International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 • Website: www.ijfmr.com • Email: editor@ijfmr.com

Agricultural Drones in Africa: Exploring Adoption, Applications, and Barriers

Peter L. Kwao[1], Gabriel M. Owusu[2], Joseph Okyere [3], Jessi K. Agbenya[4], Isaac L.N. Laryea[5], Stephen K. Armah[6]

[1,2,3,4,5]Faculty, Department of Engineering, Ashesi University
[6]Professor, Department of Engineering, Ashesi University

Abstract
The adoption of drone technology in agriculture is transforming farming practices across Africa by enhancing resource efficiency, reducing operational costs, and promoting environmental sustainability. This paper explores the various applications of drones in African agriculture, including precision farming, crop monitoring, pest control, and livestock management. Drones enable farmers to optimize the use of water, fertilizers, and pesticides, leading to increased yields and improved profitability. Despite the potential benefits, the deployment of drones faces challenges such as high costs, lack of technical expertise, and regulatory barriers. This study highlights the importance of addressing these obstacles to facilitate the widespread adoption of drone technology among both small and large-scale farmers. By leveraging drones, African agriculture can improve food security, scale up operations, and contribute to the continent's sustainable development goals. The findings of the review include case studies from Ghana, Kenya, and Nigeria which show that government intervention and private-sector partnerships are crucial for overcoming these barriers. This paper highlights the need for targeted training programs and policy reforms to enhance accessibility for smallholder farmers. By leveraging drones, African agriculture can improve food security, scale up operations, and contribute to the continent's sustainable development goals.

Keywords: Agriculture, drones, Africa, precision farming, crop monitoring, sustainable agriculture, food security

1.1. Introduction

Drones, also known as Unmanned Aerial Vehicles (UAVs), have evolved into integral technological devices that aid various human endeavors. Their applications span military uses, photography, transportation, sports and recreation, and notably, agriculture. This literature will focus on the role of drones in agriculture in Africa.

Food growth and production have become significant challenges in Africa, where many essential commodities are imported rather than being produced locally. This reliance on imports underscores the urgent need for African countries to bolster their food self-sufficiency. Key supplies include cereals, oils and fats, oilseeds, dairy products, meat and meat products, sugar, vegetables, spices, coffee, cocoa, and more [1]. The integration of technology represents a proactive approach to enhancing previous and current agricultural operations and ensuring food security and growth [2].

1.2. Application of Agricultural Drones

The scope of drone use in agriculture is vast and largely dependent on user discretion. Common applications of agricultural drones include land surveying and mapping, remote sensing, weed and pest management, irrigation management, and livestock management. According to [3] and [4], drones significantly assist farmers in applying pesticides and herbicides in hard-to-reach or hazardous areas while managing resources efficiently in terms of water and chemical use.

In addition to these applications, [5] notes that drones are also utilized for plantation, plant growth monitoring, geofencing, and preparing for adverse weather conditions, as can be seen in Figure 1 below. These capabilities help save time and labor costs, improve resource management, enhance safety by reducing human exposure to hazardous chemicals, and combat climate change impacts.

Figure 1. Farmer using a drone for monitoring farm

Furthermore, [6] includes the use of drones for monitoring nutrient status and deficiencies, disease control, water stress assessment, crop health evaluation, and weed management. In the context of integrated drone applications for soil management, [7] asserts that drones are used for soil and field analysis, aerial planting, crop spraying, crop monitoring, irrigation, and plant health assessment in Nigeria. While many of these applications are not exclusively derived from the African context—except for [7]—they can be adapted to the continent's farming systems.

1.3. Successes in the use of Agricultural Drones

Drones have proven to be transformative technologies across various sectors globally, particularly in agriculture. By offering innovative solutions to the challenges associated with conventional farming practices, the adoption of drones can lead to increased crop yields, efficient resource utilization (such as water and pesticides), and maximized farm productivity. Given the rapid growth of the world population, which directly raises food demand, alongside the impacts of climate change—resulting in weather extremes, soil degradation, and water scarcity—the integration of drones into agriculture represents a timely intervention [7].

In Uganda, pilot projects have been conducted to evaluate the benefits of adopting drone technology in agriculture [8]. These drones monitored production processes on farms, providing accurate measurements of farm size and assessing crop health to identify diseases and pests. The data collected facilitated crop yield projections, which were vital for operational planning. By pinpointing areas most affected by pests and diseases, farmers were able to avoid blanket pesticide spraying, minimizing waste. The flight and data analysis indicated that returns on soy, beans, and maize seed production could increase by an average of over $500 per acre.

In Kenya, drones have been employed on farms for crop spraying, significantly reducing spraying costs and the time required to cover large areas. This method saved approximately 40 percent of chemicals that would otherwise be wasted through conventional spraying techniques. For instance, one farm experienced a dramatic reduction in spraying time, decreasing from 14 days to just two days [9].

A similar application was observed on a rice farm in Ghana, where drones were utilized to spray fertilizers and pesticides and to survey the farm for pests, diseases, and irrigation issues [10]. Farmers using traditional knapsack sprayers often damaged or uprooted rice roots, negatively impacting crop yield. The introduction of drones mitigated this issue. Interestingly, it was discovered that while performing tasks such as spraying or identifying areas needing water, the noise generated by the drone blades scared away birds from feeding on the grains. A single drone was found to deter birds from a farm as large as three acres [11]. This development saved farmers the effort of manually scaring away birds by ringing bells and shouting.

These examples demonstrate that integrating drone technology into agriculture not only enhances crop yield but also generates savings in operational costs, increases productivity, and reduces the environmental impact of chemicals and fertilizers used on farms.

2.0. Skill Development for African Farmers

As agricultural technology, particularly drones, becomes increasingly pivotal to smart farming practices, it heralds a new era aimed at enhancing efficiency, accuracy, and yield. An overview of available training programs designed to equip farmers with the necessary skills to leverage this technology will outline the steps required to implement effective training regimens. It will also assess the impact of these training programs on agricultural output, demonstrating how the integration of drones into farming practices can escalate productivity while promoting sustainable agriculture.

2.1. Overview of Training Programs Available

The landscape of drone training in Africa is significantly shaped by contributions from governmental, foreign aid, and private sectors, each playing a crucial role in skill development. A notable government initiative is the African Drone and Data Academy, supported by UNICEF and operated in collaboration with Virginia Tech and the Malawi University of Science and Technology. Located in Lilongwe, Malawi, this academy offers comprehensive training in drone technology and data analysis. Its curriculum includes practical modules on drone maintenance, operation, and logistics, alongside advanced training in drone manufacturing and data analytics [12].

In the private sector, programs like Drone Divas (Figure 2) in South Africa are vital, focusing on empow ering women in the drone industry. This training initiative includes a significant internship component, teaching drone operation across various applications while introducing participants to entrepreneurship. The success of Drone Divas is underscored by a high employment rate for participants post-internship, highlighting the program's effectiveness in professional skill development [13].

Figure 2. Drone Divas 2022 training program for women

Both initiatives not only enhance technical skills but also foster entrepreneurship, preparing participants to launch and sustain drone-related businesses in their communities. However, these programs primarily provide general training in drone operations rather than agriculture-specific training. Therefore, it is essential to develop a curriculum tailored to the agricultural sector.

2.2. Steps Through Implementation of Effective Training Programs

Identifying Training Needs

The first step in implementing an effective training program involves identifying specific training needs within the African drone industry. By leveraging the existing curriculum from Eastern Kentucky University (EKU), the project focuses on developing an online, self-taught, remotely assisted training platform. This approach addresses the scarcity of qualified training centers in Africa, enabling individuals to acquire both theoretical knowledge and practical skills necessary for drone pilot certification [14].

Designing and Executing Training Modules

Once training needs are identified, the next phase is designing and executing training modules. These modules are delivered both online and in person through affiliated centers across Africa. The curriculum is standardized to ensure quality and consistency, establishing a benchmark for operator competency in the drone industry. The Africa Goes Digital network plays a crucial role by utilizing approved curricula to provide face-to-face training, facilitating broader adoption of these standards. This network comprises over 30 members in 19 African countries, ensuring wide access and implementation of the training [14].

2.3. Impact of Training Programs on Agricultural Output

Training programs in drone technology have significantly influenced agricultural productivity in Africa. The African Drone and Data Academy has been instrumental in equipping young individuals with the skills necessary to effectively utilize drone technology across various sectors, including agriculture. This training enhances their ability to monitor natural resources and manage agricultural activities, ultimately benefiting their communities [15].

One notable success story is from Tunisia, where eight pilots successfully completed their drone flight training, organized by the Ministry of Agriculture of Tunisia, the African Development Bank, and Busan Techno Park. This training focused on the handling, maintenance, and security aspects of operating drones. These pilots are now well-equipped to contribute to agricultural development projects, particularly in the Sidi Bouzid region, thereby enhancing efficiency and effectiveness in agricultural practices [16].

The long-term benefits of such training programs are profound. These initiatives not only improve immediate agricultural output but also promote sustainable practices by optimizing resource use and reducing environmental impacts. The integration of drone technology through skilled training programs lays a foundation for continuous agricultural growth and productivity enhancement across Africa.

Accordingly, further research and investment in drone technology and education are imperative to fully realize the potential of this innovative approach to farming, setting the stage for a prosperous and sustainable agricultural future in Africa.

3.0. Maintenance Required for Agricultural Drones in the African Context

Given the unique environmental conditions in Africa, specific maintenance requirements for agricultural drones are crucial for ensuring smooth and continuous operation. One significant concern is battery life, which is heavily influenced by temperature. Climate change is leading to rising temperatures, particularly in the Sub-Saharan region. According to the IPCC, average temperatures in this area may reach 50°C by 2100 [17]. A study [18] revealed that while high temperatures minimally affect drone flight performance, they substantially diminish battery lifespan and discharge capacity. Extreme temperatures (60°C and above) can cause irreversible battery damage after just five charge-discharge cycles. To mitigate these issues, it’s essential to avoid flying drones with low battery levels and ensure proper charging protocols are followed [20], [21].

Another critical maintenance task is the cleaning and upkeep of the drone’s camera and spraying systems. Sprayer nozzles can easily become clogged, hindering fluid output. Regular cleaning after each operation is vital to maintain functionality. Additionally, the drone's frame, propellers, and motors should be wiped down to remove debris and weeds, which can impede performance [22].

Given the variability in farm locations and crops, monitoring drone performance through flight logs is important. Key parameters to track include the date, flight distance and duration, battery life, and any issues encountered during operations. This data can help diagnose problems and inform better operational practices [23].

4.0. Integration of Drones with Other Technologies for Advanced Decision-Making

Integrating Artificial Intelligence (AI) and data analytics with drone technology has significantly expanded its applications in agriculture. Drones equipped with thermal cameras can capture high-resolution images and gather critical data on crop health indicators, including soil moisture [24].

Research has demonstrated the effectiveness of combining drone imagery with satellite data. For instance,

a study [25] utilized high-resolution drone imagery and Sentinel-1A SAR data to improve the detection and area estimation of early-stage wheat. By training machine learning classifiers with the Normalized Difference Vegetation Index (NDVI), researchers achieved better classification of various land types.
Another study [26] presented a methodology for precision agriculture in sugarcane fields, using drone and optical satellite data to classify vegetation density effectively. The accuracy of this classification was validated through visual inspection, confirming the classifier's performance.
Additionally, a framework integrating blockchain, AI, and IoT technologies for swarm drones has been proposed to address challenges related to networked aerial vehicles in agriculture [27]. This framework aims to improve operational efficiency and security within UAV networks.
In another innovative application, AI classifiers have been employed in drones for greenhouse pollination, specifically targeting tomatoes [28]. These drones autonomously identify and pollinate flowers, achieving comparable results to traditional insect pollination methods. This integration of AI into drone technology holds the promise of enhancing crop productivity and reducing agricultural waste.

5.0. Environmental Implications of Drone Use in Agriculture

Drones enable precise monitoring, allowing farmers to apply water, fertilizers, and pesticides only where needed, thereby minimizing resource wastage. In pest management, drone technology could reduce pesticide use by up to 30% by targeting specific areas, which decreases chemical runoff into ecosystems and waterways [29]. Sophisticated spraying systems ensure that pesticides are applied accurately, mitigating environmental disruption and health risks associated with chemical exposure [30].
Efficient fertilizer application through drones helps prevent over-application, reducing nitrous oxide emissions—a potent greenhouse gas—and improving nitrogen use efficiency [33]. Similarly, drones enhance irrigation practices by minimizing water waste and preventing soil erosion or nutrient leaching through targeted water application [34].
Drones can also assess soil conditions, helping identify areas affected by erosion or compaction. This data supports informed decisions about soil conservation practices, such as planting cover crops or implementing contour farming, which can mitigate the effects of extreme weather conditions [35].
Beyond crop monitoring, drones are beneficial for livestock management, tracking herd health, and facilitating herding tasks, which reduces the need for human labor while maximizing productivity [36].

6.0. Challenges Faced in the Adoption of Drone Technology in African Agriculture: Regulatory Hurdles and Infrastructure Limitations

As the world moves forward into the era of Industry 4.0, there is a conscious effort to engage in the upskilling, reskilling, and skilling of the workforce to meet the demands of both the African continent and the global economy. This shift is particularly relevant in the adoption of automation, artificial intelligence (AI), machine learning (ML), the Internet of Things (IoT), and deep learning (DL) in various sectors, including agriculture [37].
Despite the immense benefits of drones for agricultural purposes, there are numerous barriers that hinder their widespread use in Africa. According to [38], the challenges associated with the adoption of agricultural drones in Africa can be grouped into regulatory, social, technical knowledge, and economic categories. This article will explore the first three of these.

6.1. Technical Knowledge and Decision-Making Challenges

For increased agricultural productivity, there must be an intentional improvement in the literacy levels of farmers regarding the purchase, usage, and maintenance of drones [39]. The majority of African farmers live in rural areas, have limited formal education, and lack exposure to modern technology. Many of them are unaware of current global farming trends due to this lack of access [40].

Drone technologies have become increasingly sophisticated, offering enhanced potential for agricultural use. For instance, drones can now be programmed with AI and ML capabilities, greatly expanding their utility. However, even if farmers are not required to learn programming languages, they still need the ability to manipulate and interpret the data generated by these advanced systems. This requirement may reduce interest in drone usage, despite the technology's ability to improve agricultural productivity and yield [41]. Figure 3 shows a group of farmers who are being exposed to the use of drones in agricultural practices.

Figure 3. African farmers experiencing a drone being used in fertilizer application.

Furthermore, while drones have the potential to revolutionize farming practices, challenges remain. For example, Carvalho et al. raised concerns about the unintended dispersal of liquid droplets by drones, which may result in chemicals being deposited in unintended areas, potentially harming the environment. Such risks must be considered when selecting drones for agricultural purposes, especially regarding scale and intended use [42].

6.2. Cost Challenges

Most farmers in Africa fall within the small to medium-scale category and rely heavily on benevolent donors and government support to sustain their operations [43]. This means that the average farmer cannot afford the high cost of agricultural drones, which typically start at $5,000 or more [44]. In addition to the initial purchase, farmers must also factor in reinvestment in labor, other farming machinery, maintenance services, and personal or family obligations. While some farmers may attempt to save for drone purchases, the ongoing maintenance costs—particularly for drone parts—are prohibitively expensive.

It could be argued that renting drones from service agencies might mitigate the high upfront and maintenance costs [45]. However, depending on crop type and farm size, drone rental can be either cost-effective or inefficient. For instance, large farms may benefit more from drones if rental fees are not time-based, whereas small farms might struggle with fixed daily charges if their farming activities do not require full-day drone usage [47].
Small and medium-scale farmers are particularly disadvantaged when it comes to drone ownership, as they may not have the resources to hire drone pilots [48] or obtain the necessary licenses to operate drones [49]. According to [50], those who can afford drones often purchase models without advanced features like object detection and safe maneuverability, further limiting their utility. Additionally, most Civil Aviation Authorities (CAAs) in African countries do not provide readily accessible data on no-fly zones, which poses a significant challenge for farmers operating near restricted areas.

6.3. Legalization and Regulation Challenges

[50] reported that in some countries, drones are considered as large aircraft, which subjects them to the same regulations as commercial airplanes. This classification discourages farmers from purchasing drones due to the complex regulatory requirements. In other countries, where regulations are either absent or underdeveloped, authorities may seize drones from enthusiasts, or impose stringent, cumbersome customs processes [51].
Ayamga et al. also revealed that in African countries with drone regulations, the relevant information is often not accessible to the public. Furthermore, the lack of awareness among end-users about data protection and privacy rules contributes to the regulatory challenges. Developing countries, in particular, face the difficult task of determining how much access to data should be allowed, what types of data can be collected, and to what extent private property and personal information can be captured by drones. Misuse of drones could result in privacy violations, prompting some governments to consider banning their civilian use altogether in order to prevent inappropriate circumstances.

7.0. Cost-Effectiveness of Using Drones

Despite the aforementioned challenges, drone technology in agriculture is more cost-effective compared to traditional farming methods [52]. A single drone can cover up to 80 hectares in a day, identify and target specific weed types, and significantly reduce chemical and water usage by 25% to 35%. These efficiencies result in reduced time, labor, and material costs, potentially cutting costs by 15% while increasing crop yields by up to 20% [53].
According to [45], the cost of operating a drone was 2.26 times lower than that of a conventional boom sprayer. A study by [54] suggested that using a swarm of drones for large-scale farming is even more economical. For farmers cultivating around 100 hectares, [55] showed that using drones is financially more beneficial than purchasing and operating larger aircraft for farming purposes.

8.0. Impact of Drone Technology on Improving Crop Yields and Farm Productivity in African Agriculture

Drone adoption has been boosted by advanced sensors like LiDAR, ultrasonic, and thermal sensors, which enhance their capability for data collection and monitoring. The introduction of drones in African agriculture has yielded significant results, improving both farm productivity and appreciation for the technology.

In a study by [56], the use of drones, particularly the Parrot Bluegrass model, facilitated the efficient management of pineapple crops, improving growth and yield. The drones assisted in mapping farms to optimize planting space and assess crop health. Moreover, drones have proven valuable in applying the right type and quantity of fertilizers and pesticides without harming the environment, resulting in better pest and disease control, and higher productivity.
The precision offered by drone technology has led to substantial capital gains through optimized farming practices [57]. With the advancement of algorithms that enable drones to identify entities using machine learning, this technology is also applicable to livestock management and monitoring [58], as can be seen in Figure 4.

Figure 4. Drones being used in tracking and monitoring of a herd of cattle in Africa

Additionally, drones eliminate the physical burden of farmers having to walk through fields for inspection. However, a potential downside is the variability in data quality depending on the type of drone used and the availability of spatial data for the farming area [59]. Despite these challenges, drone technology has significantly increased efficiency, reduced costs, and promoted sustainability through improved irrigation and crop management practices [60].

9.0. Conclusion

In conclusion, the use of drones in agriculture has proven to reduce operational costs by optimizing resources such as labor, water, pesticides, and fertilizers, while maximizing efficiency. The negative environmental impacts of traditional farming practices are also mitigated, contributing to sustainability and environmental safety. Both large- and small-scale farmers should consider adopting drone technology to enhance and scale their operations in both plant and animal farming. Given the promising profitability and operational benefits, drones represent a bright future for the agricultural sector.

References

1. M. A. Rakotoarisoa, M. Iafrate, and M. Paschali, *Why has Africa become a net food importer? explaining Africa agricultural and food trade deficits*. Rome: Trade and Markets Division, Food and

Agriculture Organization of the United Nations, 2011.
2. B. D. Kwakye, R. Brenya, D. A. Cudjoe, A. K. Sampene, and F. O. Agyeman, “Agriculture Technology as a Tool to Influence Youth Farming in Ghana,” *Open J. Appl. Sci.*.
3. “Drone_Booklet_Low.pdf.”
4. “Kumar et al. - Drone Technology Transforming Agriculture.pdf.”
5. M. Chakraborty, “Drone Technology in Agriculture,” vol. 05, no. 02, 2023.
6. G. Dutta and P. Goswami, “Application of drone in agriculture: A review,” *Int. J. Chem. Stud.*, vol. 8, no. 5, pp. 181–187, Oct. 2020, doi: 10.22271/chemi.2020.v8.i5d.10529.
7. A. Augustine Azubuike, E. Idongesit Asuquo, and A. Victor Chike, “Integrated application of drones for soil management and precision agriculture in Nigeria,” *Niger. J. Soil Sci.*, pp. 21–30, Jul. 2020, doi: 10.36265/colsssn.2020.4404.
8. N. Dmitry, N. Anton, and K. Elena, “Drones in agriculture: Analysis of different countries,” *BIO Web Conf.*, 2023.
9. “Eyes in the Sky: How Drones and Satellites can transform African Agriculture?* | E-Agriculture.” Accessed: Aug. 21, 2024. [Online]. Available: https://www.fao.org/e-agriculture/news/eyes-sky-how-drones-and-satellites-can-transform-african-agriculture
10. “Drones help farmers to cut spraying costs - Business Daily.” Accessed: Aug. 21, 2024. [Online]. Available: https://www.businessdailyafrica.com/bd/corporate/technology/drones-help-farmers-to-cut-spraying-costs-3380338
11. S. Kimani, “Drones Offer Ghana’s Farmers Hope of Better Yields - and Income,” Voice of America. Accessed: Aug. 21, 2024. [Online]. Available: https://www.voanews.com/a/africa_drones-offer-ghanas-farmers-hope-better-yields-and-income/6175440.html
12. “Ghana’s farmers are using drones to boost crop yields – here’s how - AGRA.” Accessed: Aug. 21, 2024. [Online]. Available: https://agra.org/news/ghanas-farmers-are-using-drones-to-boost-crop-yields-heres-how/
13. “The African Drone and Data Academy | UNICEF Office of Innovation.” Accessed: Aug. 22, 2024. [Online]. Available: https://www.unicef.org/innovation/AfricanDroneAcademy
14. “giz-2023-en-cultural-and-creative-industries-drone-divas-good-practice.pdf.” Accessed: Aug. 22, 2024. [Online]. Available: https://www.giz.de/en/downloads/giz-2023-en-cultural-and-creative-industries-drone-divas-good-practice.pdf
15. “APIRG.22 - RASG.5 -WP3.6 - Synopsis_Training Africa’s drone pilots_project.pdf.” Accessed: Aug. 22, 2024. [Online]. Available: https://www.icao.int/WACAF/Documents/RASG%20AFI/RASG-AFI-5/JOINT%20Meeting/APIRG.22%20-%20RASG.5%20-WP3.6%20-%20Synopsis_Training%20Africa%27s%20drone%20pilots_project.pdf
16. “First drone and data academy opens in Africa to improve service delivery for children – UNICEF.” Accessed: Aug. 22, 2024. [Online]. Available: https://www.unicef.org/turkiye/en/press-releases/first-drone-and-data-academy-opens-africa-improve-service-delivery-children-unicef
17. A. D. Bank, “Tunisia Trains first set of Drone pilots for agricultural productivity,” African Development Bank Group. Accessed: Aug. 22, 2024. [Online]. Available: https://www.afdb.org/en/news-and-events/tunisia-trains-first-set-of-drone-pilots-for-agricultural-productivity-18860
18. “Climate-Smart-Agriculture-Investment-Plan-for-Ghana.pdf.” Accessed: Aug. 21, 2024. [Online]. Available: https://documents1.worldbank.org/curated/en/300161592374973849/pdf/Climate-Smart-Agriculture-Investment-Plan-for-Ghana.pdf

19. N. Li, X. Liu, B. Yu, L. Li, J. Xu, and Q. Tan, "Study on the environmental adaptability of lithium-ion battery powered UAV under extreme temperature conditions," *Energy*, vol. 219, p. 119481, Mar. 2021, doi: 10.1016/j.energy.2020.119481.
20. "Lithium Battery Temperature Ranges: A Complete Overview." Accessed: Aug. 28, 2024. [Online]. Available: https://www.ufinebattery.com/blog/lithium-battery-temperature-range-everything-you-need-to-know/
21. M.-T. F. Rodrigues *et al.*, "A materials perspective on Li-ion batteries at extreme temperatures," *Nat. Energy*, vol. 2, no. 8, p. 17108, Jul. 2017, doi: 10.1038/nenergy.2017.108.
22. "Expert-Approved Drone Maintenance And Storage Tips For 2024." Accessed: Aug. 28, 2024. [Online]. Available: https://flyver.co/drone-maintenance-and-storage/
23. "Malawi-UAS-Report_MOH-Draft_-FINAL_14_07_16.pdf." Accessed: Aug. 28, 2024. [Online]. Available: https://www.villagereach.org/wp-content/uploads/2017/06/Malawi-UAS-Report_MOH-Draft_-FINAL_14_07_16.pdf
24. "Zhao et al. - Impacts of Soil Moisture on Crop Health A Remote .pdf."
25. S. Petrakieva, O. Garasym, and I. Taralova, "http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7038771," Dec. 2014.
26. S. Sun *et al.*, "Investigation of Prediction Accuracy, Sensitivity, and Parameter Stability of Large-Scale Propagation Path Loss Models for 5G Wireless Communications," *IEEE Trans. Veh. Technol.*, vol. 65, no. 5, pp. 2843–2860, May 2016, doi: 10.1109/TVT.2016.2543139.
27. "IEEE Xplore Full Text PDF." Accessed: Aug. 22, 2024. [Online]. Available: https://ieeexplore.ieee.org/stampPDF/getPDF.jsp?tp=&arnumber=10087152&ref=
28. "IEEE Xplore Full Text PDF." Accessed: Aug. 22, 2024. [Online]. Available: https://ieeexplore.ieee.org/ielx7/6287639/10005208/10239389.pdf?tp=&arnumber=10239389&isnumber=10005208&ref=
29. C. Zhang and J. M. Kovacs, "The application of small unmanned aerial systems for precision agriculture: a review," *Precis. Agric.*, vol. 13, no. 6, pp. 693–712, Dec. 2012, doi: 10.1007/s11119-012-9274-5.
30. "Drones and Pest Control: A Modern Approach." Accessed: Aug. 21, 2024. [Online]. Available: https://www.airstandards.org/drones-in-pest-control/
31. "Subramanian - 2021 - Drones in Insect Pest Management.pdf."
32. "Hafeez - 2023 - Implementation of drone technology for farm monito.pdf."
33. "Lal - 2004 - Downloaded from www.sciencemag.org on February 6, .pdf."
34. C. Guarnera, "Revolutionizing Irrigation with Agricultural Drones," Blue Falcon Aerial. Accessed: Aug. 21, 2024. [Online]. Available: https://www.bluefalconaerial.com/agricultural-drones-enhancing-irrigation-efficiency/
35. J. Sullivan, "Drone Soil Analysis: Multispectral Remote Sensing for Soil Mapping - Mapware." Accessed: Aug. 21, 2024. [Online]. Available: https://mapware.com/blog/drone-soil-analysis-multispectral-remote-sensing-for-soil-mapping/, https://mapware.com/blog/drone-soil-analysis-multispectral-remote-sensing-for-soil-mapping/
36. bncfinance, "The Benefits of Using Drones in Livestock Management," BNC Finance. Accessed: Aug. 21, 2024. [Online]. Available: https://bncfin.com/drones-in-livestock-management/
37. "Li - 2022 - Reskilling and Upskilling the Future-ready Workfor.pdf."
38. "Full Text PDF." Accessed: Aug. 22, 2024. [Online]. Available: https://sajie.journals.ac.za/pub/arti

cle/download/2817/1224
39. "ReviewPaperUAVAgriculture.pdf."
40. "Full Text PDF." Accessed: Aug. 22, 2024. [Online]. Available: https://www.mdpi.com/2078-2489/10/11/349/pdf?version=1573470851
41. "Full Text PDF." Accessed: Aug. 22, 2024. [Online]. Available: https://ijees.org/index.php/ijees/article/download/89/49
42. "Full Text PDF." Accessed: Aug. 22, 2024. [Online]. Available: https://www.researchgate.net/profile/Fernando-Carvalho-25/publication/340973562_Challenges_of_Aircraft_and_Drone_Spray_Applications/links/5ee126b6a6fdcc2cd944dc8f/Challenges-of-Aircraft-and-Drone-Spray-Applications.pdf
43. "Francesca - OECD FOOD, AGRICULTURE AND FISHERIES PAPER N°176.pdf." Accessed: Aug. 22, 2024. [Online]. Available: https://www.oecd-ilibrary.org/docserver/285cc27d-en.pdf?expires=1724329818&id=id&accname=guest&checksum=03C751A977620FD6E54D7561D8E3B316
44. "Best Agriculture Drones - Droneblog." Accessed: Aug. 28, 2024. [Online]. Available: https://www.droneblog.com/best-agriculture-drones/
45. S. Umeda, N. Yoshikawa, and Y. Seo, "Cost and Workload Assessment of Agricultural Drone Sprayer: A Case Study of Rice Production in Japan," *Sustainability*, vol. 14, no. 17, Art. no. 17, Jan. 2022, doi: 10.3390/su141710850.
46. "Full Text PDF." Accessed: Aug. 22, 2024. [Online]. Available: https://www.tandfonline.com/doi/pdf/10.1080/14620316.2021.1906761
47. "Dhillon and Moncur - 2023 - Small-Scale Farming A Review of Challenges and Po.pdf."
48. "Agronomy | Free Full-Text | Remotely Piloted Aircraft (RPA) in Agriculture: A Pursuit of Sustainability." Accessed: Aug. 22, 2024. [Online]. Available: https://www.mdpi.com/2073-4395/11/1/7
49. "Bollas et al. - 2021 - Comparison of Sentinel-2 and UAV Multispectral Dat.pdf."
50. "Drones on the horizon: Transforming Africa's Agriculture | E-Agriculture." Accessed: Aug. 22, 2024. [Online]. Available: https://www.fao.org/e-agriculture/news/drones-horizon-transforming-africa%E2%80%99s-agriculture
51. "Full Text PDF." Accessed: Aug. 22, 2024. [Online]. Available: https://www.tandfonline.com/doi/pdf/10.1080/09537325.2020.1858047
52. K. Zhichkin, V. Nosov, L. Zhichkina, O. Anichkina, I. Borodina, and A. Beketov, "Efficiency of using drones in agricultural production," *E3S Web Conf.*, vol. 381, Apr. 2023, doi: 10.1051/e3sconf/202338101048.
53. "Zhichkin et al. - 2023 - Efficiency of using drones in agricultural product.pdf." Accessed: Aug. 23, 2024. [Online]. Available: https://www.e3s-conferences.org/articles/e3sconf/pdf/2023/18/e3sconf_aquaculture2023_01048.pdf
54. I. Kovalev, D. Kovalev, K. Astanakulov, V. Podoplelova, A. Voroshilova, and Z. Shaporova, "Cost-effectiveness analysis of the implementation of transport and technological cycles in the swarm use of agricultural UAVs," *E3S Web Conf.*, vol. 471, p. 04017, 2024, doi: 10.1051/e3sconf/202447104017.
55. "Advantages of Agricultural Drones Compared to Aircraft Spraying - HD TECH." Accessed: Aug. 23, 2024. [Online]. Available: https://www.huidaagtech.com/advantages-of-agricultural-drones-compared-to-aircraft-spraying.html?gad_source=1&gclid=CjwKCAjw5qC2BhB8EiwAvqa41ky9AH7KfLGTAY3DYkEO-Qf14ez55lsCkuFcgJnDkYeibIcKNWfwTRoCmOE-QAvD_BwE

56. "Howdronetechnologyimpactslivelihoods_thecaseofNsadwirfarmingcommunityinGhanaAfrica-GoesDigitalInc.pdf."
57. "case-study_eyes-in-the-sky-for-african-agriculture-water-resources-and-urban-planning.pdf." Accessed: Aug. 22, 2024. [Online]. Available: https://www.technoserve.org/wp-content/uploads/2018/01/case-study_eyes-in-the-sky-for-african-agriculture-water-resources-and-urban-planning.pdf
58. "Volkmann - Small Unmanned Aerial System Mapping Versus Conven.pdf." Accessed: Aug. 22, 2024. [Online]. Available: https://publications.cta.int/media/publications/downloads/1987_PDF.pdf
59. "Application of digital technologies for ensuring agricultural productivity - ScienceDirect." Accessed: Aug. 22, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2405844023098092?via%3Dihub
60. "Hinneh - Drone Farming How precision agriculture is transf.pdf." Accessed: Aug. 22, 2024. [Online]. Available: https://www.africa21.org/wp-content/uploads/PDF-Drone-Farming-Story_.pdf