Internet of Things for Smart Agriculture in Nigeria and Africa: A Review

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***Abstract*: The Internet of Things (IOT) has become important to almost every area of life due to the huge advantages it possesses. African countries including Nigeria are clamouring for the implementation and deployment of IOT devices to ease the difficulties individuals face in performing their various tasks. Due to the fact that the African region depends hugely on agriculture, this paper focuses on IOT for smart agriculture. This paper first defines the basic concepts where IOT could benefit agriculture in Nigeria and Africa. Furthermore, it reviews the areas where IOT can be applied to agriculture. The benefits of IOT in agriculture to Nigeria and Africa are discussed. Lastly, conclusion and lessons learnt from the review are presented.**

***Keywords*: Internet of Things, Smart Agriculture, Nigeria, Africa.**

I. IOT IN NIGERIA AND AFRICA

Recently, the Internet of Things (IOT) has applications in different areas such as management, transportation, smart home, energy, retails, smart cities, healthcare, supply chain, agriculture, and buildings amongst several others [1] [2].

In recent times, there is need for Nigeria to diversify its economy from crude oil to agriculture due to low selling prices of crude oil [3]. For the African continent, agriculture is predicted to take Africa out of poverty if technology is properly utilised for mechanised farming [4]. It is shocking to however note that, most Nigerians and Africans are still practising agriculture using traditional approaches. This calls for the government and related agencies in Nigeria and other African countries to invest heavily into smart agriculture in order to get the country and continent out of poverty [5].

A. Definition of Concepts

Smart Farming: This can be referred to as the application of modern information and communication technologies techniques/skills into agriculture in order to achieve higher productivity [6]. Smart farming or smart agriculture can provide the farmer with daily updates with respect to the soil, crop health, and energy consumption level within the farm [18].

Smart Irrigation: It uses controllers to monitor weather and soil conditions, state of evaporation and plant healthiness while adjusting watering schedules to maintain and moderate the required water on a smart farm. Smart irrigation is targeted at saving water, money and improving crop yields [7].

Poultry Management: This refers to practising smart poultry farming targeted at improving the security and quality of chickens with the inclusion of broilers [8].

Crop Monitoring: This is also termed as crop online monitoring, where weeds are detected, pest are detected, the level of water for the crops is detected, growth of crop is monitored and any animal intrusion into the farm is also detected [9].

Crop Disease Detection: This involves an automatic disease detection using the leaf or the general well-being of crop under investigation [10].

Greenhouse Management: This is the care given to a variety of plants used for landscape or floral design purposes [11]. This simply entails an environmental modification and management that allows the best weather conditions and seasons for the favourable growth of plants and crops [12].

Plant Growth Monitoring: This is the surveillance of plant growth using IOT surveillance systems to ensure steady and consistent growth of plants [13].

Energy Management: This is the utilization of IOT technologies on farmlands to optimise energy usage while reducing costs and loses [14].

Waste Management: This refers to the many methods and processes of dealing with waste at every stage from reduction and employ, animal feeding, recycling, composting, fermentation, landfills, up to burning and land application [15]. The IOT has recently been used to optimitise the process of waste management in farms and the efficient handling of waste management with low-cost IOT sensors [16].

Precision Farming or Precision Agriculture: This refers to the use of information technology to ensure that crops and soil are properly treated so they could be healthy and productive. This is usually achieved via specialised equipment, software and IT services [17].

Soil Management: The IOT has the ability to accurately detect and manage soil constituents for efficient agricultural purposes via sensors [18].

Water Management: IOT is used here for optimum watering

of agricultural crops all year round [19].

Livestock Detection Management: IOT is used to track the location of livestock, identify the livestock, check for their healthiness, locations and when properly deployed, it can solve the herders/farmers clashes [20].

Weather Monitoring: This involves the systematic approach of measuring the atmosphere and climate, including variables such as temperature, moisture, wind velocity and barometric pressure using IOT [21].

Nutrient Management: This involves the smart monitoring of soil nutrients level using IOT for effective crop production [37].

Machines for Routine Operations: This involves optimisation of routes for drivers' assistance and reducing the harvest and treatment of crops [38].

B. Application Areas of IOT in Agriculture

Table I briefly reviews the application areas of IOT in agriculture taking into consideration the particular areas of application, the implementation strategy and the advantages of the research proposed by various authors.

II. BENEFITS OF IOT IN AGRICULTURE TO NIGERIA AND AFRICA

Nigeria is made up of 36 states and the federal capital territory, Abuja. Nigeria has a huge land mass of 923,768 KM^2. Nigeria is also blessed with several rivers such as Ouémé River, Okpara River, Ogun River, Oyan River, Ofiki River, Ona River (Awna River), Ogunpa River, Osun River, Erinle River, Otin River, Oba River, Omi Osun, Benin River, Osse River, Niger River, Escravos River (distributary), Forcados River (distributary), Chanomi Creek (distributary), Nun River (distributary), New Calabar River (distributary), Anambra River, Benue River, Okwa River, Mada River, Katsina Ala River, Menchum River, Ankwe River, Donga River, Bantaji River (Suntai River), Wase River, Taraba River, Kam River, Pai River, Gongola River, Hawal River, Faro River, Gurara River, Kaduna River, Mariga River, Tubo River, Galma River (Nigeria), Moshi River, Teshi River, Oli River, Malendo River, Sokoto River, Ka River, Zamfara River, Gaminda River, Rima River, Goulbi de Maradi River, Gagere River, Bunsuru River, Bonny River, Imo River, Aba River, Otamiri River, Kwa Ibo River, Cross River, Akwayafe River, Great Kwa River, Calabar River, Asu River, Aboine River, Ekulu River no, Anyim River, Yobe River, Komadugu Gana River, Jama'are River (Bunga River), Katagum River, Hadejia River, Chalawa River, Kano River, Watari River, Ngadda River, Yedseram River [39].

Most crops and vegetables grow favourably well in Nigeria. For example, Figure 1.1 below shows the major crops produced in the different regions of Nigeria. Furthermore, it shows locations of where agricultural commodities are also produced in Nigeria [40]. In terms of poultry, in 2012, Nigeria had about 207.6 million poultry and by 2050, the number of poultry is estimated to be 1284.3 million. Considering livestock, in 2012, Nigeria had about 20.7 million cattle and by 2050, the cattle are projected to be about 53.6 million cattle [41]. Other African countries are blessed with poultry, and livestock as well.

Even though Nigeria is blessed with so much land, several rivers and most of the crops and vegetables can grow favourably well on these soils, there is need to automate and adopt the IOT techniques for agricultural purposes in Nigeria. Adopting IOT for agricultural purposes in Nigeria will have several benefits. Some of these benefits include:

a. Increased food production: Recently, Nigeria and Africa has experienced an increase in hunger and poverty. Smart farming has the tendency to perform optimization of smart cropping to include accurate planting, pesticides and herbicides application, watering and harvesting of these crops. This in turn will lead to increased food production and security, hence reducing hunger in Nigeria and Africa.

b. Conservation of Water and Proper Usage of Abundant Rivers: IOT sensors has the huge ability to detect weather conditions and moisture contents of soils. This means that watering of crops can only be done when soils lack the adequate moisture for crop growths. Providing the accurate and timely amount of moisture needed for crop growth will conserve water usage in dry seasons and also provide food all year round for Nigerians and Africans. Furthermore, most rivers in Nigeria and Africa have the tendency to be used for smart irrigation of farms. Unfortunately, smart irrigation has not been adopted properly in Nigeria and most African countries to make a proper usage of the abundant natural rivers all over Nigeria and Africa.

c. Real Time Monitoring and Insight into Production: Farms in Nigeria and Africa are most times physically managed. As such, decision making about such farms is usually slow. IOTs have the capability to assist farmers to perform real monitoring of farms in terms of visualizing what happens on such farms and taking real time decisions remotely.

d. Operation Cost Reduction: When the clearing of bushes, tillage of the land, planting of seedlings, application of herbicides/insecticides, clearing of weeds, and harvesting of crops is automated with the aid of IOTs, the cost of operating an entire farm will be reduced in Nigeria and Africa.

e. Improved Livestock Farming: The health and wellbeing of animals can be well monitored with the help of IOTs. Furthermore, the clashes between

herders and farmers in Nigeria and most African countries can be reduced by the deployment of IOT. This can be achieved by tracking the movements of livestock to avoid those encroaching farms. Furthermore, cattle rustling will be traced and offenders will be punished.

f. Monitoring of Agricultural Equipment/Machinery: Farming equipment can be effectively managed in Nigeria and Africa using IOTs based on production rates, labour effectiveness, and failure prediction. Hence, shortage of agricultural equipment and machinery can be minimized and these equipment/machineries could be effectively used on different farms routinely to achieve bountiful harvest.

III. CONCLUSION AND LESSON LEARNT

The knowledge and deployment of IOT for agriculture will benefit Nigeria and Africa towards achieving zero hunger. Failure to adopt and deploy IOT for agriculture will increase hunger and poverty in Nigeria and Africa. Do we sit back and allow hunger and poverty to destroy our dear country and continent? I don't think we will. Hence, government firms, agricultural research institutes, agripreneurs and farmers in Nigeria and Africa should utilize the benefits of IOT in agriculture to boost crop production, properly utilize our rivers and conserve water, monitor farms in real time remotely, reduce the cost of operations on farms, improve livestock farming and proper monitoring of agricultural equipment/machinery.

Lessons learnt from the applications of IOT to agriculture is that other countries especially in Europe, Asia and South America are already using IOT to solve agricultural challenges. Hence, if Nigeria and African countries apply these techniques, with their large land mass, abundant rivers and large amount of poultry and livestock, they will achieve high productivity; hence they will achieve the zero-hunger target and optimize energy usage in farms.

Table I: Application Areas of Iot in Agriculture

Area	Application	Implementation Strategy	Advantages	Research Title / Author
Smart Farming / Smart Agriculture / Intelligent Farming	IOT is applied in agriculture for effective growth of crops by monitoring and maintaining the crop healthiness. Kamble, Gottiparthi, Thool, Ghadge, and Mhaiske in [22], documented the basics of how soil quality can be tested and how kits can be developed. Based on the results gotten from the tests, suggestions of the most suitable crop for a particular soil type is made.	Kamble et al. [22], developed a sensor kit for testing the soil type and soil quality. The device performs different tests on different soils such as bulk density test, respiration test and moisture test. The results obtained from the device are used to make suggestions with respect to the type of crops to be cultivated on a particular piece of land.	This approach boosts crop yield and reduce poor harvests. Kamble et al. [22] indicated after the tests that Black soil is best for cereal crops and sunflower, Red soil is best for maize and groundnut, White soil is best for soya beans, Alluvial soil is best for cotton, rice and wheat.	Automatic Soil Detection Using Sensors. (Kamble, et al., [22]).
	IOT is used in agriculture for the collection of real time data of agriculture production environment that provides easy access to agricultural facilities through Short Massaging Service (SMS) and offers advices on weather patterns for different crops.	Patil, and Kale [23], studied and reviewed sensor technology and wireless networks integration of IOT technology based on an actual agricultural system. With the combined approach of Internet and wireless communications, the researchers proposed the Remote Monitoring System (RMS).	Helps in predicting and avoiding weather hazards for crops.	A Model for Smart Agriculture using IOT. (Patil, and Kale, [23])
Smart Irrigation	Kodali, and Sarjerao [24], designed a simple water pump controller by using a soil moisture sensor and Esp8266 NodeMCU-12E to solve an agricultural irrigation problem.	Depending on the status of the soil moisture content, a Message Queue Telemetry Transport protocol is used for transmitting and receiving sensor information. The NodeMCU-12E controls a water pump action and displays the soil moisture sensor data and water pump status on a web page or mobile application.	The farmer can turn on and off the water pump by using Internet connectivity remotely. The soil moisture sensor is also used for measuring the content of water in the ground, thus there is no need of manually turning on and off the water pump as the process is automatically done by the server.	A low cost smart irrigation system using MQTT protocol. (Kodali, and Sarjerao, [24]).
Poultry Management	Mahale, and Sonavane [25], designed an embedded system to replace the traditional chicken farming with smart and intelligent chicken farming. The system helps farmers with real time	The system design is Internet based and incorporates remote sensor microcontrollers. It generates real time based environmental notification to the remote server such	It changes traditional farm into an intelligent farm. It provides quick and accurate information about different parameters to farmers.	Smart Poultry Farm Monitoring Using IOT and Wireless Sensor Networks (Mahale, and

Area	Application	Implementation Strategy	Advantages	Research Title / Author
	control and monitoring of environmental parameters such as temperature, humidity, air quality, light intensity etc. The system can be used remotely to control the entire poultry farm with reduced time cost and man power.	as temperature, humidity, air quality (moisture). The system also controls water level for the chickens using remote monitor sensors.	It is a low cost system, asset saving and productive management in chicken farm. Effectively supports the smart monitoring of different farm parameters like temperature, light, humidity, gas etc. by using wireless sensor network	Sonavane, [25]).
Crop Monitoring and Management	Balaji, Nandhini, Mithra, Priya, and Naveena [26], proposed an online crop monitoring system using IOT to help farmers with an overall knowledge of their farm yields. Different sensors are used to monitor and collect information about different field conditions which are sent to the farmer through a GSM technology.	The design of the system is Internet based and uses soil moisture sensor YL-69 for collecting humidity of the soil, temperature and humidity sensor DHT11 utilising a capacitive humidity sensor and a thermistor to measure the surrounding air. These sensors are used basically for the collection of temperature, humidity and soil moisture. The information collected by these sensors are sent to the ARDUINO microcontroller ATmega328 for processing while results are displayed on an LCD screen by means of a web page.	The system is used for real time update of the farm environmental conditions like temperature, humidity and soil moisture. It is also used to monitor and collect information about the field conditions.	IOT Based Smart Crop Monitoring in Farm Land (Balaji, Nandhini, Mithra, Priya, and Naveena, [26]).
Crop Disease Detection and Pest Control	Fuentes, Yoon, Kim and Park, [27], presented a deep-learning-based approach of IOT to detect diseases and pests in tomato plants.	A combination of Convolutional Neural Network (CNN) and Single Shot Multibox Detector (SSD) to identify different diseases and pests in a tomato farm.	Early detection and treatment of plant disease boosts yield production.	A robust deep-learning-based detector for real-time tomato plant diseases and pests recognition. (Fuentes, Yoon, Kim and Park, [27]).
Greenhouse Management	Dan, Xin, Chongwei, and Liangliang [28], proposed a system for intelligent agriculture greenhouse monitoring based on Zigbee technology which has a front end data acquisition, data processing, data transmission and data reception modules which has the capability to control the climate condition based on the crop data sheet.	The IOT technology used was based on the browser/server structure and CC2530 was used as a processing chip for the wireless control of the sensor node. The gateway system has Linux operating system and the Coretex-A8 as the core processor. The system was able to achieve remote intelligent monitoring and control of greenhouse as well as a replacement for the traditional wired technology by wireless sensors.	The proposed system reduces the cost of man power. It also brings forth a clearer understanding of the concept of greenhouse environment. It also reduces farming cost and energy expenses	Intelligent agriculture greenhouse environment monitoring system based on IOT technology Dan, Xin, Chongwei, and Liangliang, [28].
Plant Growth Monitoring	Slamet, Irham, and Sutan, [29], developed an IOT based monitoring system for the radial growth of plants. The system used a low-cost optoelectronic sensor to monitor the growth of guava fruits (*Psidium guajava* L.). The system is powered by a battery that lasts for two months. The system has an overall success rate of 97.54%.	This system was based on the principle of optoelectronic sensor which detects alternating white and black narrow bar printed on reflective tapes. The reflective tapes were installed surrounding the fruit and the movement of the reflective tapes indicated that the fruit had some radial growth. This device was designed to measure the radial growth of the guava plant on a long term with minimum maintenance while the data collected by sensors were sent to the server for real time monitoring.	The device can be used for long term monitoring. Maintenance of the device is minimal.	IOT Based Growth Monitoring System of Guava (Psidium guajava L.) Fruits (Slamet, Irham, and Sutan, [29]).
Energy Management	In order to reduce the costs and losses involved in the application of IOT in agriculture, Suciu, Uşurelu, Beceanu, and Dobrea, [30], proposed a tool (addVANTAGE Pro) for analysing the use of some agricultural IOT solutions for plant monitoring, disease detection, frost warning, decision support, management and water quality provided by Adcon Telemetry. The data collected by these IOT solutions are viewed on	The research concentrated on assembling and testing Adcon equipment. All monitoring systems consist of the A753 remote monitoring unit, the SDI-12 temperature sensor, the OTT-RLS level sensor, the A850 data storage unit and the addVANTAGE Pro platform. Every 15 minutes, the addVANTAGE Pro receives data related to water level and	The developed system monitors crops, provides a warning about diseases outbreak, freezing conditions and makes accurate decisions.	IOT and energy efficiency for smart agriculture using adcon telemetry devices (Suciu, Uşurelu, Beceanu, and Dobrea, [30]).

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	the addVANTAGE Pro platform, which can be accessed through the Internet via a web browser in graphical or tabular form.	temperature.		
Waste Management	The optimisation of waste collection can improve the loop in waste management from waste collection, transportation and utilisation for resource recovery. Bong, Lim, Lee, Van Fan, and Klemes, [31] reviewed the role of effective waste management in smart agriculture.	At the agricultural land, the research proposed that "smart" bins with radio-frequency identification (RFID) tags and global positioning system (GPS) modules will be placed. The "smart" bins automatically sends signals to "smart" trucks when the bins are a quarter to full. The waste collected from the agricultural lands will be weighed to into the trucks and a signal sent to the waste pre-treatment unit and the adequate amount of agricultural waste is transported to the waste pre-treatment unit by the "smart" trucks.	The scheduled waste collection system is cost effective and optimum. In smart cities, the sensor-based networks have been used to monitor the waste load in a container and the route of the waste collector to improve the collection efficiency (Bong, Lim, Lee, Van Fan, and Klemes, [31]).	The role of smart waste management in smart agriculture. (Bong, Lim, Lee, Van Fan, and Klemes, [31]).
Precision Farming	Bag and Chaurasiya [32] explained that IOT is used in precision farming for crop growths and crop protection.	Remote Sensing (RS) in combination with Global Positioning System (GPS) coordinates is used to give accurate maps and models of agricultural fields. Sampling are carried out using electronic sensors such as soil probes and remote optical scanners from satellites. Geographical Information System (GIS) is then used to collect data in the form of electronic computer databases.	The application of IOT in precision farming makes the rearing of livestock and growing of crops more controlled and accurate.	Precision Farming: The Bright Future for Indian Agriculture (Bag and Chaurasiya, [32]).
Soil Management	IOT in soil management enables remote monitoring of soil characteristics via smartphones. Soil samples are collected and pH value, humidity and temperature are remotely measured in real-time via smartphones.	Na, Isaac, Varshney and Khan [33] developed a system based on STM32 NUCLEO which comprises of microcontroller block, sensing block and communication block. The system reads soil parameters such as pH, moisture and temperature and sends data acquired from sensors to smart phone via Bluetooth.	Enhance easy identification of soil pH level and moisture content thereby enabling sowing of seeds according to the level of soil. It also helps in cultivation of crops that suits a particular soil.	An IOT based system for remote monitoring of soil characteristics (Na, Isaac, Varshney and Khan [33]).
Water Management	Chellaswamy, Nisha, Sivakumar and Kaviya [34] proposed the reduction of water wastage in dams using IOT.	Different sensors are placed in the field or farm so as to observe real data and update it in the cloud. Water controller receives real data of a field or farm and then estimates the water requirement which varies with regards to the crop cultivated on the said farm. While estimating water requirement, parameters such as temperature, wind speed, humidity and types of crops in the farm are taken into consideration.	Supplies optimum proportion of water to the farm from dams to avoid wastage of water and provision of steady water supply to farms.	An IoT based dam water management system for agriculture (Chellaswamy, Nisha, Sivakumar and Kaviya [34]).
Livestock/Cattle Detection Management	Shah, Shah, Thakkar and Amrutia [35] illustrated the use of IOT in Livestock management and employed wireless sensor networks to collect ecological data for monitoring livestock location and health via the web.	The developed system provides farmers with an alert message regarding any fluctuation from the normal range provided for livestock through an email notification or a message. This system is made up of sensors, Arduino Uno, sim module and the website module.	IOT in livestock management helps in monitoring the overall health of livestock. It helps in tracking livestock, their temperature, humidity as well as heartbeat.	Livestock Monitoring in Agriculture using IOT (Shah, Shah, Thakkar and Amrutia [35]).
Weather Monitoring	IOT in weather monitoring is designed to monitor temperature, humidity, pressure, light intensity, sound intensity level and carbon monoxide (CO) levels in the atmosphere through wireless communication.	Rao, Rao and Ome [36] used the Arduino UNO board with Wi-Fi module as embedded device for sensing and storing data in cloud. This Arduino UNO board consist of analog input pins (A0-A5), digital output pins (D0-D13), inbuilt ADC	It provides an efficient and low cost solution for continuous monitoring of environment.	Internet of Things (IOT) based weather monitoring system (Rao, Rao and Ome [36]).

Area	Application	Implementation Strategy	Advantages	Research Title / Author
		and the Wi-Fi module connects the embedded device to Internet.		
Nutrient Management	Xin Yi Lau, Chun Heng Soo, Yusmeeraz Yusof, and Suhaila Isaak [37] used the photon count processing approach to monitor nutrients in soils.	It uses a FPGA feature a 16-bit Kogge Stone adder hardware architecture well suited for processing input signals, the control system is the LED light, and a setting system based on time frame and data synchronisation through the cloud based on IOT application.	A high speed nutrient management system to detect the exact nutrients in a given soil sample in order to reduce the excessive usage of fertilizers on agricultural soils.	Integrated Soil Monitoring System for Internet of Thing (IOT) Applications (Xin Yi Lau, Chun Heng Soo, Yusmeeraz Yusof, and Suhaila Isaak [37]).
Machines for Routine Operations	Basso, M., and de Freitas [38] used unarmed aerial vehicles (UAVs) for spraying agrochemicals to achieve high crops productivity and quality	It is based on UAVs using image processing techniques. The hardware part is the UAV, whereas the software part is based on crop row detection (first algorithm) and Line Filter (second algorithm).	It reduces soil compaction that would have occurred if heavy machineries were used and also reduces waste of agrochemicals in farms.	A UAV guidance system using crop row detection and line follower algorithms (Basso, and de Freitas, [38]).

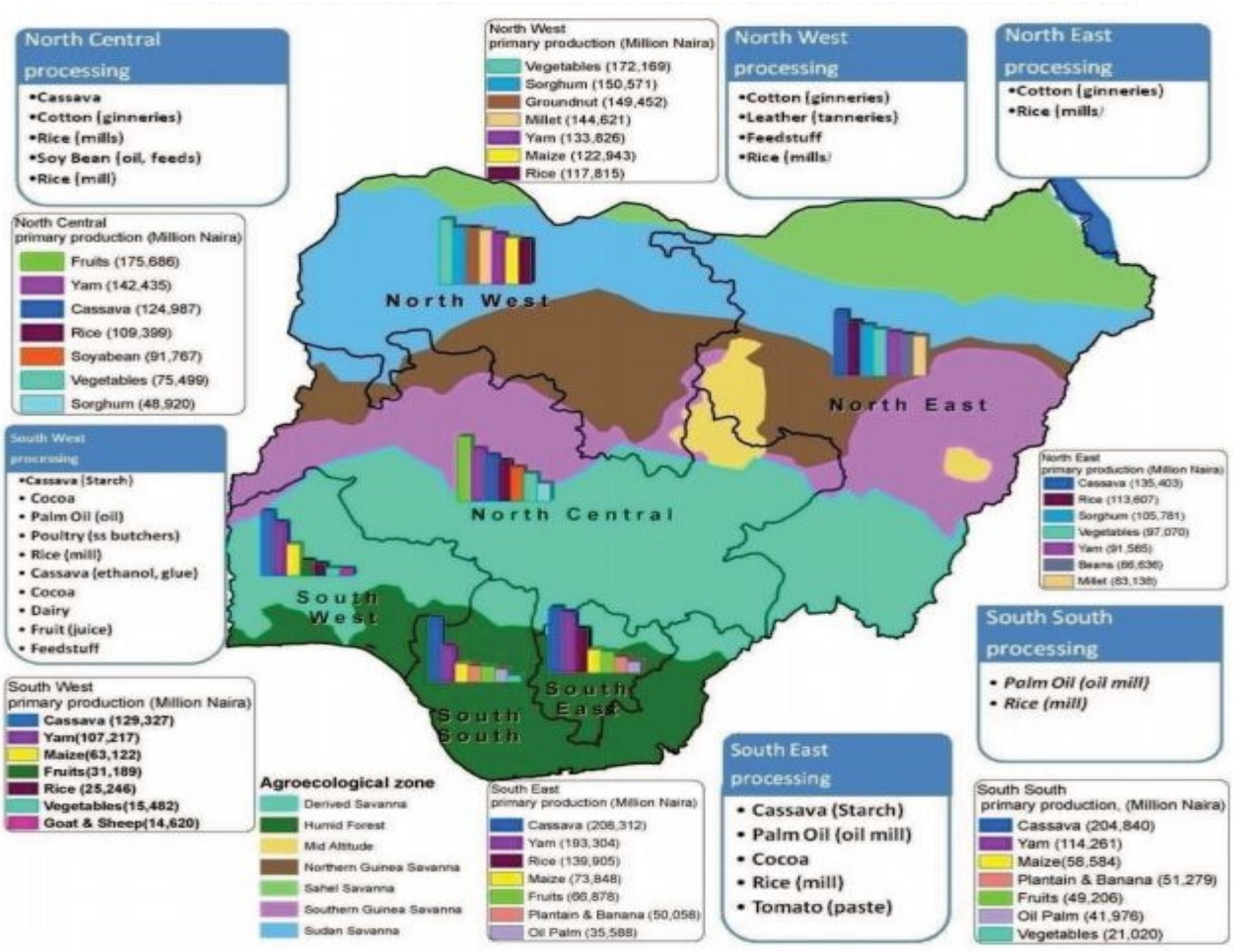

Fig. 1.1: Locations of Production and Processing of Main Agricultural Commodities [40]

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