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Article

Integration of Space Science And Technology For Agricultural Development

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Abstract: This study examined the integration of space science and technology into agriculture and its contribution to improving agricultural productivity, sustainability, and food security. The study adopted an explanatory research method in order to investigate how the integration of space science and technology in agriculture will lead to enhanced productivity in the agriculture sector. The work also made use of the review approaches by analysing recent works on key applications of satellite and geospatial technologies in agriculture. The results showed that some of the ways in which the integration of space science and technology in agriculture will lead to agricultural development are crop monitoring, crop yield prediction, weather forecasting, precision agriculture, farm mapping, early warning systems for droughts, communication, and crop area mapping. The reviewed works showed that Earth observation satellites, remote sensing, Global Navigation Satellite Systems (GNSS), Geographic Information Systems (GIS), and satellite communication technologies have significantly transformed agricultural practices through the provision of timely and accurate information for decision-making. The reviewed studies further showed that these technologies improve resource utilisation, reduce production risks, enhance disaster preparedness, increase crop productivity, and strengthen food security. The study concludes that integrating space science and technology into agriculture provides a sustainable agricultural development.

Keywords: Agriculture, crop yield prediction, early warning systems, Geographic Information Systems, weather forecasting.

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1. Introduction

Space science and technology "deal with the study of the upper atmosphere (space) and the body in outer space or a celestial body other than the earth, as well as how the engineering and scientific disciplines will be able to explore and use outer space to the benefit of humanity" [1]. Agriculture is the art and science of cultivating the soil, growing crops, and raising livestock. Reliable and timely crop-yield prediction and crop mapping are crucial for food security and decision-making in the food industry and in agro-environmental management. The global coverage, rich spectral and spatial information, and repetitive nature of remote sensing (RS) data have made them effective tools for mapping crop extent and predicting yield before harvesting [2]. The key elements that underpin food security require the adaptation of agricultural systems to support productivity increases while minimizing inputs and the adverse effects of climate change. The advances in precision agriculture over the past few years have substantially enhanced the efficiency of applying spatially variable agronomic inputs for irrigation, such as fertilizers, pesticides, seeds, and water, and we can attribute them to the increasing number of innovations that utilize new technologies that are capable of monitoring field crops for varying spatial and temporal changes [3]. The advent of remote sensing technology in agriculture offers a potentially effective means of extracting "state of the field crop" information to monitor crop growth. One of the most promising recent advancements in the field is hyperspectral imaging (HSI), which is a technology that combines spectroscopy and imaging [4]. According to Abdullahi [5], the potential of space technology to revolutionize the agricultural sector has gained significant traction in recent years. Nigeria, with its vast agricultural landscape and growing population, stands to benefit immensely from the adoption of space-based applications [6]. As agriculture is increasingly recognized as a crucial solution for Nigeria's challenges, it is essential for us to familiarize ourselves with and adopt the emerging space technologies that can address various agricultural issues faced by farmers today. In Nigeria and other developing countries today, the role of space technology cannot be overemphasized, as it has a very long way to go in this pursuit. Though some works have been done in this research area, detailed works that discuss the various aspects of space science and technology like remote sensing, Global Navigation Satellite Systems (GNSS), Geographic Information Systems (GIS), and satellite communication technologies, as treated in this work, have not been done, to the best of our knowledge; hence, the need for this work.

2. Methodology

This study made use of secondary data, which consisted of online information and library sources. It also employed an explanatory research method and review research approach using related literature to examine the role of space science and technology in improving agricultural production. Relevant scholarly articles published online in recent years were obtained from reputable databases, including MDPI, Springer, Wiley Online Library, Frontiers, ScienceDirect, and arXiv. The explanatory method focused on how the integration of space science and technology into agriculture will contribute to its development. Also, the selected materials for the review focused on major applications of space science and technology in agriculture. Information extracted from the selected publications was critically analysed to describe how satellite technologies, remote sensing, Geographic Information Systems (GIS), Global Navigation Satellite Systems (GNSS), and satellite communication contribute to improving agricultural productivity and sustainability.

3. Results and Discussion

Below are some areas in which the integration of space science and technology into agriculture will contribute to agricultural development.

3.1 Crop Monitoring

Crop monitoring is defined as the continuous observation and assessment of crop growth, health, and development throughout the growing season to determine their condition and identify factors that may affect agricultural productivity. Crop monitoring is one of the most significant applications of space science and technology in agriculture because it enables farmers to observe the condition of their crops without relying solely on physical field inspections. Earth observation satellites equipped with remote sensing sensors capture images of agricultural fields at regular intervals. These images provide valuable information about crop growth, vegetation cover, biomass, and overall plant health throughout the farming season. Unlike conventional monitoring methods, satellite technology can cover vast agricultural areas within a short period, making it an efficient tool for both small-scale and large-scale farming [7].

The satellite data are analysed using vegetation indices such as the Normalized Difference Vegetation Index (NDVI), which measures the greenness and vigour of plants based on the way vegetation reflects visible and near-infrared light. Healthy crops usually reflect more near-infrared radiation, while unhealthy or stressed crops produce different reflectance patterns. This allows farmers and agricultural experts to identify areas affected by water stress, nutrient deficiencies, diseases, pest infestations, or poor crop growth before visible symptoms become widespread. Early detection makes it possible to implement corrective measures promptly, thereby preventing further damage and reducing production losses. This targeted management approach improves resource efficiency, reduces production costs, and minimises environmental pollution caused by excessive use of agricultural inputs. Government agencies and agricultural organizations also utilise satellite-based crop monitoring to evaluate regional agricultural performance, estimate food production levels, and formulate policies that promote food security. Omia did a review of satellite-based crop monitoring using multispectral, hyperspectral, thermal, and radar sensors. The study explained that remote sensing technologies enable continuous monitoring of crop growth, vegetation health, and biomass throughout the growing season. The authors observed that vegetation indices such as NDVI are effective for detecting crop stress before visible symptoms appear. They concluded that satellite-based crop monitoring improves farm management, reduces production losses, and supports sustainable agricultural practices.

3.2 Yield Prediction

Yield prediction is defined as the process of estimating the quantity or amount of agricultural produce that is expected to be harvested from a particular field or region before the actual harvesting period. Accurate yield prediction is essential for effective agricultural planning and decision-making. Through space science and technology, Earth observation satellites continuously monitor crop development from planting to maturity. These satellites collect information on vegetation density, crop biomass, canopy development, and growth patterns, providing reliable indicators of the overall performance of crops during the growing season. The information obtained is processed together with environmental factors such as rainfall, temperature, soil moisture, and historical production records to estimate the expected harvest.

Vegetation indices, particularly the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI), play an important role in estimating crop yield. Healthy crops produce stronger vegetation signals, indicating favourable growth conditions and higher productivity, while weaker signals often indicate stress resulting from drought, nutrient deficiencies, pests, diseases, or adverse weather conditions. By analysing these patterns throughout the growing season, agricultural scientists can predict crop yields with considerable accuracy before harvesting begins.

Reliable yield prediction provides numerous economic and management benefits. Farmers can prepare for harvesting by arranging labour, storage facilities, transportation, and marketing activities well ahead of time. Agribusiness companies can estimate raw material availability for processing, while governments and agricultural agencies can assess national food production,

monitor food security, and implement timely intervention programmes where necessary. Financial institutions and insurance companies also rely on yield forecasts to evaluate agricultural risks and provide appropriate financial support to farmers.

Joshi conducted a systematic review on the use of remote sensing and deep learning techniques for crop mapping and yield prediction. The review found that satellite imagery combined with machine learning models significantly improves the accuracy of yield estimation before harvest. The authors explained that integrating vegetation indices with weather and soil information provides reliable forecasts for agricultural planning. They concluded that satellite technology has become an essential tool for improving food security and agricultural decision-making.

3.3 Weather Forecasting

Weather forecasting is defined as the process of predicting future atmospheric conditions such as rainfall, temperature, humidity, wind speed, cloud cover, and storms using scientific observations and data analysis. In agriculture, space science and technology enhance weather forecasting through meteorological satellites that continuously monitor the Earth's atmosphere and provide real-time weather information to support farming activities. Weather conditions have a direct influence on agricultural production because they determine the success of crop growth, irrigation, harvesting, and other farming operations. Through the integration of space science and technology, meteorological satellites continuously observe atmospheric conditions across different regions of the world. These satellites collect valuable data on rainfall distribution, temperature variations, humidity levels, cloud movement, wind patterns, and the development of storms. The information is transmitted to meteorological centres, where it is analysed to produce accurate weather forecasts that farmers can use for planning their farming activities. One of the major advantages of satellite-based weather forecasting is that it helps farmers determine the most suitable time for planting and harvesting crops. For example, forecasts indicating the beginning of the rainy season encourage farmers to plant when there is sufficient soil moisture for seed germination. Similarly, forecasts of dry periods enable farmers to prepare irrigation systems or delay planting until favourable conditions return. Weather forecasts also help farmers decide the best periods for applying fertilisers and pesticides, ensuring that rainfall does not wash away these inputs before they become effective.

In addition, meteorological satellites provide early warnings of extreme weather events such as heavy rainfall, floods, droughts, heat waves, and strong winds that could damage crops and reduce agricultural productivity. Receiving these warnings in advance enables farmers to adopt preventive measures, protect their crops, and minimise economic losses. Beyond individual farms, long-term satellite weather observations assist governments, agricultural agencies, and researchers in monitoring climate variability, planning agricultural programmes, and developing climate-smart farming practices. Bassine [8] critically reviewed the application of remote sensing, machine learning, and IoT technologies in modern agriculture. The authors explained that satellite-derived weather information, including rainfall and temperature data, enhances crop management and improves yield prediction. The study further showed that integrating meteorological satellite data with artificial intelligence helps farmers make timely decisions on planting and irrigation. The review concluded that accurate weather forecasting contributes significantly to climate-resilient agriculture.

3.4 Precision Agriculture

Precision agriculture is defined as a modern farming approach that uses advanced technologies such as global positioning systems (GPS), global navigation satellite systems (GNSS), remote sensing, geographic information systems (GIS), and automated machinery to manage agricultural activities accurately according to the specific needs of different parts of a farm. Precision agriculture is one of the most practical applications of space science and technology in improving agricultural productivity and resource management. By integrating satellite navigation

systems such as GPS and GNSS with remote sensing technologies, farmers can obtain highly accurate information about their farmland. Satellite positioning allows precise land surveying, field boundary mapping, soil sampling, and navigation of agricultural machinery. Modern tractors, planters, harvesters, and sprayers equipped with satellite guidance systems can operate with minimal overlap or omission, thereby improving farming efficiency and reducing operational costs. Satellite imagery and remote sensing data also help farmers understand the variability that exists within different parts of a field. Some areas may have higher soil fertility, while others may suffer from nutrient deficiencies, poor drainage, or water stress. Rather than applying the same quantity of fertiliser, irrigation water, or pesticides across the entire farm, precision agriculture allows inputs to be applied according to the actual needs of each location. This practice, known as variable-rate application, ensures that crops receive the appropriate resources required for optimal growth while reducing waste and environmental pollution. Furthermore, precision agriculture supports continuous monitoring of crop performance throughout the growing season. Farmers can quickly identify areas showing signs of poor growth and implement corrective measures before problems become widespread. The efficient use of agricultural inputs lowers production costs, increases crop yields, conserves natural resources, and minimises the environmental impact of farming activities [9]. Getahun [10] conducted a systematic review on the application of precision agriculture technologies for sustainable crop production and environmental sustainability. The authors explained that technologies such as GPS/GNSS, remote sensing, drones, variable-rate technology (VRT), and Internet of Things (IoT) devices enable site-specific management of crops, soil, water, and nutrients. The review found that these technologies improve input-use efficiency, increase crop productivity, and reduce environmental impacts by minimising the excessive use of fertilisers, pesticides, and irrigation water. The authors concluded that precision agriculture is an effective approach for achieving sustainable and climate-resilient agricultural production.

3.5 Farm Mapping

Farm mapping is defined as the process of creating accurate maps that show the boundaries, size, physical features, soil characteristics, crop locations, irrigation systems, and other important information about agricultural land. Space science and technology improve farm mapping through the use of satellite imagery, Global Navigation Satellite Systems (GNSS), Geographic Information Systems (GIS), and remote sensing technologies, which provide detailed and up-to-date information about farmland. Farm mapping is an essential aspect of modern agricultural management because it provides farmers with a clear understanding of the physical characteristics and resources available on their farms. Traditionally, farm maps were produced through manual surveys, which were often time-consuming, expensive, and less accurate. The integration of space science and technology has transformed this process by enabling the collection of precise spatial information using Earth observation satellites and satellite navigation systems. High-resolution satellite images provide detailed views of farmland, making it easier to identify field boundaries, access roads, water bodies, drainage systems, irrigation facilities, and different crop zones. Satellite-based farm mapping also helps farmers identify variations in soil conditions, topography, and vegetation across different sections of a farm. This information supports better planning of farming activities, including crop selection, irrigation design, soil conservation, and land preparation. Farmers can divide their fields into management zones based on soil fertility, moisture availability, and crop performance, thereby improving the efficiency of agricultural operations. In addition, farm maps simplify record keeping by providing permanent digital records that can be updated whenever changes occur on the farm. Furthermore, agricultural organisations, extension services, and government agencies use satellite-generated farm maps to monitor agricultural development, allocate farming resources, and implement agricultural support programmes. Accurate farm maps also facilitate land registration, reduce land ownership disputes, and improve agricultural planning at both local and national levels.

Espinel [11] reviewed the application of artificial intelligence in agricultural mapping using satellite imagery and geospatial technologies. The authors explained that combining remote

sensing with AI significantly improves the accuracy of farm boundary delineation, field identification, and digital farm mapping. The review further showed that these technologies provide reliable spatial information for land management, precision agriculture, and resource allocation. The authors concluded that AI-assisted satellite mapping has become an essential tool for efficient farm management and sustainable agricultural development.

3.6 Early Warning for Droughts, Floods, and Pests

Early warning for droughts, floods, and pests is defined as the timely detection and prediction of environmental hazards and biological threats that may affect agricultural production before they cause significant damage. Agriculture is highly vulnerable to natural disasters and biological threats, making early warning systems essential for reducing crop losses and improving food security. Through the integration of space science and technology, satellites continuously monitor environmental conditions over large geographical areas and provide real-time information on rainfall, soil moisture, vegetation health, temperature, and water levels. These observations enable scientists and agricultural agencies to detect the early signs of drought, flooding, and pest outbreaks before they become severe.

Satellite imagery is particularly effective in identifying drought conditions by monitoring vegetation health and soil moisture levels. Declining vegetation indices, such as the Normalised Difference Vegetation Index (NDVI), often indicate that crops are experiencing water stress due to insufficient rainfall. Similarly, satellites can detect rising river levels, excessive rainfall, and flood-prone areas, allowing communities and farmers to prepare before flooding occurs. Earth observation systems also monitor environmental conditions that favour the spread of destructive agricultural pests such as fall armyworms, desert locusts, and other insect infestations[12]. Identifying these high-risk areas early enables agricultural authorities to implement pest control measures before infestations spread to neighbouring farms.

The information generated by satellite-based early warning systems allows farmers to take preventive actions such as adjusting planting schedules, improving irrigation management, protecting harvested produce, relocating farm equipment, or applying appropriate pest control measures. Governments and disaster management agencies also rely on satellite information to coordinate emergency responses, distribute agricultural support, and develop long-term adaptation strategies for climate-related challenges. Munyati conducted a systematic review of remote sensing technologies for agricultural insect pest monitoring. The review explained that satellite imagery, multispectral sensors, and vegetation indices enable the early detection of pest outbreaks by identifying changes in crop health before severe damage occurs. The authors further noted that integrating Earth observation data with predictive models strengthens early warning systems for sustainable crop protection. They concluded that satellite-based monitoring supports timely interventions and reduces agricultural losses caused by pests.

3.7 Land Use

Land use is defined as the way land is utilised for different human activities such as agriculture, forestry, settlements, industry, conservation, and transportation. Effective land use planning is essential for increasing agricultural productivity while ensuring the sustainable management of natural resources. The integration of space science and technology has significantly improved the ability to monitor and manage land resources by providing detailed satellite images of the Earth's surface. These images enable researchers, farmers, and policymakers to identify different land cover types, including forests, grasslands, wetlands, urban areas, and agricultural fields. By analysing these satellite observations, it becomes possible to determine which areas are suitable for farming and which should be preserved for environmental conservation. Remote sensing technology also plays an important role in identifying arable land by evaluating soil characteristics, vegetation cover, terrain, and water availability. This information helps farmers select appropriate locations for cultivating different crops and supports governments in developing agricultural expansion plans. In addition, satellite imagery allows continuous

monitoring of land use changes such as deforestation, urban expansion, soil degradation, desertification, and the conversion of farmland into residential or industrial areas. Detecting these changes early enables authorities to implement policies that protect agricultural land and promote sustainable land management.

Furthermore, land use information generated through space technology assists agricultural planners in allocating resources, improving irrigation development, managing watersheds, and implementing environmental conservation programmes. It also supports national agricultural policies by providing reliable data for land administration, food production planning, and climate change adaptation strategies. Ali [13] reviewed the role of remote sensing technologies in site-specific crop management and land resource utilisation. The study explained that satellite observations provide accurate information for land-use classification, monitoring land-use changes, and identifying suitable agricultural areas. The authors observed that these technologies improve sustainable land management by supporting precision farming and reducing environmental degradation. They concluded that remote sensing has become indispensable for agricultural planning and efficient land utilisation.

3.8 Communication and Market Access for Rural Farmers

Communication and market access for rural farmers refer to the ability of farmers to obtain and exchange agricultural information, communicate with extension services, and access markets where they can buy farm inputs and sell their agricultural products. One of the major challenges facing rural agriculture is the limited availability of reliable communication infrastructure, which often restricts farmers' access to agricultural information and profitable markets. The integration of space science and technology has addressed this challenge by using communication satellites to extend internet and mobile network services to remote farming communities that are difficult to reach through conventional terrestrial communication networks. This improved connectivity enables farmers to communicate with agricultural experts, extension officers, researchers, financial institutions, and buyers regardless of their geographical location. Satellite communication also provides farmers with real-time access to important agricultural information such as weather forecasts, market prices, pest and disease alerts, improved farming techniques, and government agricultural support programmes. With access to timely and reliable information, farmers can make better decisions regarding planting, harvesting, storage, transportation, and marketing of their produce. Digital platforms supported by satellite internet also enable farmers to participate in e-agriculture services, online training programmes, mobile banking, electronic payments, and digital marketplaces where they can sell their products directly to consumers or large commercial buyers. Furthermore, improved market access reduces the influence of middlemen, allowing farmers to negotiate better prices and increase their incomes. Governments and agricultural organisations also use satellite communication to deliver extension services, coordinate agricultural interventions, and disseminate emergency information during natural disasters or disease outbreaks. As a result, integrating space science and technology into rural communication enhances information sharing, strengthens market participation, improves farmers' livelihoods, promotes agricultural innovation, and contributes to sustainable rural development.

Ngulube [14] reviewed the contribution of information and communication technologies to sustainable agriculture among smallholder farmers in tropical Africa. The study revealed that digital communication platforms supported by satellite and mobile technologies improve farmers' access to agricultural information, extension services, weather forecasts, and market opportunities. The review found that improved digital connectivity enhances decision-making, increases productivity, and strengthens rural livelihoods. The author concluded that ICT-supported communication is essential for promoting sustainable agricultural development in rural communities.

3.9 Crop Area Mapping

Crop area mapping is defined as the process of identifying, measuring, and documenting the

geographical distribution and total area occupied by different crops within a particular farm, region, or country. Space science and technology enhance crop area mapping through the use of Earth observation satellites, remote sensing, Geographic Information Systems (GIS), and satellite positioning technologies, which provide accurate and up-to-date information on crop distribution.

Crop area mapping has become an essential component of modern agricultural management because it provides reliable information about the location and extent of cultivated land. Accurate crop area maps assist farmers and agricultural planners in estimating the total land devoted to specific crops, assessing cropping patterns, and evaluating agricultural productivity. The information also supports the estimation of national food production, allowing governments to plan food supply, storage facilities, import requirements, and agricultural support programmes more effectively. Furthermore, crop area mapping helps identify abandoned farmland, monitor illegal land conversion, and evaluate the effects of natural disasters such as floods, droughts, and pest infestations on cultivated areas. In addition, satellite-based crop area mapping provides valuable information for agricultural research, environmental monitoring, and policy formulation. It supports precision agriculture by helping farmers monitor field boundaries, improve farm management, and optimise the use of agricultural resources. Government agencies and international organisations also rely on crop area maps to monitor food security, allocate agricultural subsidies, and develop long-term strategies for sustainable agricultural development.

Akinyemi [15] presented a comprehensive review of advancements in crop mapping using remote sensing technologies. The review explained that integrating optical and radar satellite imagery with deep learning techniques has significantly improved the accuracy of crop area mapping across different agricultural regions. The authors reported that multi-source satellite data provide timely information for estimating cultivated areas, monitoring cropping patterns, and supporting food security planning. They concluded that modern remote sensing technologies have greatly enhanced national and regional agricultural mapping programmes.

4. Conclusion

The study on the integration of space science and technology for agricultural development has been done using explanatory and review research methods. The research also made use of secondary data consisting of majorly online sources and some data in the library. The findings showed that satellite-based technologies provide reliable information for monitoring crop health; predicting yields; forecasting weather conditions; mapping farms and crop areas; monitoring land use; detecting disasters and pest outbreaks; as well as improving communication between farmers and agricultural stakeholders. These technological innovations support precision farming by enabling efficient management of agricultural resources while reducing production costs and environmental impacts. The reviewed literature also highlights the importance of satellite communication in enhancing access to agricultural information and market opportunities for rural farmers. It can be concluded that integrating space science and technology into agriculture provides a sustainable agricultural development.

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