

Nigeria's Agriculture and Technology Use: Current Structure and Challenges

Achoja Roland Onomu ¹, Michael Aliber ¹

¹ *University of Fort Hare*

King Williams Town Road, 5700, Alice Campus, South Africa

DOI: [10.22178/pos.111-3](https://doi.org/10.22178/pos.111-3)

LCC Subject Category: S1-972

Received 25.10.2024

Accepted 28.11.2024

Published online 30.11.2024

Corresponding Author:

Achoja Roland Onomu

roland.onomu@gmail.com

© 2024 The Authors. This article is licensed under a Creative Commons Attribution 4.0 License 

Abstract. Nigeria's agricultural sector plays a crucial role in the economy. It employs not less than 70% of the labour force and contributes to improving food security. However, the agricultural sector faces a series of challenges, including poor and inefficient use of technology. This research reviewed the literature on Nigeria's agricultural sector and farmers' use of technology. It analysed the current behavioural responses of the farmers to technology applications and programmes that target technology adoption in Nigeria, thereby describing one of the successful agricultural programmes in Nigeria and the procedural steps followed in executing the programme. The findings show that Nigeria has a low investment in agricultural technology. Nigeria has rich agricultural potential yet to be fully explored or exploited, with 77% of the country's land mass being arable. Evidence shows that Nigeria's agricultural sector leans more toward smallholder farming, with not less than 70% of farmers falling under this category. Smallholders produce 80% of the local staple foods. Most Nigerian farmers lagged in using technologies, with not more than 1% of all the farming households owning tractors and more than 70% of the farmers depending on crude implements. Reports on irrigation use show that not more than 6% of the arable land is irrigated. Information technology has not significantly impacted Nigeria's agricultural sector because many farmers have not used modern information communication technology (ICT) in their agricultural activities. Nigeria's agriculture growth is below the level required to reduce poverty and food insecurity. For instance, the released 2024 food security statistics reveal that 79% of Nigerians live in one form of food insecurity crisis or the other, of which 20% are plunged into severe food insecurity and 59% wallow in moderate food insecurity. Nigeria's agricultural sector value-added per capita rose less than 1% annually for over a decade (not less than 20 years). However, the trend in technology adoption is changing in Nigeria, with many farmers expressing willingness to pay for technology adoption. There is more market for hiring technology services. This research recommends that the government should critically evaluate its policies before implementation, as these could positively or negatively hamper the growth of the agricultural sector. Entrepreneurial market-driven hired technology services that would promote the efficient use of technology should be encouraged.

Keywords: mechanisation, irrigation, efficiency, information, technology, trend.

INTRODUCTION

Agricultural technology is the application of tools, machines, and techniques in agricultural enterprises [1]. It also entails the scientific techniques that modify the attributes of farms, inputs, prod-

ucts, and farming systems [2]. Gene improvement, general biotechnology, blockchain, and hydroponics are evidence and integral parts of agricultural technology (AgTech) [3, 4]. Heavy-power agricultural technologies include motorised

mechanisation, such as four-wheel tractors, trucks, planters, combine harvesters, and threshers [5]. Meanwhile, applying irrigation technology to supply water also plays a pivotal role in agricultural activities. For example, various irrigation technologies, including Terraced, Furrow, Drip, Centre Pivot, and Sprinkler irrigation systems, have been developed and adopted to supplement agricultural water requirements [6]. Besides television and radio, information technology systems are also being used to access weather agricultural information [7], including modern advanced information technology apps such as MarketWatchFarm, AgriPriceTracker, and WeatherFarm.

Earlier research shows that the transformation of the agricultural sector would not be realised without the application of technologies. Evaluation of earlier debates on the fulcrum of economic development showed that modernisation of the agricultural sector through agricultural technology applications had direct and indirect positive effects on all indices of human development, growth, and economic transformation [8]. In another development, tracking sensors, Geographic Information Systems (GIS), and Global Positioning System (GPS) were also noted as having the leverage to promote precision agriculture in livestock management and tracking [9]. The Global Positioning System also assists in easy yield documentation to aid precise data analysis. Sensors and GPS assist in planning and effective farm management by providing information on the health of crops and livestock [10].

Moreover, a proper swath is made possible through GPS. The effect of technology such as GPS in agricultural transformation is that GPS makes agricultural activities more precise and less wasteful in applying inputs such as seeds, fertilisers, and fuel utilisation [11]. Computer programs assist in self-steer activities and monitoring [11]. Emerging technology aids friendly eco-regeneration and stimulates resilient agriculture that benefits both the environment of farming communities and the larger economy [11]. Biotechnology enables the cultivation of pest and disease-resistant hybrids, thereby reducing pesticide application, disease, and pest incidences, translating to agricultural sustainability. On the other hand, applying ultrasound technology helps analyse meat quality, DNA, and the animal's foetus.

Primary tillage technological implements, including mouldboard, subsoil, rotary, chisel, and disk ploughs, increase the speed with which the soil is loosened and rearranged to improve soil aeration [12]. Soil pulverisation that ensures a better seedbed is made possible by various secondary tillage technological tools such as the soil surgeon, rotary cross-harrow, disk, spring, and spike-tooth, which are examples of common harrows. Meanwhile, the V-shaped wheel roller is another secondary tillage implement that crushes clods to destroy weeds and convey moisture in seedbed preparation [1]. To facilitate the processing of agricultural products, forced-air-drying and grain cradle threshers are used for drying and threshing, respectively. Residue recycling technology creates organic residue that stimulates soil fertility [14]. Generally, technology application ensures better farm working conditions and careful operations and improves agricultural produce, productivity, quality, and quantities. It stimulates market participation and income generation [15]. It also improves efficiency and reduces workload and drudgery.

Agricultural innovative technology development, awareness, and adoption are evolving. Modern technologies, such as drones [16], AI [17], blockchain [18], hydroponics [19], robotics, and automation [20] are increasingly being used in the agricultural sector. The design, advancement, and reinvention of technologies have altered the fashions in which different technologies are used to grow, harvest, or process crops [21]. The evolution of agricultural technology predicted the mass adoption of an autopilot/driverless tractor that functions using GPS maps and electronic sensors in the developed world [11].

The effective use of technologies has enabled the overwhelming establishment of Clean, Green, and Gourmet (CGG) food for indoor factory farming in Australia [22]. The attractiveness for middle- and upper-class individuals of CGG food constituted the drive for pilot farm establishment of CGG in several world-leading countries and cities such as Israel, Japan, China, Singapore, New York, and London [22]. While the advantages and disadvantages of indoor factory farming are being analysed, vertical farming was introduced with the aid of innovation and technologies that include the effective use of genetics, illumination, and light-emitting diode (LED) [22]. The transformation of the agricultural sector with the help of technology in Ukraine brought the country closer to the range of technologically-driven advanced

nations of the world [23]. Over several decades, the developed world has used improved technologies to advance its agricultural sector, transforming farmers and the general economy. Ironically, farmers from less developed countries, especially smallholders, have not benefited from half a similar trend [11]. Analysing studies of more than 100 countries, comprising developing and developed countries, revealed a recurring trend that developed countries exhibit ascendancy in technological progress in adoption. In contrast, developing countries stagnate or display retrogression in technological adoption [24]. Sadly, there remains a lack of research information presenting step-by-step footprint, implementation, and adopted programs that enable the application of targeted technology by overwhelming farmers in developing countries such as Nigeria. More so, research has shown that significant numbers of farmers still lag and lack the use of agricultural technologies in their farming activities [25]. More challenging is the lack of research organising and presenting how the adopted technologies are utilised efficiently across different technologies [26]. There is also a need to evaluate the top-down report and analyse farmers' demand and willingness to react toward technology adoption [27, 28].

Based on the benefits and challenges of technology adoption and application in developing countries, this study strives to investigate code findings and advancement revealed in the literature on the nature of agricultural technology and its applications in Nigeria. It also analysed the potential gap, such as technology investment commitment and programmes that warrant further research efforts, as well as the approach for methodological guidance and conceptualisation of agricultural technology in developing countries, with a focus on Nigeria. Specifically, this research investigated levels of technology usage by farmers in Nigeria, analysed the farmers' efficiency in using different technologies, presented current behavioural responses of the farmers to technology applications, and showcased a successful programme that has facilitated technology adoption in Nigeria. This study has aimed to summarise and provide up-to-date information on agricultural technology applications, growth, and challenges in Nigeria. The research also seeks to contribute to the literature that provides information on pathway to revolutionise and stimulate effective utilisation of technology in the agricultural sector. Literature on biotechnology

was skeletally mentioned. However, this review focused not on biotechnologies but on unveiling through studies the application of machine and digital technologies in Nigeria's agricultural sector.

METHODOLOGY

This study area is Nigeria, which currently has the largest population in Africa, with an average of 216,783,381 people as of 2022 [29]. The estimated projection of Nigeria's population growth is expected to be 400 million by 2050 [30]. It is flagged in the tropical region of West Africa, bordering the coast of the Gulf of Guinea between longitude 30 and 150E latitude 40N of the Greenwich meridian and 140N of the equator [26]. Hence, it borders the south of the Atlantic Ocean and shares boundaries with the east of Cameroon, northeast of Chad, north of Niger, and west of Benin.

Nigeria has a total land mass averaging 923767 km². It is, on average, four times the size of the United Kingdom and a little above twice the size of California [31]. However, a recent report by the Food and Agriculture Organization (FAO) shows that its agricultural land is, on average, 71 million hectares (ha) [32] and 70.8 million ha [33]. The agricultural land represents 77% of the country's total land mass [33]. This means that a higher proportion of the country's land is arable. The description of Nigeria, which shows the various ecological zones of the country, is presented in Figure 1.



Figure 1 – Map of Nigeria indicating countries bordering it [34]

The study applied a narrative literature review. Hence, it reviewed literature on the application of agricultural technology in Nigeria. It starts with a review of the literature on Nigeria's agriculture. Both hard and soft copy materials on the use of technologies by Nigerian farmers were consulted. Different search engines and databases were used, including Microsoft Edge, Firefox, Opera Browser, Google Chrome, ResearchGate, and eBooks. In addition, the University of Fort Hare database sources of the various publishing bodies such as ScienceDirect, Wiley, SpringerLink, SAGE Research Methods, Science Online and Science Classic, Agricola (EBSCOhost), Scopus, Academic and Agricultural Journals (ProQuest) were used.

RESULTS SAN DISCUSSION

Nigeria agricultural sector. The agricultural sector is major in Nigeria's micro and macro-economic development. The composition of rural households' income generation makes agriculture an economic mainstay of most rural households. For example, the income portfolio of rural households in Nigeria is such that most rural households derive half of their income from farming [35]. Hence, combining two or more agribusiness activities remains a foundation and integral part of the rural household's income and diversification strategies [36]. Aside from the agricultural sector's crucial role in Nigeria's rural household livelihoods, it has contributed several times to Nigeria's gross domestic product (GDP) with evidence of a short and long-run causality relationship between agricultural output and GDP [37]. For instance, the agriculture sector contributed 22.35% to GDP growth between January and March 2021 [30, 32].

The agricultural enterprise in Nigeria provides massive employment through direct labour absorption, processing, packing, and marketing of agricultural produce [38]. This makes the agricultural sector one of Nigeria's most crucial sectors because it employs not less than 70% of the labour force [32]. These views are cemented by other studies stating that more than 70% of Nigerians are involved in agriculture [30], with an average of 70% engaging in crop farming [33]. Notwithstanding, the proportion of the employment pattern in Nigeria's agricultural sector seems skewed in favour of women, with statistics revealing that 60-70% of the agricultural labour force are women, who are mainly involved in

processing and marketing agricultural products [39].

Nigeria's agricultural sector was rejuvenated a few years ago, and it is currently the highest producer of cassava on a global scale but still competes behind Egypt in the world cassava export market [40]. In collaboration with the FAO, a report from Nigeria's Federal Ministry of Agriculture and Rural Development revealed that the country's agricultural sector also leads the world as the largest producer of Sorghum, cowpea, and yam [41]. However, due to the fast-growing nature of Nigeria's population, domestic demand for agricultural produce in Nigeria overwhelms local food production, and this has stimulated the national food deficit and caused a rise in food shortages [41]. A practical example is rice production in Nigeria, which rose to 4.0 million metric tons (MTs) in 2018 from the 3.7 million MTs locally produced in 2017. However, the country imported 43% of the rice consumed in 2018 due to a deficit in local rice production, stimulating rice and other food crises, including rice smuggling into Nigeria [32].

Additionally, recent research indicates that 79% of Nigerians are living in different categories of food insecurity crisis, of which 20% are engulfed with severe food insecurity and 59% are moderately food insecure [42]. The importation of agricultural products in Nigeria is not limited to rice but also includes wheat, fish, and livestock [33]. Outside the population growth that has contributed to putting import pressure on Nigeria, many niche areas, including livestock, remain potentially untapped and underutilised due to different factors [33]. Some of the factors include poor investment and funding, which have negative implications for food security. For example, authors [43] opined that the lack of adequate budgetary provision and policy implementation in the agricultural sector is a bane for the current food shortages and crisis bedevilling the African continent, with Nigeria being the worst hit. On the budgetary allocation to the agricultural sector, it has been noted that the Nigerian government failed to invest the necessary amount of money required for the Comprehensive African Development Program as agreed on by African Heads of State in Maputo, Mozambique, at the 2003 African Union Summit [43]. Rather than reaching the 10% of budgetary allocation as standard, the share of agriculture in total government budgetary expenditure in Nigeria has consistently declined for the past two decades, as stated in the

2024 national budget of 30062.94 billion nairas, which represents 1.32% earmarked for the Federal Ministry of Agriculture [43].

The high level of staple food import witnessed in Nigeria in the twenty-first century was not the case before the oil boom in the 1970s [26]. Before the oil boom, Nigeria's primary source of income and foreign exchange earnings was from the export of cocoa, groundnut, palm oil, and cotton, but as the export of oil increased from the period 1970-2011, the export of agricultural produce decreased, and this could be aligned with the neglect of the agricultural sector by the government to focus on oil [44]. Agricultural growth in Nigeria is far below the 10% requirement for food security and poverty reduction due to most agriculturists' small and unchanging nature [26]. For example, the agricultural sector value-added per capita for more than 20 years in Nigeria rose less than 1% annually, making most smallholder agribusiness activities perpetually small [26]. An average of 70 to 80% of Nigeria's farmers are smallholders, producing 80% of the local staple foods [11, 45]. For example, previous research highlights that most farmers in Delta and Benue states, Nigeria, cultivated not more than 2.2 hectares [46]. Similarly, findings in Kano and Kaduna states revealed that 90% of farmers cultivated a farm size of 1.13% ha [47].

Smallholder agriculture. Smallholder agriculture is described as the farm sector mainly operated by owners' labour on a small scale with minimal resources and thus consists primarily of family members, who often also depend on income from non-farm activities/sources [48, 49]. Distinguishing between smallholder and commercial farmers, [50] opined that the significant feature differentiating commercial from smallholder farmers is limited access to improved technologies such as machines; instead, they mainly use family labour with crude implements. However, the heterogeneous nature of smallholder agriculture makes it difficult to define it precisely.

Identifying the various attributes of smallholder farmers, the International Finance Cooperation (IFC) stated that smallholder farmers, particularly those in developing countries, are easily recognised by their low production and productivity levels. Except in rare cases, they cultivate a maximum of three hectares or less [33]. However, using farm size to describe smallholders is arbitrary, as farm size is sometimes a function of population density and type of land. For example,

given the separation of smallholder farmers across the developmental levels in developed and developing nations, the authors observed that while most smallholders in developing countries farm an average of around two hectares, smallholders in developed nations average around 10 hectares. Hence, the use of hectares only in defining the concept of smallholder agriculture was criticised, who argued that such an approach fails to take into account, perhaps, the more essential characteristics of smallholders, such as the nature of their institutional arrangements (e.g. markets), the types of crops grown, and the quality of the other inputs used by the farmer. The New Partnership for Africa's Development (NEPAD) opined that 80% of smallholder farmers in Africa depend solely on family members for their operations. From another perspective, authors referred to smallholder farmers as those individuals who earn relatively little income with more production for consumption. In distinguishing the income level of smallholder farmers in South Africa, [53] stated that the maximum income generated by smallholders studied in South Africa was R545 per month. However, [53] further revealed that some smallholders generate income as low as R65 per month, while some do not. The fundamental reason that smallholder agriculture defies a universal definition is that it is homogenous but very diverse, and the level of its diversity is necessary for effective target programme implementation [54].

Mechanisation technology. Mechanisation is the application of machines in the farming system to enhance animal labour. It covers simple hand tools and machines that use shafts, cranks, cams, gears, sheaves, or pulleys [55]. It also entails using a drill, auger, plough, scraper, tractor, power shovel, bulldozer, backhoe, and trencher. Mechanisation plays several crucial economic roles. Early reports point to the introduction of farm machines as the foundation for modern factories [56]. Thus, mechanisation stimulates productivity and effectiveness along the food production value chain. It reduces labour struggle and enhances land preparation through increased efficiency [57]. It transforms the farming system and increases the quantity of yield and market opportunity.

The evolution of agricultural mechanisation in Nigeria. Over the years, considerable investment and effort have been made in agricultural mechanisation in Nigeria [58]. An effective mechanisation drive started in Nigeria during the colonial

era but concentrated on cash crops such as palm nuts, cotton, rubber, groundnut, and cocoa, mainly produced for British industries [58]. However, to increase employment opportunities and income generation through export earnings, the mechanisation policy was continued with the establishment of tractor-hiring. When Nigeria gained independence, the Nigerian government imported 462 tractors between 1960 and 1974, especially between 1972 and 1974, worth 16 million naira [59]. This period could be described as the era before the oil boom, where agriculture accounted for not less than 50% of Nigeria's GDP [59]. After this era came the period of mechanisation expansion, and various farm programmes, research institutions, and policies such as the Transformation Agenda, Structural Adjustment Program (SAP) of 180 to 1989, Green Revolution, Cocoa Research Institute (CRIN), Veterinary Research Institute (VRI), and National Cereal Research Institute (NCRI) were introduced in Nigeria, which were supported by income generated from oil, especially during the 1980s [60, 61]. Hence, by 1983, the total number of imported tractors to the country had increased to 22,050. The establishment of hire tractor services was continued by the federal and regional civilian governments and the era of the military governments until the discovery and economic boom of the oil sector. However, not much success was achieved in the mechanisation programme, with the failure of mechanisation being blamed on the random importation of unsuitable tractors to the country.

Nevertheless, the awareness of the need for mechanisation technology kept growing. The awareness and the need to promote effective mechanisation resulted in the establishment of Operation Feed the Nation (OFN) farm settlement towards the end of the first military government, and the civilian government continued this farm settlement programme with the launch of the "Green Revolution" farm settlement with emphasis and priority on the drive for mechanisation. The era of slow growth is due to reduced governmental support for draft animals and power machine intermediaries that do not equate to population growth. For instance, the government imported only 950 tractors and 150 implements, including threshers, between 2010 and 2018 [62]. Also, very few people were trained in mechanisation management, especially mechanisation project-funded management personnel [62].

The mechanisation and tractorisation adoption in Nigeria. The adoption and diffusion of technologies vary across countries and sectors [63]. Only 1% of households in Nigeria own a tractor [64]. In Nigeria, most smallholder farmers have poorly adopted mechanisation technology [65]. However, while commercial farmers have a reasonable level of technology adoption, most smallholders are behind in the adoption of technologies [66]. Research revealed that, as of 2001, only 2% of agricultural production from Nigeria is mechanised [67]. As of 2017, another research revealed that, generally, 90% of farming activities in Nigeria are carried out using hand and manual tools [68]. A study conducted in Delta State, Nigeria, showed that 65% scarcely used machines [69]. However, another study jointly conducted in Delta and Benue States, Nigeria, by [46] opined that 72% of smallholders do not use tractors. Specifically, research in Oyo State found that only 27.8% of the farmers applied mechanised implements in planting, while the larger proportion (72.2%) planted using crude implements [70]. On weeding, 20% of the farmers used improved implements, while 20% depended on crude implements using hand [70]. The high cost of hiring tractor services and limited tractor hiring sources are 65 and 19 % responsible for the poor adoption of tractor technology by the smallholder farmers in Nigeria [71]. Mechanisation level (heavy machine application) in Nigeria stands at 0.27 horsepower/hectare, which is far below the 1.5 minimum recommended horsepower/hectare by FAO [68]. This implies that the application of power engines in Nigeria's agricultural sector is 1.23 horsepower/hectare short of the minimum expected usage. The situation in Nigeria is that only 6 tractors are available for use in every 10,000 hectares of arable land, unlike Thailand, which boosts the application of an estimated 281 tractors in every 10000 arable land [68].

The use of tractors forms the foundation for actualising mechanisation [72]. Tractors are a vital tool in any farm mechanisation system that aims to increase the area under cultivation, facilitate the accomplishment of tasks that are difficult to perform by hand, reduce the pressure on human labour, improve the quality of work and products, and thereby promote labour efficiency and increase productivity [73]. The use or management of tractor services to ensure that the tractor task is performed in the agricultural sector is called tractorisation operation. In other words,

tractorisations is the farmer's use of tractors in agriculture [65].

Farm power, including two- and four-wheeled tractors, is essential in agriculture to raise labour productivity and boost production [74]. While tractorisation plays a significant role in farm mechanisation, its growth has been hampered for various reasons, including criticism that using the tractor will displace human labour [75]. In a report, authors stated that tractorisation does not lead to reduced human labour employment; on the contrary, tractors overcome the challenges associated with difficult cultivating areas, increasing farm employment. The survey revealed that tractor usage increased the employment of owners and their operational team, and users derived 63% higher gross income per hectare compared to traditional bullock farms [77]. Moreover, the greater use of tractors for transportation can enable farmers to get their products to markets more quickly, which implies lower post-harvest losses [78, 79]. Tractorisation aids farm product transportation, such as transporting farm inputs, fetching fire, taking the product to market, and powering another farm implement used for disking, ridging, ploughing, harrowing, and losing hard soil [65, 80]. Even in conservation agriculture, being widely promoted by some agricultural experts, tractors can play a significant role. For example, the two-wheeled tractor and appropriate implements such as seeders can facilitate minimum tillage [81].

Willingness to pay for mechanisation technology (tractor services) in Nigeria. Research indicated that most African farmers' lack of demand for mechanisation in the past contributed to the failure of early mechanisation [27, 82]. However, there is now an evolutionary change in demand for modern agricultural technologies by farmers, including smallholders in Africa [83]. The current condition is that farmers in Nigeria and some other African countries are not only demanding tractor services but also showing a willingness to pay for tractor services [84]. The present condition is that smallholders have to book for tractor services several weeks before the service is provided due to the high demand for tractor services and the limited supply of tractors [85, 86]. Another report opined that farmers needing to hire tractor service must deposit money three months ahead instead of booking for weeks. Evidence from Delta and Benue states, Nigeria, revealed that despite the larger proportion of the farmers in Nigeria not using tractors, the demand for

tractor services was on a constant increase in 2013, 2014, 2015, and 2016, respectively. For example, 97.3% expressed willingness to adopt and apply modern farming technologies [87]. Sometimes, tractor service providers do not meet the demand during planting season because the market is overwhelmed [86]. Many farmers in Nigeria are more willing to use different technologies such as sensors, GIS, and GPS, with evidence from Gombe and Bauchi stating that 92% and 96% of the farmers studied were willing to adopt precision agriculture [88].

Factors increasing demand pressure for tractor services in Nigeria. As food demand is expected to double by 2050, an increase in population growth, together with the demand for sufficient and quality food, has intensified and placed pressure on demand for an improved system of farming using efficient methods and appropriate machines [89]. The demand for tractor services increased due to the drop in farm labour in rural areas in Ogun state, Nigeria [90]. Reporting further, [91] stated that the surge in demand for tractor services in Nigeria is because many farm labourers have migrated to the cities with good jobs and social amenities in search of better livelihood. In some cases, the non-disabled men who were formally farm labourers preferred to drive taxis and commercial motorcyclists rather than remain as farm labourers, increasing demand for better alternative labour due to the shortfall of farm labour. The gain recorded in demand for tractor services could also be linked to the challenge arising from animal traction [91]. According to [91], farmers using animal traction are searching for alternative farm labour due to challenges such as theft, sales, disease, and pests such as the tsetse fly-free.

Challenges limiting the use of tractors in Nigeria. The demand for mechanisation in Nigeria is high. Still, many factors result in poor use of mechanisation, especially in using most farmers' tractors [46]. On the supply side (from tractor service providers), factors including stiff competition from government-owned tractor hire services, the high price of diesel, lack of government support, and lack of access to finance limit the adequate and efficient supply of tractor services by SME tractor service providers to many farmers in Nigeria, especially to smallholder farmers [86]. Generally, the high maintenance cost, the challenge of long-distance travel for repair, the fragmentation of the smallholder farms due to the land tenure system, the impact of too many

stumps, and the lack of training are among the core challenges affecting the effective utilisation of tractor services in Nigeria. On the other hand, some farmers struggled to use tractors due to limited tractor service providers besides the high prices charged by the service providers and the duration it takes for the service providers to meet the services required by farmers, all of which limit the effectiveness of tractor use by farmers in Nigeria [86]. Irrespective of the farmers' willingness to pay for tractor services [84], in some cases, tractor service providers were not satisfied with the price paid for tractor services by the farmers [86].

Similarly, [46] stated that the non-availability of tractors affected the adoption of mechanisation in Ondo State, Nigeria. The dependency on household labour and involvement of the household in other occupations besides farming negatively influences some of the farming household heads' decisions to mechanise their farm. Conversely, the increase in the educational status and area of land cultivated positively determined the farmers' decision to mechanise, including using tractor service [46]. The findings indicate that as farm size increases, the likelihood of the farmers using tractors increases vis-à-vis.

Irrigation technology. Irrigation technology is crucial for agriculture, and it enables the supply of water other than rain to the farm to meet agricultural requirements through different irrigation technologies and techniques [94]. Across the globe, irrigation and its technology play a critical role in providing employment, mitigating dependence on rainfed agriculture, promoting stable food supply, preventing crop failure, and increasing yield quality and quantity [95]. After considering annual investment replacement costs associated with irrigation in Ethiopia, smallholder-managed irrigated farmers' minimum gross margin income was 29.7%, surpassing rainfed smallholders dependent [96]. For example, non-irrigated smallholders among farmers generated an average income of 147 United States dollars per hectare (ha). Still, the income (\$323 United States dollars per/ha) from irrigated smallholder farmers was more than double that of smallholders who depend on rainfed [96].

Use of irrigation in the agricultural sector in Nigeria. The artificial application of water (irrigation) is not a new phenomenon in Nigeria's agricultural sector, as the country's traditional method of

irrigating can be traced back to the 19th century [97]. However, collective irrigation development and water sources driven by the state and related agricultural stakeholders did not take place in Nigeria until 1955, when the need to adopt a pragmatic approach to harness water resources for irrigation and other productive use was raised by the International Bank for Reconstruction and Development (IBRD) [98]. This has enabled Nigeria's irrigation development and regulation to support large-scale public irrigation programmes since its inception [99]. To this end, Nigeria's first national irrigation effort came on board in 1973 by establishing two pilot texts through an organ called River Basin Development Authorities (RBDAs) [100].

The establishment of the RBDAs at Sokoto and Chad basins was instigated by the Sahel region drought in the early 1970s, the oil boom in Nigeria, and overcoming dwindling agricultural production for sustainable and productive agriculture [100]. This brought in the development of dams and irrigation schemes in the 1970s [100]. Hence, RBDAs created several agencies, such as the River Niger Commission and Lake Chad Basin, for effective regulation, management, and utilisation of water resources [101]. Thus, as a strategy to optimise the potential for broader water resources, achieve the goals of promoting food self-sufficiency, increasing productivity, promoting the export market, and preventing the slow growth of the RBDA, the federal government established the Federal Ministry of Water Resources in 1975 [102]. Therefore, the 11 RBDAs and the National Water Resources Institute were merged to function under the Federal Ministry of Water Resources for effective management, budgeting, and supervision to harness the irrigation goal of income generation and food sufficiency in 1979 [98]. However, the RBDA, though brought under the Federal Ministry of Water Resources, was still in operation, making the RBDA to be restructured into 18 branches as of 1984. Again, for effective cooperation and delivery of water resources benefit to the agricultural sector, the Ministry of Water Resources, which the 18 RBDAs and National Water Resources Institute were fused, was recreated to accommodate the Ministry of Agriculture to become the Water Resources and Rural at the same time in 1984 [98]. Notwithstanding, in 1987, another recreation took place due to changes in government. The new regime reversed the RBDA back to 11 [98].

In reality, Nigeria's irrigation management and development have gone through turbulence due to inconsistency in policies [98]. Ironically, the dividend of Nigeria's irrigation development in improving agricultural productivity, output increment, food security, the well-being of rural households, and general societal growth will not be possible without robust institutional frameworks supporting effective irrigation programmes [102]. Hence, the Fadama irrigation scheme was later established in 1992 to support farmers and supplement the previous irrigation projects that had encountered challenges [103]. Fadama is derived from the Hausa language to mean irrigable lowland, and it is recognised as one of Nigeria's most successful irrigation programmes [104]. Due to the success of the Fadama pilot test, various Fadama irrigation schemes have been established across the 36 states of Nigeria, including the Federal Capital Territory (FCT).

The Fadama initiative was a collaboration between the World Bank and the Nigerian government, and the programme was executed in three stages. The Fadama programme was structured to take advantage of what worked well in the Agriculture Development Program (ADP) and addressed the identified weaknesses and challenges of the ADP by providing basic irrigation alongside [104]. Besides establishing primary irrigation through the Fadama programme, the programme was well organised by aggregating the beneficiaries into units and groups to be supported and mentored by professionals. The professional facilitators helped, moderated, and guided the beneficiaries at each stage of the programme to have adequate operational knowledge required of them and achieve their goals. Institutional building, technical, and financial, which were responsible for the huge success recorded in the programme, were provided to the beneficiaries. More so, Fadama Users Equity Fund (FUEF) was introduced to beneficiary members due to the positive outcome that enabled Fadama beneficiaries to witness more than a 60% increase per hectare in the sales of vegetables and no less than a 500% increase in the sales of rice paddies [104].

By the end of Fadama 111, a total of 64,347 Fadama User Groups (FUGs) consisting of 20 members in 5 407 communities have been researched [103]. This shows that the number of beneficiaries from the programme nationwide was very small. The beneficiaries were only

trained in how to access the local market [104]. While the Fadama programme was comprehensive, only basic irrigation, such as flood-based irrigation, was introduced despite the financially intensive programme. The Fadama project was planned to be completed in 2013 [105]; however, it was finally completed in 2019 [104]. More recently, in December 2023, the federal government sought more information flow, synergy, and coordination among heavy water users through the inauguration of Water User Association Desks Officers [106].

Regardless of the government and other stakeholders' efforts in promoting innovative technologies such as irrigation, agricultural production performance in Nigeria is still predominantly rainfed [107]. On average, not less than 90% of agricultural production in Nigeria depends mainly on rain [26]. Though there was variance in the reports, indication shows that a low level of irrigation application exists among farmers in Nigeria. Findings [109] reported that only 1% of cropland is irrigated in Nigeria. However, a similar report from the Federal Ministry of Water Resources revealed that Nigeria possesses at least 3.14 million hectares of land with irrigation capacity; only 169,718 hectares, representing 5%, have been developed for irrigation.

To promote efficient irrigation use among farmers in Nigeria, the government in 2021, through the Federal Ministry of Water Resources, agreed to collaborate with FAO to establish drip irrigation across the country [110]. One of the reasons for the planned conversion of the public irrigation scheme to a drip irrigation system is to encourage efficient water use [110]. Agriculture is responsible for at least 70% of freshwater withdrawal globally, with irrigation accounting for a more significant proportion, and this has resulted in the promotion of drip irrigation systems, which seem to encourage more efficient water use [111]. In a similar report, [112] opined that irrigation utilised 70% of freshwater worldwide.

Limitations of Irrigation Development in Nigeria. Nigeria has made a reasonable amount of effort and investment in developing water resources, including irrigation, but still faces sizeable challenges [34]. The constant and rapid increase in water demand and policy pitfalls exacerbate these challenges. Nigeria's irrigation system, in particular, especially public irrigation, has the problem of a poor maintenance culture bordering around insufficient irrigation materials and a

lack of commitment from both government and staff members [113]. For example, there is inadequate availability and distribution of suitable water that meets the standard for irrigation purposes [114], as well as irrigation infrastructure underutilisation and performance in nearly all public irrigation schemes [115].

Furthermore, poor water management, such as lack of coordination, inadequate monitoring of government irrigation schemes, and uncontrollable water use, seemingly due to old irrigation systems, including motor pumps and gravity flow systems, has also been noted [116]. Authors [34] also highlight federal and state governments' ubiquities and interwoven role in water resources. Inefficient and inconsistent government provision of water subsidies has also been noted.

Information and communication technology (ICT) in Nigeria's agricultural sector. Quality agricultural information aims to facilitate efficiency in all the spheres of agriculture production and marketing [117]. For example, constant market information dissemination and application is a key motivational influence stimulating market participation [117]. It enables some smallholder farmers to diversify their crop production patterns [118]. The role of information in market participation possesses excellent potential for improving income generation in agriculture by connecting farmers to local and international markets. It, therefore, enables farmers to make specific resolutions in input use and quantities sold and market to engage in [119].

Moreover, the availability of market information over some time can help the farmer to a large extent in knowing the trend and price flow patterns for the marketing purposes of their product. Furthermore, market information reinforces farmers' bargaining power. According to [120], price information and knowledge about the market condition of a product provide a strong negotiating power, thereby enlightening the farmers on the lowest price they can sell their product at a given time. This is because market information sends price signals to the rural farmer based on the behaviour and demand level of the urban consumers regarding the varieties and quantities required.

Timely and regular access to market information is noted to reduce risk, and the amounts of money farmers spend on their transaction costs. For instance, timely and regular access to the inputs

information market may result in farmers purchasing farm inputs, implements, and tools when the price is low [118]. On the other hand, lack of prompt access to market information is said to give rise to massive losses, which are said to increase farmers' risk that may occur due to uncertainty on when to harvest and sell [121].

Agricultural information is essential for stakeholders in the farming sector; efficiently harnessing and managing agricultural market information becomes a significant challenge, especially among smallholder farmers [122]. This relates to getting answers to where to sell, how much to sell, where to buy inputs, how much to buy, and other market information such as who to sell to, which constantly poses challenges for farmers, especially smallholders and emerging farmers [121]. Finding answers to these questions has remained problematic among many farmers. Still, information and communication technologies have been identified as tools to arrive at quick answers to market information challenges [123].

Information and communication technology enables processes, storage, implementation, installation, or transmission of information using any technology such as radio, television, computer, internet, hardware or software [124]. Information technology (IT) has long been viewed to have great potential in helping farmers make agricultural market decisions [125]. With the increase in technology growth, a wide range of people using IT has been creatively championing market participation in agriculture. Information technology has linked farmers to market information within a country and connected them to the global market [126]. It supports market participation in reducing the cost spent on transportation because farmers who use information technology can know the market condition [121]. In this modern age, ICT plays a crucial role in the planning, clearing, cultivation, harvesting, processing, and selling of agricultural products.

Irrespective of the stream of gains inherent in information technology, research studies in Nigeria established that most smallholder farmers lack information technologies for accessing agricultural output/input market information [127]. A study of ICT use among smallholder farmers in the Federal Capital Territory of Nigeria revealed that 96% of the farmers mentioned poor access to ICT infrastructure as one of their major prob-

lems [128]. A similar study [130] on farmers in Northern Nigeria revealed that 85 and 89% of the farmers stated that cell phones and radio, respectively, are the major ICT used for their agricultural activities, with [130] reporting that cell phones are mainly used for text messaging and calls. Television, radio, and cell phones are the most significant ICT farmers use in South-West Nigeria. However, the study of ICT use in Ebonyi State of South East Nigeria observed that, on average, 54% of the farmers had access to cell phones. Still, the majority (58%) did not have access to or use computers.

Due to poor adoption and application, information technology has not produced the needed results to transform the Nigerian agricultural sector [132]. Most farmers relied mainly on direct calls and text messages out of the 14 investigated ways of communicating using a phone, including apps such as Facebook, WhatsApp, E-wallet, and Instagram [133]. Only 3% of the farmers agreed to have used the E-wallet app created by the government as a medium for informing farmers about fertiliser availability, while only 1.3 had used Instagram [133]. A study of livestock farmers in Imo state, Nigeria, revealed that only 2.9% of the farmers used a tracing app to trace their animals [134]. In a similar report, [135] stated that the use of information technology in many developing countries is reduced due to low levels of computer literacy and usage in agribusiness. Besides the reduced use of computers, most farmers in developing countries are in remote villages without access to the internet and electricity, resulting in poor use of information technologies and electronic media means such as television, radio, handset, and social networks. More so, most smallholders are laggards and do not see the need to develop themselves toward the use of information technology in promoting market participation. This is because some believe using information technology, like computers and the internet, may be difficult for them to learn. Additionally, since smallholder farmers can easily take their produce to the farm gate where they can be sold, the drive to make use of modern information technology becomes depleted [15]. Furthermore, it is pertinent to note that most smallholders rely mainly on extension officers and one another for market information, which equally affects their desire to use information technologies [136].

Fear of perceived risks such as application hacking, technical glitches, and likely failures associated with the system, as well as the cost of data and the expensive nature of the machine (phone), negatively affect farmers' adoption and application of mobile apps [137]. The complexity of some phones and apps, poor network [129], and poor power supply to charge the phones/gadgets are also strong constraints to using mobile phones for agricultural activities in Nigeria [133]. In this regard, experience and awareness influence the use of mobile apps, as low awareness results in a minimal level of adoption of the application in North-West Nigeria [138]. Low levels of education also affect the adoption and appropriate application of technologies in Nigeria. For example, the application of modern digital technologies in nutrient management called Nutrient Expert (NE) revealed that only 21% of all the selected farmers applied the right technique and recommended procedure [47].

The role of extension services in agricultural information (selected African countries). Extension services could influence smallholders' production, thus impacting their market participation [14, 139]. Extension services help enhance knowledge, skill, information, and advice to unlock most smallholders' built talents and entrepreneurial behaviours, facilitating and promoting their products and ability to adopt new techniques [14]. Research shows that extension agents are usually identified as significant sources of information on new production techniques and market information for farmers [140]. In Madagascar, for instance, the smallholder farmers who received regular extension training and visits enhanced the market production level [139]. Extension services positively stimulated the number of potatoes traded by smallholder potato producers in Angola [141]. Similarly, [34] observed that the choice of smallholder farmers to participate in a village or town market, among other things, was determined by access to information from extension services in Kenya. Nigeria is no exception, as observations have been made that extension service providers played critical roles in the success of Fadama in Nigeria. However, the report shows that many urban farmers do not have access to extension services and credit facilities or belong to farmers' associations [143].

Level of other types of agricultural technologies usage in Nigeria. Many farmers in Nigeria depend on traditional conventional techniques in their farming, with only 1.1% and 0.3% of the farmers studied in South-West Nigeria assessing soil fertility using soil tests technology and digital applications, respectively [87]. A recent study in Nigeria shows that most farmers depend on the perception, appearance of the vegetation, and yield performance of the immediate past season as a soil fertility assessment. In another development, [144] reported that only 32% of the farmers access new crop varieties. In the investigation of drone utilisation among farmers in Nigeria, the result stated that at least 66% of all the farmers agreed that drones are poorly and less used [144]. Whereas previous research shows that there has been poor use of information technologies among farmers in Nigeria, some researchers have discovered that some farmers scantily utilise some information technology strategies in accessing market information in Africa [119, 145]. Some of the farmers have a positive attitude toward the use of mobile phone apps [133]. Therefore, as a means to improve the use of ICT and other modern apps, the government of Nigeria has planned a digital agriculture strategy (2020-2030). Hence, in June 2021, the government organised training on WeedManager and RiceAdvice, besides the E-Wallet app already developed [146].

Precision agriculture is a modern practice that requires the appropriate use of technology and farming systems. It involves proactive measures that stimulate exact inputs used based on information from data [147]. Precision agriculture is facilitated by Yield Monitor (YM), GIS, GPS, Remote sensing (RS), and Variable Rate technology (VRT). However, limited knowledge and poor use of GIS and GPS have affected the adoption of precision agriculture in Nigeria [148].

Effective and efficient use of technologies in Nigeria farm. Efficient application of technology is critical in the agricultural sector. For example, as the efficiency of irrigator users reduces, their revenue also reduces [107]. Due to the inability of the applied technology to produce the desired result, the cost of technology acquisition becomes higher than marginal labour productivity,

which is coming from the stimulant of inefficiency in labour [113]. Conversely, the gain in technology applications is lower than the cost of labour inputs due to inefficiency [113]. For instance, 3.5 tons/ha yield from irrigated rice farmers is a good outcome but falls below 6 tons/ha potential for the efficient irrigated farmer [115]. A study of the channels through which water was applied to some crops resulted in 41%, 87%, and 43% efficiency outcomes for the bucket channel, groundwater motor pump, and gravity flow channel, respectively [113]. Seemingly, despite irrigating their crop, some of the farmers who irrigated their crops using buckets were 59% inefficient. For example, 33% of vegetable production output variation came from technical inefficiency by irrigated urban vegetable farmers of Lagos State, Nigeria [143]. This situation is such that many farmers in Nigeria exhibit inefficiency in the use of many agricultural resources, including irrigation [149]. The study of different rice irrigation schemes across Nigeria shows that many schemes recorded declined yield in output [113]. Nigeria's assessment of irrigation potential reported unsatisfactory performance, which could be attributed to an array of factors, such as institutional, environmental, and inherent socio-economic factors [115]. On using power machine technology in Nigeria, reports that tractor-user smallholders were more efficient than non-tractor users, decreasing return to scale with an inefficiency of 22%.

Structure of technology use in Nigerian agriculture. From the reviewed literature, the researchers operationalised the pattern/structure of technology use in Nigeria's agricultural sector as presented in Figure 2.

A specific/related technology is categorised into a specific group based on literature and functions. For example, heavy power and operational machines are grouped into mechanisation technologies, the technologies that aid artificial water applications to the farms are referred to as irrigation technologies, and the technologies deployed for information gathering are grouped as agro-information and communication technologies.

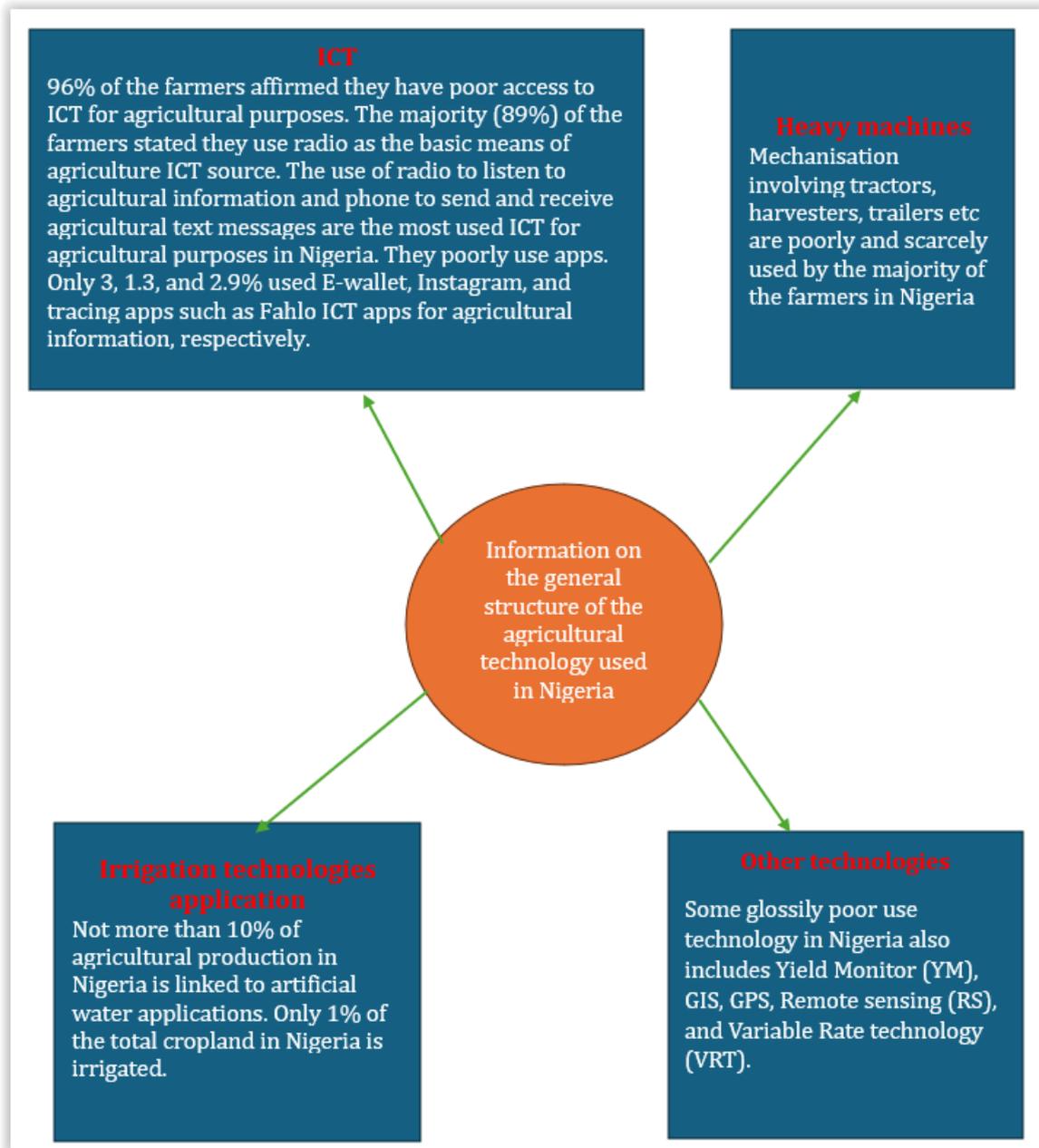


Figure 2 – Summary and level of technology usage in Nigeria

CONCLUSIONS

This review shows that Nigeria's agricultural sector is evolving in a progressive direction but at a slow pace of technology adoption. The review shows that agricultural technologies involve devices, systems, methods, techniques, and scientific knowledge that encompasses their application. It facilitates growth, efficiency, and general transformation in the agricultural sector, stimulating market participation, food security, and better income generation. Some fundamental challenges associated with technology use in developing countries such as Nigeria include a lack of technical know-how resulting in inefficiency, poor management, and a lack of access to mod-

ern technology caused by limited finance and availability. Fear of perceived risks such as hacking of the app, technical glitches, and likely failures associated with the system, as well as the cost of data and expensive nature of the machine (for example, computer, phone and drone), negatively affect its adoption and application of mobile apps by farmers. Poor levels of education, which result in high illiteracy, also affect the adoption of technologies in Nigeria. This research has shown that government policies and programmes, such as the Fadama programme, affected farmers' use of agricultural technologies in Nigeria. However, there has not been any report stating the positive impact of the government tractor service programme on the farmers; ra-

ther, evidence shows that the government hire tractor service competes with individual entrepreneurs who hire tractor service providers. It also shows that a holistic programme such as the Fadama programme could be followed to transform the agricultural sector in developing countries. Very few farmers have used modern technologies such as drones, Apps, Drip irrigation, GIS, GPS, and many sensing technologies in the agricultural sector. For example, only 3% of the farmers agreed to have used the E-wallet app created by the government as a medium for informing farmers about fertiliser availability, 1.3% used Instagram for agricultural information, and only 2.9% of the farmers used a tracing app to trace their animals. Ironically, many farmers in Nigeria still do not use modern technology. Poor funding affects the diffusion and adoption of technology in Nigeria; for example, almost all successful irrigation projects in Nigeria are either initiated or financially supported by external stakeholders such as the World Bank, FAO, or AfDB.

Moreover, budgetary allocation to agriculture has been low in Nigeria. Some farmers are showing determination to use modern technology. Hence, some pay for such services and make bookings ahead of time to use the technology service rendered by hire service providers.

For agricultural transformation to occur in developing countries, there is a need for a targeted, holistic approach that covers power machines, irrigation, information technologies, logistics, marketing, and financing. There is also a need to improve the farmers' socio-economic characteristics through training and retraining, as in the case of the Fadama project. Governments at all levels should make a conscious effort to improve the annual budgetary allocation and development framework for the sustained implementation of budgetary allocation in the agricultural sector.

Highlight of the study

- The agricultural sector in developing countries such as Nigeria has not effectively used farming technologies.
- The dwindling agricultural budget and allocation are problems that affect the agricultural sector, especially regarding technology use.
- More so, inconsistencies in government policies also affect the growth and application of technology in Nigeria.

- Lack of initiative and adequate financial support from within the country also affects the use of technology in Nigeria's agricultural sector.
- Poor investment, especially on the part of Nigeria's government, affects agriculture and its technological development, growth, and diffusion.
- Inadequately skilled personnel and weak institutions to support agriculture affect growth.
- Technologies and farm resources are still largely poorly managed in Nigeria.
- Small areas of cultivated farms result in lesser use of technology, and bigger areas of cultivated farms result in greater use of technology.
- Nigeria has rich arable agricultural land.
- Many farmers are not efficient in using technology.
- There is limited/inadequate information on modern technologies, such as drones and GPS, in Nigeria's agricultural sector. This indicates poor use of those technologies.
- The farmers in Nigeria mainly depend on rain-fed agricultural outputs.

Conflict of interest

The author declares that no funders, enumerators, or anything else influenced this research's outcome, investigation, design, interpretation, or publication. Hence, the authors affirm no conflict of interest.

Acknowledgement

Special thanks and appreciation go to Professor Amon Taruvinga and Professor Willie Tafadzwa Chinyamurindi (the promoters of the corresponding author) for their guidance and support. Special thanks also go to all the emulators who joined the researcher in the data collection.

Data availability

This research review duly references and acknowledges all resources.

Funding

This research received financial assistance from Govan Mbeki Research & Development Centre (GMRDC).

REFERENCES

1. Wang, Z., Zhao, W., Fu, J., Xie, H., Zhang, Y., & Chen, M. (2023). V-shaped toothed Roller Cotton stalk puller: Numerical modelling and Field-Test validation. *Agriculture*, 13(6), 1157. doi: [10.3390/agriculture13061157](https://doi.org/10.3390/agriculture13061157)
2. Tripp, R. (2004). *Technology and its Contribution to Pro-Poor Agricultural Development*. London: Department for International Development (DFID) and Overseas Development Institute (ODI)
3. Prazeres, A. R., Albuquerque, A., Luz, S., Jerónimo, E., & Carvalho, F. (2017). Hydroponic system: a promising biotechnology for food production and wastewater treatment. In *Elsevier eBooks* (pp. 317–350). doi: [10.1016/b978-0-12-811372-1.00011-7](https://doi.org/10.1016/b978-0-12-811372-1.00011-7)
4. Xiong, H., Dalhaus, T., Wang, P., & Huang, J. (2020). Blockchain Technology for Agriculture: Applications and Rationale. *Frontiers in blockchain*, 3. doi: [10.3389/fbloc.2020.00007](https://doi.org/10.3389/fbloc.2020.00007)
5. Waris, A., Khamidi, M. F., & Idrus, A. (2013). *Heavy Equipment Acquisition in Malaysian Construction Industry. Conference: IEEE Symposium on Business, Engineering and Industrial Applications*.
6. Irmak, S., Mohammed, A. T., & Kukal, M. S. (2022). Maise response to coupled irrigation and nitrogen fertilisation under centre pivot, subsurface drip and surface (furrow) irrigation: Growth, development and productivity. *Agricultural Water Management*, 263, 107457. doi: [10.1016/j.agwat.2022.107457](https://doi.org/10.1016/j.agwat.2022.107457)
7. Saud, D. (2022). *Best Agriculture Apps for Farmers 2023*. Retrieved from <https://agrierp.com/blog/apps-for-farmers/>
8. Self, S., & Grabowski, R. (2007). Economic development and the role of agricultural technology. *Agricultural Economics*, 36(3), 395–404. doi: [10.1111/j.1574-0862.2007.00215.x](https://doi.org/10.1111/j.1574-0862.2007.00215.x)
9. Banu, S. (2015). Precision Agriculture: Tomorrow's Technology for Today's Farmer. *Journal of Food Processing & Technology*, 06(08). doi: [10.4172/2157-7110.1000468](https://doi.org/10.4172/2157-7110.1000468)
10. Helwatkar, A., Riordan, D., & Walsh, J. (2014). Sensor technology for animal health monitoring. *International Journal on Smart Sensing and Intelligent Systems*, 7(5), 1–6. doi: [10.21307/ijssis-2019-057](https://doi.org/10.21307/ijssis-2019-057)
11. Rehman, A., Jingdong, L., Khatoon, R., & Hussain, I. (2016). *Modern Agricultural Technology Adoption Its Importance, Role and Usage for the Improvement of Agriculture*. *American-Eurasian Journal of Agriculture & Environment Science*, 16(2), 284–288.
12. Prem, M., Swarnkar, R., Kantilal, V., Jeetsinh, P., & Chitharbai, K. (2016). Combined Tillage Tools– A review. *Current Agriculture Research Journal*, 4(2), 179–185. doi: [10.12944/carj.4.2.07](https://doi.org/10.12944/carj.4.2.07)
13. Yegül, U., Eminoğlu, M. B., Orel, O., & Çolak, A. (2014). *Determination of Equivalent Stress and Total Deformation in Different Types Of Harrows*. *Tarım Makinaları Bilimi Dergisi*, 10(1), 65-71.
14. Iheke, O. R., & Nwaru, J. C. (2013). Innovation adoption, farm productivity and poverty status of rural smallholder farm households in South-East, Nigeria. *2013 Fourth International Conference, September 22-25, 2013, Hammamet, Tunisia*. doi: [10.22004/ag.econ.161627](https://doi.org/10.22004/ag.econ.161627)
15. Onomu, A. R. (2023). Smallholder's Market Participation, Characteristics, Tractor Use Implication and Determinants in Nigeria. *Journal of Developing Areas*, 57(4), 1–27. doi: [10.1353/jda.2023.a908644](https://doi.org/10.1353/jda.2023.a908644)
16. Dileep, M. R., Navaneeth, A. V., Ullagaddi, S., & Danti, A. (2020). *A Study and Analysis of Various Types of Agricultural Drones and its Applications*. *Conference: Fifth International Conference on Research in Computational Intelligence and Communication Networks (ICRCICN)*.
17. Javaid, M., Haleem, A., Khan, I. H., & Suman, R. (2022). Understanding the potential applications of Artificial Intelligence in the Agriculture Sector. *Advanced Agrochem*, 2(1), 15–30. doi: [10.1016/j.aac.2022.10.001](https://doi.org/10.1016/j.aac.2022.10.001)

18. Alobid, M., Abujudeh, S., & Szűcs, I. (2022). The Role of Blockchain in Revolutionising the Agricultural Sector. *Sustainability*, 14(7), 4313. doi: 10.3390/su14074313
19. Sheikh, B. A. (2006). Hydroponics: Key To Sustain Agriculture In Water Stressed And Urban Environment. Retrieved from <https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=5109e0d8e536202a64d4cb0da563e65f083c732>
20. Mahmud, M. S. A., Abidin, M. S. Z., Emmanuel, A. A., & Hasan, S. (2020). Robotics and Automation in Agriculture: Present and Future Applications. *Modelling and Simulation*, 4(1), 130–140.
21. Rockefeller Foundation. (2008). *Promoting Fertiliser Use in Africa: Current Issues and Empirical Evidence from Malawi, Zambia, and Kenya*. Retrieved from https://www.researchgate.net/publication/46471892_Promoting_Fertilizer_Use_in_Africa_Current_Issues_and_Empirical_Evidence_from_Malawi_Zambia_and_Kenya
22. Benke, K., & Tomkins, B. (2017). Future food-production systems: vertical farming and controlled-environment agriculture. *Sustainability Science Practice and Policy*, 13(1), 13–26. doi: 10.1080/15487733.2017.1394054
23. Kyrylov, Y., Hranovska, V., Zhosan, H., & Dotsenko, I. (2022). Innovative development of agricultural enterprises of Ukraine in the context of the Fourth Industrial Revolution. *AIP Conference Proceedings*, 2413, 040014. doi: 10.1063/5.0079277
24. Coelli, T. J., & Rao, D. S. P. (2005). Total factor productivity growth in agriculture: a Malmquist index analysis of 93 countries, 1980–2000. *Agricultural Economics*, 32(s1), 115–134. doi: 10.1111/j.0169-5150.2004.00018.x
25. Barrett, C. B. (2008). Smallholder market participation: Concepts and evidence from eastern and southern Africa. *Food Policy*, 33(4), 299–317. doi: 10.1016/j.foodpol.2007.10.005
26. Okoye, B., & Adamade, C. (2016). *Agriculture in Nigeria: Country Report for FAO-Nigeria*. Federal Ministry of Agriculture and Rural Development.
27. Mrema, G. C., Baker, D., & Kahan, D. (2008). *Agricultural mechanisation in sub-Saharan Africa: time for a new look*. Rome: Food and Agriculture Organization of United Nations.
28. Rowland, F. (2004). Hiring machinery rather than ownership. In *Agric-Thriving Transit* (pp. 134–138).
29. Adeniran, P. A. (2023). *Demographic Statistics Bulletin 2022*. Retrieved from https://www.nigerianstat.gov.ng/pdfuploads/DEMOGRAPHIC_BULLETIN_2022_FINAL.pdf
30. Babamaaji, R., & Ekwe, D. O. (2009). *Country Profile Of Nigeria On Agriculture Development And Crop Monitoring For Food Security*. Strategic Space Applications Department National Space Research and Development Agency (NASRDA).
31. Onah, E. I. (2020). Nigeria: A country profile. *Journal International Studies*, 10. doi: 10.32890/jis.10.2014.7954
32. FAO (2021). *Nigeria at a Glance. FAO in Nigeria – Food and Agriculture Organization of the United Nations*. Retrieved from <https://www.fao.org/nigeria/fao-in-nigeria/nigeria-at-a-glance/en/>
33. Juwonlo, M. (2023). *Nigerian farmers have displayed commendable resilience and flexibility due to ever-shifting climate dynamics*. Nigeria News Brief and Action Alert. Retrieved from <https://www.climatescorecard.org/2023/09/nigerian-farmers-have-displayed-commendable-resilience-and-flexibility-due-to-ever-shifting-climate-dynamics/>
34. FAOLEX. (2016). *National water resources policy*. Retrieved from <https://www.fao.org/faolex/results/details/en/c/LEX-FAOC180225/>
35. Babatunde, R. (2008). Income portfolios in Rural Nigeria: Composition and determinants. *Trends in Agricultural Economics*, 1(1), 35–41. doi: 10.3923/tae.2008.35.41

36. Dedehouanou, S. F. A., & McPeak, J. (2019). Diversify more or less? Household Income generation Strategies and food security in rural Nigeria. *The Journal of Development Studies*, 56(3), 560–577. doi: 10.1080/00220388.2019.1585814
37. Sertoğlu, K., Ugural, S., & Bekun, F. V. (2017). The Contribution of Agricultural Sector to Economic Growth in Nigeria. *International Journal of Economics and Financial Issues*, 7(1), 547-552.
38. Okwudili, I. V., Muhammad, Y. M. A. H. Gorondutse, A. H., & Rahmon, T. A. (2020). Implications of Agricultural Processed Value Chain Products to Job Creation in Nigeria. *European Academic Research*, 7(12), 6031–6052.
39. Boeckmann, C. (2024, April 17). How to Collect and Clean Chicken Eggs. Plus, How to Store Fresh Eggs from Backyard Chickens. Retrieved from <https://www.almanac.com/raising-chickens-101-collecting-storing-and-hatching-chicken-eggs>
40. Otekunrin, O. A., & Sawicka, B. (2019). Cassava, a 21st Century Staple Crop: How can Nigeria Harness Its Enormous Trade Potentials? *Acta Scientific Agriculture*, 3(8), 194–202. doi: 10.31080/asag.2019.03.0586
41. Hesan, B. (2017). *Agricultural Sector Food Security and Nutrition Strategy 2016 – 2025. Federal Ministry of Agriculture and Rural Development*. Retrieved from https://ngfrepository.org.ng:8443/jspui/bitstream/123456789/5377/1/Agriculture-FSN-Strategy-2016-25_Printed-Version_1562696265%20%281%29.pdf
42. Vanguard (2024). *Only 21% of Nigerian households are food secure – Report*. Retrieved from <https://www.vanguardngr.com/2024/05/only-21-of-nigerian-households-are-food-secure-report-2/>
43. Purokayo, S. G., & Umaru, A. (2012). Global Food Crisis: Public Capital Expenditure and Agricultural Output in Nigeria. *Journal of Food Research*, 1(1). doi: 10.5539/jfr.v1n1p286
44. Ogbonna, I. C. (2013). Oil exploitation and agricultural commodity export in Nigeria: An empirical evaluation of the extent and impact of the Dutch disease. *IOSR Journal of Humanities and Social Science*, 14(1).
45. Chiaka, J. C., Zhen, L., Yunfeng, H., Xiao, Y., Muhirwa, F., & Lang, T. (2022). Smallholder farmer's contribution to food production in Nigeria. *Frontiers in Nutrition*, 9. doi: 10.3389/fnut.2022.916678
46. Onomu, A. R., & Aliber, M. (2021). Factors influencing smallholder farmers mechanisation decisions in Nigeria: the case of tractor use in the Fourth Industrial Revolution ERA. *Asian Journal of Agriculture and Rural Development*, 11(2), 199–209. doi: 10.18488/journal.ajard.2021.112.199.209
47. Aliyu, K. T., Shehu, B. M., & Adam, A. M. (2024). Digital Technology In Maise Nutrient Management Research In Northern Nigeria Amid COVID-19 Pandemic. *Scientific Reports*, 14(1). doi: 10.1038/s41598-024-58740-1
48. Berdegué, J. A., & Fuentealba, R. (2014). The state of smallholders in agriculture in Latin America. In *Oxford University Press eBooks* (pp. 115–152). doi: 10.1093/acprof:oso/9780199689347.003.0005
49. Cleave, J. H. (1974). *African farmers: labour use in the development of smallholder agriculture*. New York: Praeger
50. Sims, B., & Kienzle, J. (2016). Making mechanisation accessible to smallholder farmers in Sub-Saharan Africa. *Environments*, 3(2), 11. doi: 10.3390/environments3020011
51. International Finance Corporation. (2023). *Working with Smallholders: A Handbook for Firms Building Sustainable Supply Chains (3rd ed.)*. Washington DC: World Bank.

52. Lowder, S. K., Scoet, J., & Raney, T. (2016). The number, size, and distribution of farms, smallholder farms, and family farms worldwide. *World Development*, 87, 16–29. doi: [10.1016/j.worlddev.2015.10.041](https://doi.org/10.1016/j.worlddev.2015.10.041)
53. Machethe, C. L. (2004). *Agriculture and poverty in South Africa: Can agriculture reduce poverty? Paper presented at the Overcoming Underdevelopment Conference held in Pretoria*, 28-29.
54. Paloma, S. G. Y., Riesgo, L., & Louhichi, K. E. (2020). The role of smallholder farms in food and nutrition security. In *Springer eBooks*. doi: [10.1007/978-3-030-42148-9](https://doi.org/10.1007/978-3-030-42148-9)
55. Waswa, F., Shitanda, D., & Mukolwe, M. (2022). *Farm Energy, Power and Machinery for Non-Engineers: A Reader for University and College Students in Kenya*. KurArts Designs and Digital Printers Limited.
56. Gunn, T. G. (1982). The Mechanization of Design and Manufacturing. *Scientific American*, 247(3), 114-131.
57. Onomu, R. (2022). *Assessment of Tractor Use Efficiency among Smallholder Farmers in Nigeria*. *Journal of Human Ecology*, 77(2), 23-35.
58. Yisa, M. (1997). *Agricultural Mechanisation in Nigeria: How Far and What's Next. Conference: Quarterly Lectures of the Nigerian Society of Engineers, Minna Branch A*
59. Fogg, C. D. (1965). Economic and Social Factors Affecting the Development of Smallholder Agriculture in Eastern Nigeria. *Economic Development and Cultural Change*, 13(3), 278-292.
60. Shimada, S. (1999). *A Study Of Increased Food Production In Nigeria: The Effect Of The Structural Adjustment Program On The Local Level*. *African Study Monographs*, 20(4), 175-227.
61. Shaibu, U. M. (2023). Agricultural Sector Policy Periods and Growth Pattern in Nigeria (1960–2020): Implications on agricultural performance. In *IntechOpen eBooks*. doi: [10.5772/intechopen.111382](https://doi.org/10.5772/intechopen.111382)
62. Daum, T., & Birner, R. (2020). Agricultural mechanisation in Africa: Myths, realities and an emerging research agenda. *Global Food Security*, 26, 100393. doi: [10.1016/j.gfs.2020.100393](https://doi.org/10.1016/j.gfs.2020.100393)
63. Comin, D., Dmitriev, M., & Rossi-Hansberg, E. (2012). The Spatial Diffusion of Technology. *National Bureau of Economic Research*, 18534. doi: [10.3386/w18534](https://doi.org/10.3386/w18534)
64. Takeshima, H., Nin-Pratt, A., & Diao, X. (2013). Mechanisation and Agricultural Technology evolution, Agricultural Intensification in Sub-Saharan Africa: Typology of Agricultural Mechanization in Nigeria. *American Journal of Agricultural Economics*, 95(5), 1230–1236. doi: [10.1093/ajae/aat045](https://doi.org/10.1093/ajae/aat045)
65. Mwangi, M., & Kariuki, S. (2015). *Factors Determining Adoption of New Agricultural Technology by Smallholder Farmers in Developing Countries*. *Journal of Economics and Sustainable Development*, 6(5).
66. Faborode, M. O. (2001). Strategies for sustainable National Agricultural Infrastructures Development. *Proceedings of the National Engineering Conference*, PotHarcourt, Rivers State, (pp. 126-131).
67. Sahel. (2017). *Nigeria's Mechanisation Landscape*. *Sahel Capital Partners & Advisory Limited Sahel Capital Agribusiness Managers Limited*, 17.
68. Ebewore S.O. (2016). *Adoption level of Farm Machines by Crop Farmers in Delta State, Nigeria*. *Journal of Agriculture and Veterinary Sciences*, 3(1), 66-71.
69. Yinusa, B., & Bangboye, A. I. (2015). *Investigation of Crop Production Mechanization in Akinyele Local Government Area of Oyo State*. *Agric Eng Int: CIGR Journal*, 17(3), 117-119.
70. Ajah, J. (2014). Factors limiting Small-Scale farmers' access and use of tractors for agricultural mechanisation in Abuja, North Central Zone, Nigeria. *European Journal of Sustainable Development*, 3(1), 115–124. doi: [10.14207/ejsd.2014.v3n1p115](https://doi.org/10.14207/ejsd.2014.v3n1p115)

71. Achora, J. C. (2015). Are two-wheeled tractors the trigger for smallholder farm mechanisation? Retrieved from <https://aifsc.aciar.gov.au/news/are-two-wheeled-tractors-trigger-smallholder-farm-mechanization.html>
72. Singha, K., Jaman, S., & Aditya Chavali, A. (2012). Tractorisation and Agricultural Development in India. *Journal of Global Economy*, 8(4)
73. Sims, B., & Kienzle, J. (2017). Sustainable agricultural mechanisation for smallholders: What is it and how can we implement it? *Agriculture*, 7(6), 50. doi: 10.3390/agriculture7060050
74. Emami, M., Almassi, M., Bakhoda, H., & Kalantari, I. (2018). Agricultural mechanisation, a key to food security in developing countries: strategy formulating for Iran. *Agriculture & Food Security*, 7(1). doi: 10.1186/s40066-018-0176-2
75. Verma, S. R. (2006). *Impact of Agricultural Mechanization on Production, Productivity, Cropping Intensity Income Generation and Employment of Labour: Status of Farm Mechanization in India*. Ludhiana: Punjab Agricultural University, 133-153.
76. Alam, A. (2002). Mechanisation in Agriculture and On-farm Agro-processing. *Journal Of The Indian Society Of Agricultural Statistics*, 55(1), 17-31.
77. Daum, T., & Birner, R. (2020). Agricultural mechanisation in Africa: Myths, realities and an emerging research agenda. *Global Food Security*, 26, 100393. doi: 10.1016/j.gfs.2020.100393
78. FAO. (N. d.). Sustainable Agricultural Mechanization. Retrieved from <https://www.fao.org/sustainable-agricultural-mechanization/strategies/mechanization-strategies/en/>
79. Khan, N., Shahzad, Idrees, M., Shah, M., Ali, A., & Muhammad, N. (2009). The tractor impact in the rural area of District Peshawar. *Sarhad Journal of Agriculture*, 25(3), 509-515.
80. Haque, M. E., Bell, R. V., Islam, A. K. M. S., Sayre, K., & Hossain, M. M. (2011). Versatile multi-crop planter for two-wheel tractors: an innovative option for smallholders. *World Congress on Conservation Agriculture*.
81. Pingali, P., Bigot, Y., & Binswanger, H. P. (1987). *Agricultural Mechanisation and the Evolution of Farming Systems in Sub-Saharan Africa*. Baltimore and London: The Johns Hopkins University Press.
82. Ruttan, V. W. (2002). Productivity Growth in World Agriculture: Sources and Constraints. *Journal of Economic Perspectives*, 16(4), 161-184.
83. Onomu, A. R. (2020). Smallholders' willingness to pay for mechanisation (Tractor services) in Delta and Benue states, Nigeria. *Journal of Human Ecology*, 72(1-3). doi: 10.31901/24566608.2020/72.1-3.3293
84. Diao, X., Cossar, F., Houssou, N., & Kolavalli, S. (2014). Mechanisation in Ghana: Emerging demand, and the search for alternative supply models. *Food Policy*, 48, 168-181. doi: 10.1016/j.foodpol.2014.05.013
85. Onomu, A. R., Aliber, M., & Agbugba, I. K. (2020). Tractor services challenges and current demand trends by smallholder farmers in Nigeria. *Journal of Agribusiness and Rural Development*, 58(4), 379-391. doi: 10.17306/j.jard.2020.01288
86. Akinbode, S. O., Folorunso, O., Olutoberu, T. S., Olowokere, F. A., Adebayo, M., Azeez, S. O., Hamed, S. G., & Busari, M. A. (2013). *Farmers' Perception and Practice of Soil Fertility Management and Conservation in the Digital Soil Information System Era in South-west Nigeria*. Retrieved from <https://www.preprints.org/manuscript/202312.0400/v1>
87. Ezeaku, C., Ani, A., Adama, J., Job, V., Sule, S., Onwualu, A., Nwankwojike, B., Otoijamun, I., & Ogbobe, P. (2024). Willingness to adopt precision agriculture: An analysis of Gombe and Bauchi States of Nigeria. *Nigerian Journal of Technology*, 43(1), 198-206. doi: 10.4314/njt.v43i1.21

88. Herdt, R. W. (2009). Chapter 63 Development Aid and Agriculture. In *Handbook of agricultural economics* (pp. 3253–3304). doi: [10.1016/s1574-0072\(09\)04063-8](https://doi.org/10.1016/s1574-0072(09)04063-8)
89. Dauda, S. M., Gbabo, A., & Shotunde, M. A. (2010). Agricultural Tractor Ownership and Off-season Utilization in Ogun State, South Western Nigeria. *World Journal of Agricultural Sciences*, 6(1), 83-89
90. Mgbenka, R. N., Mbah, E. N., & Ezeano, C. I. (2015). A Review of Smallholder Farming in Nigeria: Need for Transformation. *Agricultural Engineering Research Journal*, 5(2), 19-26
91. Abubakar, M. S., & Ahmad, D. (2010). Utilisation of and Constraints on Animal Traction in Jigawa State, Nigeria. *Australian Journal of Basic and Applied Sciences*, 4(6), 1152-1156,
92. Iosr, J., Ayandiji, A., & OT, O. (2015). Socio-Economic Factors Affecting Adoption of Farm Mechanization by Cassava Farmers in OndoState, Nigeria [Dataset]. In *Figshare*. doi: [10.6084/m9.figshare.1347403.v1](https://doi.org/10.6084/m9.figshare.1347403.v1)
93. Oleson, J. P. (2000). Irrigation. In Ö. Wikander, *Handbook of ancient water technology* (pp. 183–215). Leiden –Boston – Koln: Brill.
94. Darghouth, M. S., Dinar, A., Naugle, J. A., & Sellen, D. (2010). *Investing in smallholder irrigation*. Washington: World Bank Group.
95. Hagosa, F., Makombe, G., Namara, R., & Awulachew, S. (2011). Importance of Irrigated Agriculture to the Ethiopian Economy: Capturing the direct net benefits of irrigation. *Ethiopian Journal of Development Research*, 32(1). doi: [10.4314/ejdr.v32i1.68597](https://doi.org/10.4314/ejdr.v32i1.68597)
96. FAO. (2016). *AQUASTAT Country Profile – Nigeria*. Retrieved from <https://openknowledge.fao.org/server/api/core/bitstreams/0a4ad920-8167-4cbd-b34f-c3211c8d5bfe/content>
97. Federal Ministry of Water Resources. (1991). *Situation Report on Nigeria*. Retrieved from <https://www.ircwash.org/sites/default/files/824-NG91-9753.pdf>
98. Takeshima, H. (2016). Understanding Irrigation System Diversity in Nigeria: A Modified Cluster Analysis Approach. *Irrigation and Drainage*, 65(5), 601–612. doi: [10.1002/ird.1973](https://doi.org/10.1002/ird.1973)
99. Adams, W. (1985). River basin planning in Nigeria. *Applied Geography*, 5(4), 297–308. doi: [10.1016/0143-6228\(85\)90009-8](https://doi.org/10.1016/0143-6228(85)90009-8)
100. Olayide, S. O., Eweka, J. A., & Bello-Osagie, V. E. (1980). Nigerian Small Farmers: Problems and Prospects in Integrated Rural Development. University of Ibadan. Centre for Agricultural and Rural Development, Benin-Owena River Basin Development Authority
101. E.A. Aiyedun, E. A. (1991). Irrigated Agriculture In Nigeria: Problems And Prospects. *African Journal Of Agricultural Sciences*, 18(1).
102. Hima, H., Santibanez, C., Roshan, S., & Lomme, R. (2016). The Nigeria Fadama National Development Series. In *World Bank, Washington, DC eBooks*. doi: [10.1596/24413](https://doi.org/10.1596/24413)
103. Jenane, C., & Oredipe, A. A. (2022). *Delivering development: collaboration the key to success in Nigeria's FADAMA projects*. Retrieved from <https://blogs.worldbank.org/en/nasililiza/delivering-development-collaboration-key-success-nigerias-fadama-projects>
104. African Development Bank. (2013, June 30). *Nigeria - Fadama Development Project*. Retrieved from <https://projectsportal.afdb.org/dataportal/VProject/show/P-NG-A00-005>
105. Precious, M. (2023). *FG to invest in irrigation systems to boost food production*. Retrieved from <https://businessday.ng/agriculture/article/fg-to-invest-in-irrigation-system-to-boost-food-production/>

106. Xie, H., You, L., & Takeshima, H. (2017). Invest in small-scale irrigated agriculture: A national assessment on the potential to expand small-scale irrigation in Nigeria. *Agricultural Water Management*, 193, 251–264. doi: [10.1016/j.agwat.2017.08.020](https://doi.org/10.1016/j.agwat.2017.08.020)
107. You, L., Takeshima, H., & Xie, H. (2018). *Cultivating growth in Nigerian agriculture with small-scale irrigation*. IFPRI Blog: Issue Post Development Strategy and Governance (DSGD). Retrieved from <https://www.ifpri.org/blog/cultivating-growth-nigerian-agriculture-small-scale-irrigation/>
108. Nnodim, O. (2022). *There's only 5.4% irrigated farmland in Nigeria – FG*. Retrieved from <https://punchng.com/theres-only-5-4-irrigated-farmland-in-nigeria-fg/>
109. FAO. (2021). *FAO and Federal Ministry of Water Resources to promote drip irrigation in Nigeria*. Food and Agriculture Organization of the United Nations (FAO). Retrieved from <https://www.fao.org/nigeria/news/detail-events/en/c/1414506>
110. Pérez-Blanco, C. D., Hrast-Essenfelder, A., & Perry, C. (2020). Irrigation Technology and Water Conservation: A Review of the Theory and Evidence. *Review of Environmental Economics and Policy*, 14(2), 216–239. doi: [10.1093/reep/reaa004](https://doi.org/10.1093/reep/reaa004)
111. Kulkarni, S. (2011). *Innovative Technologies for Water Saving in Irrigated Agriculture*. *International Journal of Water Resources and Arid Environments*, 1(3), 226-231.
112. Ezekiel, N. A. A. (2016). Economic analysis of maize production among irrigation farmers in Orire Local Government Area, Oyo State, Nigeria. *Sociology Study*, 6(3). doi: [10.17265/2159-5526/2016.03.004](https://doi.org/10.17265/2159-5526/2016.03.004)
113. Ukpai, S. N. (2022). Water policy reform in the Nigeria water governance system: assessment of water resources management based on OECD Principles on Water Governance. *Water Policy*, 24(10), 1704–1722. doi: [10.2166/wp.2022.135](https://doi.org/10.2166/wp.2022.135)
114. Kebbeh, M., Haefele, S., & Fagade, S. O. (2003). *Challenges and Opportunities for Improving Irrigated Rice Productivity in Nigeria*. Abidjan: West Africa Rice Development Association (WARDA).
115. Tijani, M., Obayelu, A., Sobowale, A., & Olatunji, A. (2014). Welfare analysis of smallholder farmers by irrigation systems and factors affecting their production outputs in Nigeria. *Sustainability of Water Quality and Ecology*, 3–4, 90–100. doi: [10.1016/j.swaqe.2014.12.002](https://doi.org/10.1016/j.swaqe.2014.12.002)
116. Baourakis, G., Kourgiantakis, M., & Migdalas, A. (2002). The impact of e-commerce on agro-food marketing. *British Food Journal*, 104(8), 580–590. doi: [10.1108/00070700210425976](https://doi.org/10.1108/00070700210425976)
117. Shepherd, A. (2001). *Market Information Services*. In D. Giovannucci, *A Guide To Developing Agricultural Markets And Agro-Enterprises*. World Bank.
118. Byron, Z., Nelson, M., Kefasi, N., & Shephard, S. (2014). Determinants of soybean market participation by smallholder farmers in Zimbabwe. *Journal of Development and Agricultural Economics*, 6(2), 49–58. doi: [10.5897/jdae2013.0446](https://doi.org/10.5897/jdae2013.0446)
119. WTO. (2009). *Global Problems, Global Solutions: Towards Better Global Governance*. Geneva: World Trade Organization Public. Retrieved from https://www.wto.org/english/forums_e/public_forum09_e/public_forum09_e.htm
120. McNamara, K., Belden, C., Kelly, T., Pehu, E., & Donovan, K. (2017). Introduction: ICT in Agricultural development. In *The World Bank eBooks* (pp. 1–14). doi: [10.1596/978-1-4648-1002-2_module1](https://doi.org/10.1596/978-1-4648-1002-2_module1)
121. Oluwatusin, F. M., & Ojo, O. S. (2017). *ICT-Based Market Information Services Utilisation by Small scale Farmers in South-west Nigeria*. *Report and Opinion*, 9(2).
122. Okello, J. J., & Ndirangu, L. K. (2010). Does the environment in which ICT-based market information services (MIS) projects operate affect their performance? Experiences from Kenya. *Cape Town: African Association of Agricultural Economists Third Conference/AEASA 48th Conference*.
123. Beebwa, I. E., Marwa, J., Chacha, M., & Ally Dida, M. (2019). Stakeholders' Attitude on the Use of ICT Tools for Sustainable Propagation of Indigenous Knowledge in Tanzania: A Case of Traditional

- Medical Knowledge of Medicinal Plants. *International Journal of Information Technology and Computer Science*, 11(11), 34–43. doi: [10.5815/ijitcs.2019.11.04](https://doi.org/10.5815/ijitcs.2019.11.04)
124. Jairath, M. S., & Yadav, H. (2012). Role of ICT in Decision-Making in Agricultural Marketing – A Case of Arid India. *Indian Society of Agricultural Economics*, 67(3), 1-9.
125. McNamara, K. (2009). *Improving Agricultural Productivity and Markets: The Role of Information and Communication Technologies*. Washington: World Bank, Agricultural and Rural Development note.
126. Anyoha, N., & Orusha, J. (2017). Effects Of The Use Of Information And Communication Technologies (Icts) On Farmers' Agricultural Practices And Welfare In the Orlu Agricultural Zone Of Imo State, Nigeria. *International Journal of Research in Agriculture and Forestry*, 4(3). doi: [10.22259/ijraf.0403002](https://doi.org/10.22259/ijraf.0403002)
127. Muhammad, H. U., Adesiji, G. B., Tyabo, I. S., Muhammed, Y., & Loko, A. I. (2019). Assessment of factors influencing the use of information and communication technologies by small-scale farmers in Federal Capital Territory (FCT), Abuja, Nigeria. *Journal of Agriculture and Environment*, 15(2).
128. Sennuga, S., Olayemi, F., Taiye, O., & Thaddeus, H. (2020). Factors Influencing Adoption of Improved Agricultural Technologies (IATs) among Smallholder Farmers in Kaduna State, Nigeria. *International Journal of Agricultural Education and Extension*, 6(2), 382-391.
129. Farayola, C. O., Gbadamosi, F. Y., Alalade, O. A., & Baba-Yusuf, K. (2020). Analysis of the Usage of Information Communication Technologies (ICT) in Accessing Agricultural Information by Smallholder Farmers in Kwara State, Nigeria. *American Journal of Sciences and Engineering Research*, 3(2)
130. Williams, E. E., & Agbo, I. S. (2013). Evaluation of the Use of ICT in Agricultural Technology Delivery to Farmers in Ebonyi State, Nigeria. *Journal of Information Engineering and Application*, 3(10).
131. Uduji, J. I., & Chijionwu, R. O. (2011). Information Technology And The Future Of Agricultural Marketing In Nigeria. *The Nigerian Journal of Research and Production*, 19(2).
132. Abdullahi, K., Oladele, O., & Akinyemi, M. (2021). Attitude, knowledge and constraints associated with using mobile phone applications by farmers in North West Nigeria. *Journal of Agriculture and Food Research*, 6, 100212. doi: [10.1016/j.jafr.2021.100212](https://doi.org/10.1016/j.jafr.2021.100212)
133. Godson-Ibeji, C. C. G. C. C., Chikaire, J. U. C. J. U., & Aminu, G. O. A. G. O. (2022). Rural livestock farmers' perception of the role of information and communication technology tools in livestock production, management, and improvement in Imo State, Nigeria. *South Asian Research Journal of Agriculture and Fisheries*, 4(1), 1–6. doi: [10.36346/sarjaf.2022.v04i01.001](https://doi.org/10.36346/sarjaf.2022.v04i01.001)
134. UNESCO. (2023, June 12). *UNESCO to report on free and independent Indigenous media*. Retrieved from <https://www.unesco.org/en/articles/unesco-report-free-and-independent-indigenous-media>
135. Tschumi, P., & Hagan, H. (2008). *Perspectives on the Making Markets Work for the Poor (M4P) Approach*. UK Department for International Development (DFID) and the Swiss Agency for Development and Cooperation (SDC).
136. Victor, O., Nic, J. L., & Xiaomeng, L. (2021). Factors affecting the adoption of mobile applications by farmers: An empirical investigation. *African Journal of Agricultural Research*, 17(1), 19–29. doi: [10.5897/ajar2020.14909](https://doi.org/10.5897/ajar2020.14909)
137. Abdullahi, K. A., Oladele, O. I., & Yusuf, O. J. (2019). Use of mobile phone applications by farmers in north-west Nigeria. *Journal of Agricultural Extension*, 23(3), 182. doi: [10.4314/jae.v23i3.16](https://doi.org/10.4314/jae.v23i3.16)
138. Ton, G., & Proctor, F. (2013). *Empowering smallholder farmers in markets. Experiences with farmer-led research for advocacy*. Wageningen: LEI.

139. Machethe, C. L., Mollel, N. M., Ayisi, K., Mashatola, M. B., Anim, F. D. K. & Vanasche, F. (2004). *Smallholder Irrigation and Agricultural Development in the Olifants River Basin of Limpopo Province: Management Transfer, Productivity, Profitability and Food Security Issues*. University of the North, School of Agriculture and Environmental Sciences.
140. World Bank. (2016). *Implementation Completion And Results Report (COFN-C1270, IDA-45020 TF-57303 TF-57845)*. Retrieved from <https://documents1.worldbank.org/curated/pt/762221475519467246/ICR-clean-09282016.docx>
141. Geoffrey, S. K., Hillary, B. K., Lawrence, K. K., & Mary, M. C. (2014). Determinants of Market Participation among Small-Scale Pineapple Farmers in Kericho County, Kenya. *Journal of Economics and Sustainable Development*, 4(19), 59–66. doi: 10.22004/ag.econ.243452
142. Obayelu, O. A., Obayelu, A. E., & Usman, Z. A. (2015). Irrigation technology and technical and Resource-Use efficiencies in smallholder urban vegetable farming. *International Journal of Vegetable Science*, 22(1), 91–100. doi: 10.1080/19315260.2014.960548
143. Piate, R. C., Udongwo, G. E., & Etim, G. J. (2022). A Critical Assessment of Drone Technology: Its Prospects and Roles in Sustainable Agriculture and National Food Security in Nigeria. *World Atlas International Journal Of Education & Management*, 5(1).
144. Cousins, B. (2012). Smallholder Irrigation Schemes, Agrarian Reform and 'Accumulation from Above and from Below' in South Africa. *Journal of Agrarian Change*, 13(1), 116–139. doi: 10.1111/joac.12000
145. Resilient Food Systems (2021). New apps are proving invaluable tools for Nigerian farmers. Retrieved from <https://www.resilientfoodsystems.co/news/a-new-app-is-proving-an-invaluable-tool-for-nigerian-farmers>
146. ICTP. (2010, April). Scientific Calendar Event. Retrieved from <https://indico.ictp.it/event/a09138/other-view?view=ictptimetable>
147. Adekunle, I. O. (2013). Precision Agriculture: Applicability and Opportunities for Nigerian Agriculture. *Middle-East Journal of Scientific Research*, 13(9), 1230-1237
148. Gani, B., & Omonona, B. (2009). Resource Use Efficiency among Small-Scale Irrigated Maize Producers in Northern Taraba State of Nigeria. *Journal of Human Ecology*, 28(2), 113–119. doi: 10.1080/09709274.2009.11906226