setup 3-

Helicopter (UAV) (53)	UVR66 spray systemAlign Demeter E1SR20 and SR200 of Rotary motion		remote area where high payload capability is needed Crop height estimations Soil and field analysis Crop classification	Capacity 2- Higher flight time 3- Higher speed 4- Strong and durable	High altitude flight 4-Noise and vibration 5-Stability problem
Fixed Wing	1-AgEagle RX60	Medium-	Large area monitoring large area crop	1-Simpler architecture	1-Limited accessibility
(12,23,31) Multi-copter	2- eBee Ag 3- Precision Hawk Lancaster 4- Sentera Phoenix 2Trimble UX5 1- DJI Phantom 4 PRO	High Low -	growth monitoring Crop health status monitoring Fertilizer and pesticide spraying Nutrition, and crop stress considering	Easier maintenance process Long endurance and range Higher flight speed 1-Site-specific	2-Less wind resistance 3-Difficulties in launching 4-Difficulties in landing 1-low speed 2-low payload
	2-AGCO Solo	Medium	local field needs Spot pesticide spraying small field	management 2- Low altitude flight capability 3- Better stability 4- Stable fixed flight capability	weight 3-capability Complex 4-architecture Difficult maintenance process Limited flying time and range Lower flight speed

Source: Singh *et al.*, 2024 [97]

Soil and Field Analysis

Drones are able to obtain high-resolution topographic and soil information through sensors like LiDAR, multispectral, and thermal imaging (Olson, and Anderson, 2021) [75]. They help in precise field mapping, soil texture classification, and fertility determination. Drones aid in precision land management approaches by analyzing changes in soil moisture, organic matter levels, and compaction (Ioja *et al.*, 2022) [44]. This information assists farmers in maximizing field planning, irrigation scheduling, and site-specific application of nutrients, finally leading to better soil health and crop yield (Gorai *et al.*, 2021) [38].

Disaster Management

Under floods, droughts, insect infestations, and other crop catastrophes, drones offer timely and high-definition evaluations, allowing for immediate decision-making for relief actions (El-Tabakh *et al.*, 2024) [31]. With thermal imaging, multispectral sensors, and live video transmission, drones can survey damaged areas, determine damage, and pinpoint key intervention points (Rathinakumar, and Ntantis, 2024) [88]. This allows for timely resource assignment, aids precision rescue efforts, and maximizes the effectiveness of post-disaster recovery plans. In addition, drones assist in tracking soil erosion, waterlogging, and disease epidemics, which are vital inputs for long-term disaster planning in agricultural areas (Kirpalani *et al.*, 2024) [53].

Extension Service Delivery

Drones can be used for on-site demonstrations, recording high-definition videos for training courses, and increasing farmer awareness through visual learning (Ubina, and Cheng, 2022) [104]. They allow extension agents to develop real-time, location-based training materials, make virtual farm visits, and transmit live monitoring sessions to a wider audience (Pavlik, 2020) [80]. In addition to this, drones enable participatory learning as farmers can see ideal practices in crop management, soil conservation, and pest control through a different perspective from the air, thus enhancing technology adoption and knowledge transfer (Ahirwar *et al.*, 2019) [8].

Table 4: The Role of Drones in Agriculture

Application	Function	Benefits
Crop Monitoring and Health Assessment	High-resolution cameras and multispectral sensors capture detailed images of vegetable fields.	Early identification of nutrient deficiencies, water stress, and diseases.
	Helps in detecting variations in plant color, growth patterns, and leaf structure.	Prevents crop loss and reduces chemical treatments.
Early Detection of Problems	Image analysis detects early signs of diseases, pests, and deficiencies.	Enables timely intervention to prevent spread and minimize yield loss.
Assessing Plant Vigor	NDVI (Normalized Difference Vegetation Index) measures plant health by comparing near-infrared and red light absorption.	Helps in evaluating plant growth, vigor, and stress conditions.
Precision Agriculture and Variable Rate Application	Site-specific crop management using drone-collected data.	Reduces input costs, minimizes environmental impact, and enhances efficiency.
	Enables targeted application of water, fertilizers, and pesticides.	
Variable Rate Application (VRA)	Prescription maps created for precise fertilizer and pesticide application.	Inputs are applied only where needed, improving resource efficiency.
Optimizing Irrigation	Drones identify water-stressed areas and integrate data with smart irrigation systems.	Ensures optimal water distribution, reducing waste and improving crop health.
Field Mapping and Plant Counting	Advanced imaging software creates detailed topographical and 3D field maps.	Helps in planning planting patterns, irrigation, and drainage systems.
Plant Counting and Density Estimation	Drones automatically count plants and estimate crop density.	Useful for assessing crop establishment and predicting yield.

Disease and Pest Management	Drones capture real-time crop health data for early pest and disease detection.	Enables targeted pest control and reduces pesticide use.
Disease Identification	Multispectral and thermal sensors detect physiological changes caused by diseases before visible symptoms appear.	Allows for early treatment, preventing disease spread.
Pest Monitoring	Identifies pest-prone areas for targeted interventions.	Minimizes pesticide use, reducing costs and environmental impact.
Aerial Spraying and Seeding	Drones equipped with spraying systems apply pesticides, herbicides, and fertilizers.	Enables precise application, reducing chemical exposure and usage.
Aerial Spraying	Drones spray crops from the air, covering hard-to-reach areas efficiently.	Reduces chemical runoff and labor costs.
Precision Seeding	Drones distribute seeds evenly, especially in difficult terrains.	Ensures uniform crop establishment and reduces seed wastage.

Satellite Imaging in Agricultural Extension

Satellite imagery presents a holistic and extensive picture of agricultural landscapes and delivers useful information for extension services (Atzberger, 2013) [14]. Through the use of high-resolution remote sensing technologies, satellites allow for real-time and periodic monitoring of multiple agricultural parameters, allowing for data-based decision-making (Omia *et al.*, 2023) [76]. These technologies assist in evaluating vegetation health, identifying land-use changes, optimizing resource distribution, and forecasting climate-related issues (Kumar *et al.*, 2022) [55]. The use of Geographic Information Systems (GIS) in conjunction with satellite data further improves the capacity to analyze and visualize trends in agriculture over time, assisting policymakers, researchers, and extension professionals in formulating focused agricultural strategies (Raihan, 2024) [87]. Its uses are:

Arge-Scale Crop Monitoring

Satellites deliver real-time and periodic information on crop (Source Makam *et al.*, 2024) [60]

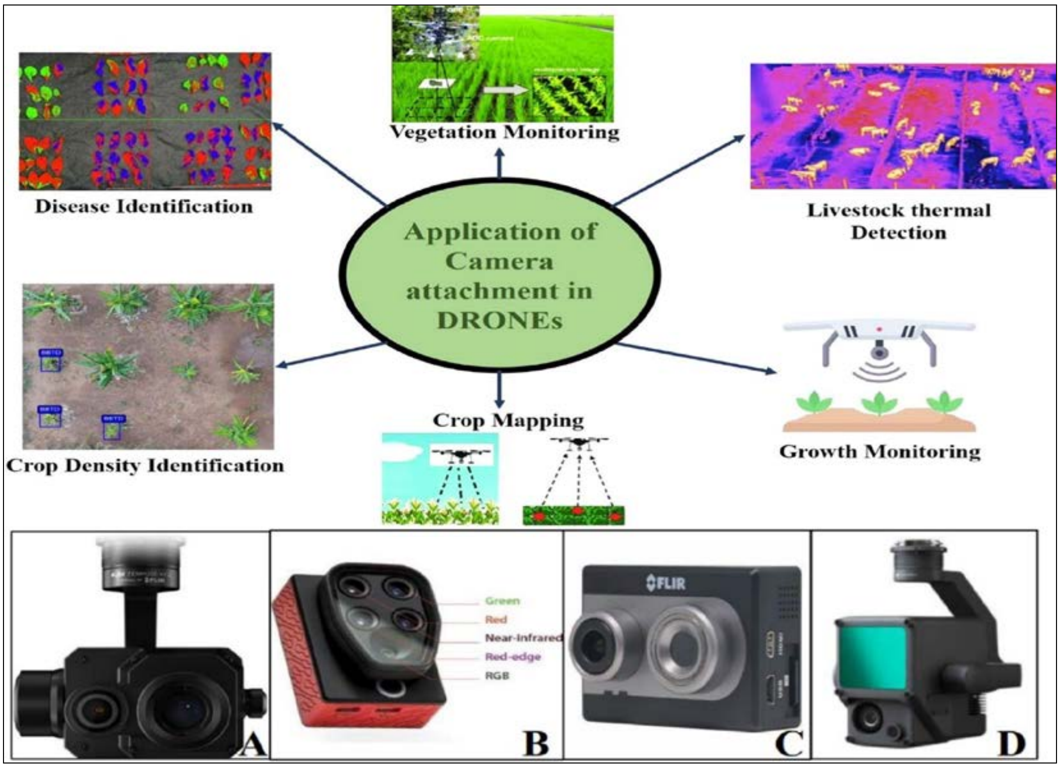
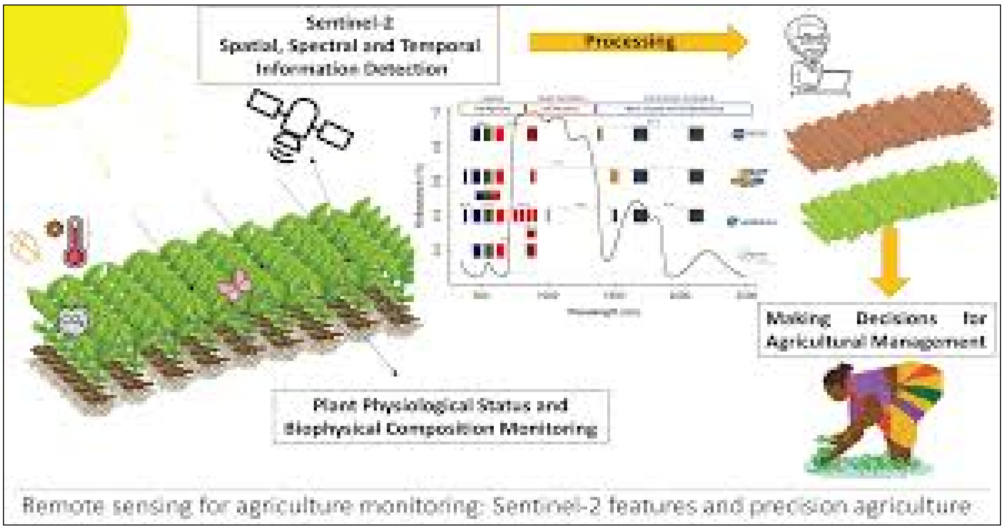


Fig 4: Working different type of cameras and their work. a Visual camera, b multispectral camera, c thermal camera and d LiDAR cam- eras

Using sophisticated remote sensing methods, including multispectral and hyperspectral imaging, satellites can evaluate crop health, identify stress factors, and measure biomass accumulation (Gerhards *et al.*, 2019) [35]. These data allow for early detection of problems like nutrient deficiencies, water stress, and pest infestations, enabling extension officers to advise appropriate interventions (Dutta *et al.*, 2020) [26]. Moreover, long-term satellite data is used to trace trends in agriculture productivity, yield potential forecasting, and policy determination for sustainable farming (Rembold *et al.*, 2013) [90].



Source: Segarra *et al.*, 2020

Fig 5: Satellite Imaging in Agricultural Extension

Segarra, J., Buchaillot, M. L., Araus, J. L., & Kefauver, S. C. (2020). Remote sensing for precision agriculture: Sentinel-2 improved features and applications. *Agronomy*, *10*(5), 641.

Drought and Water Management

Satellite remote sensing assists in monitoring soil wetness levels, rainfall patterns, and drought susceptibility (AghaKouchak *et al.*, 2015) [7]. With high-end spectral imagery and microwave sensing, satellite technology offers accurate readings of evapotranspiration levels (Brown, and Smith, 2020) [22], groundwater over-extraction, and surface water availability (Jahan, 2022) [48]. Such data sets facilitate advance drought mitigation activities, enabling water conservation measures to be implemented as well as improved irrigation scheduling, by policymakers as well as by extension agents (Rudnick *et al.*, 2020) [92]. Satellite imagery aids early warning of impending water deficit, enabling the farmer to suitably modify their cropping pattern by adjusting to expectant water dearth, so improving climate variability resilience (Stankovic *et al.*, 2022) [98].

Climate and Weather Forecasting

Emerging satellite technologies predict weather patterns from atmospheric data observation, cloud status, temperature patterns, and rain patterns (Thies, and Bendix, 2011) [101]. These technologies help farmers to make wise decisions regarding sowing, irrigation, and harvesting as they receive precise short-term and long-term weather forecasts (Easton *et al.*, 2017) [27]. Moreover, satellite-based weather forecasting models help in the early warning of extreme weather conditions like storms, droughts, and frost so that the farmers can prevent any damage to their crops with preventive measures (Tarnavsky, and Bonifacio, 2020) [99]. By combining meteorological information with agricultural extension services, satellite imagery improves climate resilience and adaptive farming practices (Antwi-Agyei, and Stringer, 2021) [13].

Land Use and Soil Mapping: Satellite imagery helps in soil classification, land suitability evaluation, and long-term agricultural planning by offering precise information on soil texture, organic matter content, and nutrient distribution (AbdelRahman *et al.*, 2021) [3]. Satellite images help identify erosion-susceptible areas, moisture retention capacity, and salinity levels, which are important for making informed land management decisions (Balabathina *et al.*, 2020) [16]. Moreover, remote sensing technologies provide continuous monitoring of land-use alterations, assisting policymakers and farmers in adopting sustainable agricultural practices, optimizing crop rotation, and improving conservation efforts for sustainable long-term agricultural productivity (Kumar *et al.*, 2022) [55].

Pest and Disease Surveillance

Satellite data can monitor the movement of pests and diseases across vast expanses by identifying vegetation stress patterns, temperature anomalies, and spectral signatures (Liang, 2015) [57]. Remote sensing technologies enable early detection of infestations by identifying irregularities in crop health before visible symptoms appear (Abdullah *et al.*, 2023) [4]. This proactive approach allows for timely intervention through targeted pesticide application, biological control measures, and precision spraying techniques (Meshram *et al.*, 2022) [63]. Additionally, satellite imaging helps in monitoring resistance patterns, forecasting potential outbreaks, and assessing the effectiveness of pest control strategies, ultimately reducing economic losses and minimizing environmental impact (Abd El-Ghany *et al.*, 2020).

Table 5: Different AI tool used for disease identification in Agriculture

AI Tool/App	Functionality	Key Features
Plantix - Your Crop Doctor	Enables farmers to detect pests and diseases in crops within seconds.	Supports Android; covers major crops; detects over more types of plant damage.
Plant Disease Identifier	Identifies plant diseases based on changes in color, shape, and texture of leaves.	Recognizes disease symptoms like leaf withering, yellowing, spots, blotches, and lesions.
Leaf Doctor	Uses AI and a vast database to diagnose plant diseases and provide care recommendations.	Identifies diseases through leaves, roots, and overall plant yield health.
Agrio	Offers a user-friendly plant recognition and monitoring system.	Features a plant database, map-based search, and geolocation-based recognition.
Google Lens	Provides image search, translation, barcode scanning, and plant identification.	Identifies plants, animals, landmarks, artworks, and even skin conditions; aids in shopping and homework.

Benefits of Applying Drones and Satellite Imagery

Drones and satellite imagery have transformed agricultural extension by making it possible for farmers and extension specialists to benefit from sophisticated equipment for precision observation, data-informed decision-making, and enhanced resource use (Mihret *et al.*, 2025) [64]. These technologies come with a series of benefits that include:

Better Decision-Making

High-resolution, real-time data allows farmers to make knowledgeable decisions about crop health, pest control, irrigation, and the application of inputs (Evans *et al.*, 2017) [33].

Cost and Time Savings

Drones and satellites vastly minimize the necessity of regular on-ground field surveys, thus reducing labor expenses and increased efficiency in farming monitoring (Andújar *et al.*, 2019) [12].

Improved Precision Farming: Through the targeted application of fertilizers, pesticides, and water, these technologies reduce wastage of inputs, minimize environmental pollution, and increase yields (Wu, and Ma, 2015) [110].

Sustainability: Remote sensing optimizes the use of resources, promotes soil conservation, and minimizes excessive chemical use, resulting in ecologically sustainable agriculture (Rai *et al.*, 2023).

Early Pest and Disease Detection

Drones' and satellites' multispectral and hyperspectral imagery can detect crop stress, nutrient deficiency, and early signs of pest infestations, enabling interventions in advance (Anderson, 2024) [11].

Scalability and Affordability

Satellite imagery offers extensive coverage of large agricultural tracts, while drones offer microscopic details at a low level, hence applicable for large-scale commercial agriculture as well as smallholder farming (Sikakwe, 2023) [95].

Climate and Disaster Resilience

These technologies improve readiness against natural disasters by monitoring droughts, floods, and abnormal weather patterns, enabling farmers to adopt climate-resilient farming practices (Prasad *et al.*, 2014) [84].

Enhancement of Extension Services

Drones and remote sensing images aid extension officers in digital training, virtual farm tours, and instant data provision to farmers, enhancing outreach and knowledge transfer (Phanith *et al.*, 2023) [83]

Table 6: Potentials and Problems of Using Drones in Agriculture

Aspect	Potential Benefits	Challenges & Problems
Soil Analysis for Field Planning	Creates 3D soil maps	High initial cost of drone technology
	Measures moisture, erosion, and soil characteristics	Requires expertise in data analysis
	Optimizes planting schedules	
Seed Pod Planting	Reduces labor costs	Not widely adopted yet
	Enables precise seed and nutrient placement	Requires specialized drone attachments
Crop Monitoring	Automates crop health tracking	Unpredictable weather may affect drone performance
	Uses multispectral sensors for early issue detection	Large datasets require advanced processing capabilities
	Improves decision-making for irrigation and fertilization	
Crop Spraying	Reduces chemical exposure to workers	Limited payload capacity
	More efficient and precise than traditional methods	Requires accurate calibration to prevent over/under-spraying
	Works on various topographies using height-adjustment sensors	
Irrigation Management	Uses thermal/multispectral sensors to detect dry areas	Can't replace all traditional irrigation methods
	Ensures precise water distribution	Dependent on sensor accuracy and data interpretation
Crop Health Assessment	Detects plant stress through infrared imaging	Requires specialized sensors
	Helps in early intervention	Affected by weather conditions (cloud cover, wind)
Crop Surveillance &	Aids in estimating crop conditions	Implementation cost for insurance companies

Insurance	Helps verify insurance claims using infrared cameras	Data processing requires trained personnel
Weed, Pest, and Disease Control	Identifies affected field regions	Limited effectiveness in dense vegetation
	Enables targeted pesticide application	Not all pests/diseases are detectable via drones
	Reduces overall pesticide usage	
Tree/Crop Biomass Estimation	Uses LiDAR sensors to measure crop/tree biomass	Requires high-tech equipment
	Supports yield estimation and forestry management	Expensive for small-scale farmers
Bird Control	Drones can scare away birds to protect crops	Needs regular drone flights for effectiveness
		Birds may adapt over time

Advantages of Utilizing Drones in Agriculture

Precision Farming: Drones are fitted with sophisticated sensors and GPS, allowing for accurate application of fertilizers, pesticides, and water (Yadav, and Sidana, 2023) [111]. Targeting specific spots instead of applying inputs across the board, drones assist in: Minimizing wastage of expensive agricultural inputs. Avoiding over-application of chemicals, minimizing soil and water pollution. Maximizing plant health by applying nutrients and pesticides only where necessary.

Effective Crop Monitoring: Aerial photography and multispectral sensors enable farmers to track crops better by: Identifying plant stress, diseases, and infestations early on before they become critical (Barbedo, 2019) [18]. Examining patterns of plant growth and nutrient deficiency through real-time data. Mapping field differences and pinpointing areas that need extra care, enhancing farm management in general

Lower Labor Costs: Conventional farming makes extensive use of manual labor for crop scouting, spraying, and field checks (Yang *et al.*, 2016) [112]. Drones eliminate these tasks, resulting in: Reduced reliance on farm labor, lower salary costs (Bazargani, and Deemyad, 2024) [19]. Lower human exposure to toxic chemicals with pesticide application. Capability to blanket large fields in a matter of minutes, increasing farm productivity and reducing costs (Hunt, 2008) [43].

Time-Saving: Drones significantly cut down time for a variety of activities in agriculture, including: Crop Scouting - Aerial photography covers huge areas in minutes, taking over time-consuming manual scouting (Edenhart-Pepe, 2019) [28]. Spraying Pesticides & Fertilizers - Spraying with drones can do the job in a matter of minutes, as opposed to conventional spraying techniques (GULAK *et al.*, 2019) [40]. Planting Cover Crops & Seeds - Certain drones are designed to seed-disperse, speeding up the process of planting large fields.

Enhanced Yield & Productivity: Through the use of real-time information and precision farming methods, drones help towards: Increased crop yields as a result of pre-emptive detection and maintenance of plant disease problems (Mohite, 2007) [67]. Improved soil moisture management via aerial irrigation surveys, avoiding under- or over-watering. Improved decision-making from precise farm data, resulting in improved resource allocation and productivity (Wienhold *et al.*, 2024) [109].

Environmental Benefits: Sustainable agriculture is key to long-term agricultural prosperity. Drones assist by: Minimizing excessive chemical applications, reducing the environmental footprint of fertilizers and pesticides (Vellingiri *et al.*, 2025) [105]. Reducing fuel usage by substituting conventional tractor-based applications, lowering carbon emissions. Preventing water wastage by identifying areas that require irrigation, thus conserving water resources (Ward *et al.*, 2008) [108].

Improved Disaster Management & Risk Reduction

Drones play a crucial role in assessing damages from natural disasters like floods, droughts, or pest invasions (Auma, 2023) [15]. Farmers can: Quickly evaluate the extent of crop damage and plan recovery measures. Use aerial mapping to file insurance claims with precise evidence. Implement targeted pest and disease control strategies to prevent widespread losses.

Improved Resource Management & Data Gathering

Agricultural drones gather copious amounts of data that may be used to plan for long-term farm strategies (Pathak *et al.*, 2020) [78]. These are: Monitoring the health of soil to enable farmers to maximize preparation of land. Monitoring crop performance season after season, recognizing patterns and enhancing strategies of farming (Bégué *et al.*, 2018) [20]. Cutting total input costs by making data-based choices for selecting seeds, application of fertilizers, and watering (Paul, *et al.*, 2022) [79].

Table 7: Benefits Using of Drones in Agriculture

Category	Description	Impact
Security	Trained pilots operate drones remotely, keeping farmers and laborers away from hazardous chemicals.	Reduces health risks and improves worker safety.
High Field Capacity & Efficiency	Drones can spray 50-100 acres/day, which is 30 times faster than traditional knapsack sprayers.	Saves time and increases productivity.
Wastage Reduction	30% reduction in pesticide use due to better atomization and precise spraying.	Lowers chemical costs and reduces environmental impact.
Water Saving	90% water savings compared to traditional spraying methods using ultra-low volume spraying technology.	Promotes sustainable water usage.
Lower Cost	Drone spraying is 97% cheaper than traditional spraying methods.	Reduces operational expenses for farmers.
Ease of Use & Maintenance	Drones are built for durability, require minimal maintenance, and have easily replaceable parts.	Ensures long-term cost savings and ease of adoption.

Challenges and Limitations

In spite of all their benefits, the extensive use of drones and satellite imagery in agricultural extension is limited by a number of issues and challenges. These are financial, technical, regulatory, and infrastructural limitations that affect accessibility and proper use. A solution to these issues is important for achieving the full potential of these technologies in contemporary agricultural systems.

High Initial Cost

Purchase and upkeep costs of drones, as well as the fee of using high-resolution satellite information and required software, may act as huge deterrents. All this entails spending on buying specialist sensors, replacing hardware, and getting licenses for processing software. Further, the availability of resources such as capital by small farmers or resource-scarce extension agencies can deter adoption of such technology without sponsorship or subsidies, or collective funding drives.

Technical Competence

Proper use of these technologies requires specialized training for extension agents and farmers, including data interpretation, drone flying, satellite image interpretation, and linking with current farming practices. Capacity-building programs, hands-on training, and digital literacy programs are necessary to make the adoption and use in agricultural extension successful.

Regulatory Constraints: Drone flight is subject to strict airspace regulation, and the procedure for obtaining required approvals is often cumbersome and time-consuming.

Data Processing and Interpretation

The large amounts of data obtained by satellites and drones require advanced analytical software and specialized skills to interpret and make effective decisions.

Connectivity and Infrastructure

Poor internet connectivity and underdeveloped technology infrastructure in rural areas complicate data accessibility, uninterrupted communication, and timely agricultural decision-making.

Future Prospects and Recommendations

The future of agricultural extension will be increasingly shaped by intelligent technologies like drones and satellite imaging. To enable their wider use and optimize their impact, the following recommendations are made:

Policy Support

Governments need to develop holistic policies and offer financial incentives to encourage the widespread use of these technologies, making them accessible to all farmers.

Capacity Building

Extensive training programs must be developed to provide extension officers and farmers with sophisticated technical skills, ensuring proper use of drone and satellite technologies in farming practices.

Public-Private Partnerships

Public-private partnerships among governments, research organizations, and private technology companies promote innovation, increase accessibility, and speed up the adoption of sophisticated agricultural technologies.

Integration with AI and IoT

Merging satellite and drone data with Artificial Intelligence (AI) and the Internet of Things (IoT) can enhance predictive analytics and precision agriculture.

Conclusion

Drone and satellite photography are revolutionizing agricultural extension by offering accurate, current, and big-picture information about farm conditions. Though there are obstacles, ongoing innovation and policy support can ensure their broad deployment. These technologies' adoption will augment agricultural productivity, sustainability, and climate change resilience.

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