Impact of Smart Agriculture and Innovation on Food Security in Africa: Evidence from Nigeria

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Abstract- This study examined the impact of smart agriculture and innovation on food security in Africa using evidence from Nigeria. The study utilized time series data from 1960 – 2019, sourced from World Development Indicators – WDI (2020) and Food and Agricultural Organization of the United Nations (2020) data set, and applied econometric approach based on Ordinary Least Squares technique. It was found by the study that with respect to smart agriculture, fertilizer intensity has negative significant impact on food security by about 1.378546%, while that of tractor intensity revealed that it has positive significant impact on food security by about 0.0050153%. On innovation, the results on number of internet subscribers revealed that it has positive but insignificant impact on food security by about 0.074778%, while human capital development has positive significant impact on food security by about 56.6469%. The study therefore recommended among others that government and its agencies on food security should encourage people more to use natural manure or organic fertilizer instead of inorganic fertilizer. This can be done by boosting crop yields through numerous practices and technologies such as nutrient management practices and technologies geared towards organic fertilizer.

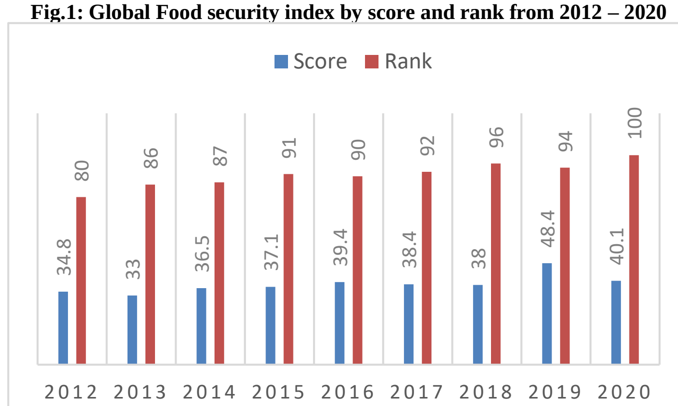
***Index Terms*-** Africa; Econometric Approach; Food Security; Innovation; Smart Agriculture.

I. INTRODUCTION

Globally, increasing lack of access to safe, nutritious and affordable food has been part of the greatest challenge of the world economies (FAO, IFAD and WFP, 2015). Solution to this global challenge has been part of main focus of the United Nations Sustainable Development Goals (SDGs). In order to achieve SDG-2, which is to "end hunger, achieve sustainable food security, improved nutrition and promote agriculture by 2030", there has been global call for climate-smart and innovative agriculture. Due to poor agricultural productivity occasioned by lack of smart agriculture and innovation, Africa has been the epic center of this global menace of food insecurity and malnutrition, with about 26% of 153 million adult populations suffering severe food insecurity (FAO report, 2016). Furthermore, the United States Department of Agriculture (USDA) prediction suggests that Sub-Sahara Africa (SSA) would remain the region with the highest level of food insecurity up to the year 2025 (Tandon et al., 2017). In African region, Nigeria is feared to be one of the countries said to be most at risk, due to her heavy food import-dependent, with an estimated value of food importation worth of 22 billion US dollar (Ogundiran, 2019). This has been linked to lack of agricultural technology adoption and heavy subsistence farm participation of greater populace in Nigeria.

More so, World Bank's records revealed that 90% of agricultural production in Nigeria is made up of inefficient output of small scale farmers (Matemilola, 2017). Hence, farmers only succeed to produce enough food to sustain their household members. Consequently, high level of food insecurity prevalence resulted to frequent high food prices and exposure to global commodity market shocks. The precarious state of food insecurity in Nigeria is also evident in the Global Hunger Index (GHI). Nigeria is ranked 98th out of the 107 countries with a score 29.2, which falls in the serious category (Global Hunger Index report, 2020). This reveal also that Nigeria is far from track in attaining the SDG-2 target. More so, Global Food Security Index (GFSI) score and rank as shown in figure 1 below indicates that Nigeria's ranking has continued to worsen since 2013 with a rank of 86 among 107 countries with 33/100 score and a rank of 94 among 113 countries with a score 48.4/100 in 2019, behind her African counterparts like Ethiopia, Niger and Cameroon (Economist Intelligence Unit [EIU], 2020).

Fig.1: Global Food security index by score and rank from 2012 – 2020



Source: EIU (2020)

However, evidence has shown that existing, new and emerging agro technologies can go a long way to address different dimensions of food security in Nigeria and Africa in general (Adeagbo, 2012). These technologies, such as irrigation technology could assist in food availability, while post-harvest and agro-processing innovation can promote food accessibility. Tapping into these existing and emerging smart agricultural technologies for food security requires investments in physical and human capital. Sadly, most farmers in Nigeria are smallholder participants with low agro-tech knowledge and also lack access to affordable cultivating and harvest equipment (Mapfumo et al., 2015). Thus, most farmers depend on manual labour for farm activities (Matemilola el al., 2017).

Despite the high rate of tele-density witnessed in couple of decades in Nigeria, with over 203.5 million active telecommunications subscribers, Nigeria have not effectively harness the full potential of e-agriculture (Agrobusiness times report, 2021). Unlike countries such as India (Reuters Market Light), Ghana (mFarms), Kenya (MPesa, iCow), that have utilized ICT innovations to increase their agricultural outputs. Reuters Market Light (RML) in India for instance has improved farmers' productivity by 14-16 % with farmers trading even more profitably (IFPRI, 2002). The adoption of the emerging innovation by smallholder farmers in Nigeria has been slow and low (Jack, 2013).

Though concerted efforts have been made by private investors as well as the government to promote innovation and give a new face to agriculture in Nigeria. Like the adoption of 130 farmers in Jigawa state into the National Adopted Village for Smart Agriculture program by the Nigeria's Federal Ministry of Communications and Digital Economy. The program was targeted at providing farmers a means to showcase their farm produce to digital world market. Other efforts by successive governments to promote agricultural production include establishment of agencies and several policy intervention initiatives like Operation Feed the Nation, Lower River Basin Development Authorities, National Seed Policy and Seed Development Plan, Green Revolution and regulatory bodies such as the Directorate of Foods, Roads and Rural Infrastructure (DFRRI), Agricultural Transformation Agenda and National Agricultural and Land Development Authority (NALDA) among others. Yet these concerns and efforts by the Nigerian government have not translated into effective policy interventions and implementation. Nigeria still depends on massive importation of food and could not solve the long term food insecurity challenges.

Hence, this study seeks to investigate the effects of smart agriculture and innovation on food security in Nigeria. The rest of this paper is structured as follows; section 2 discussions on literature review, section 3 captures the methodology and data sources, while section 4 and 5 is the result discussion and policy recommendations.

II. Literature Review

The concept Smart Agriculture is referred to as the application of modern technological techniques/skills into agriculture in order to increase productivity (Spandana & Pabboju, 2019). Smart Agriculture can furnish the farmers with daily/weekly updates with respect to the soil quality, crop health and energy consumption level within the farm (Spandana & Pabboju, 2019). Also, it can assist farmers in the following farm activities; smart irrigation, crop monitoring, crop disease detection, green house management, plant growth monitoring and energy management among others (Iorliam, Iorlian & Blum, 2021). According to Jack (2013) agriculture innovations could enhance yields in Africa. This view is also corroborated by Senz et al. (2017) that indicated that smallholder farmers can feed Africa if the regions' small-scale producers adopt intensified agro practices with seeds and fertilizers.

Theoretical discussions relating smart, diffusion of innovations and agriculture abound in the agricultural technology adoption literature (see Bishwanger & Ruttan, 1978; Hayami, 1981; Ruttan & Hayami, 1984). These theories connect and facilitates development of hypotheses on smart agriculture adoption. For instance, diffusion of innovations theory by Rogers (2003) specifies the characteristics of an innovation, which include among others; compatibility, complexity, relative advantage, trialability and visibility. These characteristics shape the rate of agriculture innovation adoption. Rogers relates diffusion as a dynamic process that transcends via communication. Diffusion of innovation is a communication process that volute overtime through certain channels in a social system. The important notion of diffusion of innovation literature is centered on the understanding on when and why innovation is rejected or accepted. The assumption that guides this notion is that a good diffusion approach is a good thing, because it results to a swift and widespread innovation adoption, even despite unanticipated and negative consequences revealed in literature (Peixotio, Castro, & Nasamento, N.A).

Another theory by Hayami and Ruttan (1971, 1985) termed induced innovation hypothesis, relates technological and institutional innovations in agriculture with economic conditions and opportunities (Jaleta et al., 2018; Pradhan & Ranjan, 2016). The theory asserts that resource endowment or constrains, like labour and capital, influence the level adoption of innovations (Pradhan & Ranjan, 2016). Their argument was based on the idea that new innovations is an economic activity that can be significantly influenced by economic conditions (Sunding & Zilberman, 2000). The possibility of emergence of new innovation could be a response to scarcity of resources and/or economic opportunities. Existing empirical studies have corroborated with this theory and demonstrates that availability of resources (including assess to credit and labour) constitutes a major determinant of smart and innovative agricultural practices (Caspe & Dalabajan, 2017; Lopez- Ridaura et al., 2018).

In line with these views, factors that aid adoption of agricultural technologies have remained rather inconclusive. At both micro and macro level, a number of studies have found different determinants as important in making adoption decisions by farmers (Arslan et al., 2014; Kabunga, Dubois & Qaim, 2012; Mariano, Villano, & Fleming, 2012; Pannell, Llewellyn & Corbeels, 2014). Past literature indicates that there are several barriers to technology adoption, ranging from lack of insurance and limited access to credit to price risk, and majorly focuses on the effect of production risk on overall output (Kassie et al., 2008; Di Falco et al., 2011; Di Falco et al., 2014).

While some other empirical studies have focused on the implications of climate-smart agriculture on food security using micro data obtained from use of questionnaires (Hassan et al., 2018; Amadu, 2018; Wekesa et al., 2018; Jelagat, 2019). Their findings revealed that climate-smart agriculture practices significantly influenced food security. Amadu (2018) noted also that available knowledge on agricultural innovations was not available to small-scale farmers and therefore farmers continued practicing unsustainable farming in Southern Malawi.

Furthermore, literature expanded on the impact of ICT on crop production. Some of the studies in this area used macro data (Vanek et al, 2010; Aker, 2011; Armstrong. & Gandhi, 2012; Asenso-Okyere & Mekonnen, 2012; Chavula, 2013; Salampasis & Theodoridis, 2013; Adamides & Stylianou, 2013); Vosough et al, 2015; Zhang, et al, 2016), while others utilized micro data (Hassan et al, 2011; Chukwunonso, Abubakhar & Obidi, 2012; Ramli et al., 2013). Most of these empirical studies revealed that ICT adoption and internet utilization have positive impact on agricultural output. Though these studies also indicate that most of the framers are not acquainted with these ICT tools and they are easily accessed by farmers in the communities studied (Ejemyovwi et al., 2017; Ugboh & Tibi, 2008). Therefore, recommended that ICT facilities be made accessible in most rural areas in various localities (Ugboh & Tibi, 2008).

In addition to ICT and internet utilization implications on agricultural output, quality of labour has also been identified in the literature as a key factor that affects agricultural output. A study in West Africa on the role of ICT on agriculture; labour and capital were elastic, which implies that any change in labour and capital would proportionately increase agricultural output (Akimuda, 2014).

Empirical literature on the impact of smart agriculture and innovation on food security abound in developed and developing countries. Most scholarly works have found a positive relationship between food security and smart agriculture, while other studies found inverse relationship. However, this current study would build on the existing knowledge by further assessing how smart agriculture and innovation impact on food security in Nigeria. Thus, this current study would utilize time series data from FAO and WDI, unlike most previous studies in Nigeria that used primary data.

III. Theoretical Framework and Method of Analysis

A. Theoretical Framework

The Solow's technological change growth model serves as a theoretical framework for this study. The model provides a good insight for analysing the effect of technological innovation on agricultural sector production. The theoretical postulates of Solow relate to the explanation of the determinants of output growth including agricultural sector outputs as given below in equation (3.1):

$$Q = f(k, l, t) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.1)$$

where; Q = total output, k = capital, l = labour, t = time which allows for technical change or innovation, and f = functional notation.

We presume in this study that the quantity of output produced by the agricultural sector is a function of the number of technological factors applied. In this wise, it will be possible to relate food security (i.e., the growth in quantity of food production) with technological changes. Solow's ideologies challenged assertions of others that solely believe that savings and capital accumulation are the main determinants of food security (Osabohien, Osabuohien & Urhie, 2017). With insight from Solow's theory, technological change among others factors which include human development, economic efficiency, and infrastructural development can affect food security (Osabohien et al., 2017).

B. Method of Analysis

In order to investigate the effects of smart agriculture and innovation on food security in Nigeria, this study adopted econometric approach based on Ordinary Least Squares (OLS) technique. The functional form of the econometric model states that food security is a function of smart agriculture and innovation. This can be seen in equation one specified below:

$$foodsec = f(smtagric, innov, hcd) \dots\dots\dots\dots\dots\dots\dots. (3.2)$$

where;
foodsec = food security (proxied by food production index)
smtagric = smart agriculture (proxied by fertilizer intensity, and tractor intensity)
innov = innovation (proxied by number of internet subscribers/number of individuals using the internet (% of population)).
hcd = human capital development (proxy for labour)
f = functional notation

However, there are other variables that could influence food security other than smart agriculture and innovation, such as employment in agriculture % of total employment), and foreign direct investment (FDI) inflows. For example, foreign direct investment (FDI) inflows have been shown to exhibit some impact on food security in Nigeria since Nigeria is an import dependent country. Therefore, modifying the functional form of the econometric model to capture each variable, and capturing the effects of employment in agriculture and that of FDI as control variables in the model, the study specifies the mathematical form of the model as given below:

$$foodsec = \alpha_0 + \alpha_1 fertintern + \alpha_2 tractintern + \alpha_3 internetsub + \alpha_4 empagric + \alpha_5 fdi + \alpha_6 hcd \dots\dots\dots\dots\dots\dots\dots\dots\dots.\dots\dots.\dots. (3.3)$$

where;
foodsec = food security (proxied by food production index)
fertintern = fertilizer intensity,
tractintern = tractor intensity,
internetsub = number of internet subscribers/number of individuals using the internet (% of population) (proxy for innovation)
empagric = employment in agriculture % of total employment
fdi = foreign direct investment inflows
hcd = human capital development
α_0= the constant term
$\alpha_{i's}$ = the parameters of the model, for i = 1, 2, …, n

Hence, in line with the mathematical specification of the model, the econometric specification of the model is given as:

$$foodsec = \alpha_0 + \alpha_1 fertintern + \alpha_2 tractintern + \alpha_3 internetsub + \alpha_4 empagric + \alpha_5 fdi + \alpha_6 hcd + \mu_t \dots\dots\dots.\dots\dots\dots\dots\dots\dots.(3.4)$$

where; the variables remained as defined above. μ_t = stochastic error term.

C. Data and Data Sources

The data for the study is a time series data from 1960 – 2019, sourced from World Development Indicators – WDI (2020) and Food and Agricultural Organization of the United Nations (2020) data set. While food production index (proxy for food security), , number of internet subscribers/number of individuals using the internet (% of population) (proxy for innovation), employment in agriculture % of total employment, and foreign direct investment (FDI) were sourced from WDI (2020) data set, fertilizer intensity, and tractor intensity (proxies for smart agriculture) were sourced from FAO (2020) data set. The study performed some pre-estimation tests such as the descriptive statistics, unit root test and cointegration test.

IV. Results and Discussions

Before analyzing the model, the study looked at pre-estimation tests like the summary statistics, unit root test and the cointegration test, in order to inspect the nature and time series characteristics of the variables of the model. These are examined in the sub-sections that follows as given below:

A. Summary Statistics

The summary statistics results presented in the table 4.1 shows the raw data level forms of the model variables. It also reveals the nature and characteristics of the model variables inspected in a bid to observe whether the variables vary sufficiently in their mean, standard deviation, and minimum and maximum values. Consequently, the study presents the summary statistics of the variables applied in the model as given below in table 4.1:

Table 4.1: Summary Statistics Results of the Model Variables

Variable	Obs	Mean	Std. Dev.	Min	Max
foodsec	60	61.40779	35.63483	22.91	125.77
fertintern	60	3.42925	2.846379	.01	11.27
tractintern	60	9875.917	7009.825	500	24800
internetsub	60	5.548633	12.85764	.008833	57.9175
empagric	60	47.11308	4.624483	36.384	50.172
fdi	60	1.728601	1.136197	-1.150856	5.790847
hcd	60	0.5469188	0.1427099	0.267353	0.8716762

Source: Author's Computation from Available Data

The summary statistics results indicate that all the variables of the model revealed sufficient variations in their mean, standard deviations, and their minimum and maximum values respectively. The results show that there 60 observations corresponding to data generated from 1960 – 2019 for all the model variable.

B. Unit Root Test

The study applied the Augmented Dickey-Fuller (ADF) test for unit root in order to examine the level of integration or level of stationarity of the variables. Hence, the ADF test for unit root can be seen summarily as presented in table 4.2 given below:

Table 4.2: The Summary Results of Unit Root Test

Level			First Difference		Oder of Integration
Variable	ADF t-Statistics	5% Critical Values	ADF t-Statistics	5% Critical Values	
foodsec	0.780	-2.923	-11.634	-2.924	Oder one (i.e.I(1))
fertintern	-0.919	-2.923	-8.984	-2.924	Oder one (i.e.I(1))
tractintern	5.243	-2.923	-7.467	-2.924	Oder one (i.e.I(1))
internetsub	3.741	-2.923	-8.183	-2.924	Oder one (i.e.I(1))
empagric	3.245	-2.923	-5.070	-2.924	Oder one (i.e.I(1))
fdi	-3.900	-2.923			Oder zero (i.e.I(0))
hcd	-6.751	-2.923			Oder zero (i.e.I(0))

Source: Author's Computation from Available Data

The results of the unit root test presented in table 4.2 indicate that all the variables of the model food security (foodsec), fertilizer intensity (fertintern), tractor intensity (tractintern), number of internet subscribers/number of individuals using the internet (% of population) (internetsub), and employment in agriculture % of total employment (empagric), are all integrated of order one (i.e.I(1)), except for foreign direct investment (fdi) and human capital development (hcd) which were found to be integrated of order zero (i.e.I(0)).

C. Cointegration Test

The study applied the two-step Engel cointegration test in order inspect if there exist long run relationship among the variables of the model. If there is evidence of cointegration among the variables of the model, the study would implement the error correction model (which is also known as the short run model), otherwise, the study would utilize the long run econometric model based on OLS for its analysis. The cointegration test results can be seen in table 4.3 as follows:

Table 4.3: The Cointegration Test Results

	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	0.613	-3.567	-2.923	-2.596

MacKinnon approximate p-value for Z(t) = 0.9879
Source: Author's Computation from Available Data

The cointegration test results show that there is no cointegration among the variables of the model since the absolute value of the ADF t-statistic, 0.613, is less than its 5% critical value, -2.923 in absolute terms (that is; /0.613/</-2.923/). Therefore, there is no need for constructing error correction model or short run model. This implies that the long run econometric model based on OLS would suffice for the study's analysis and interpretations of results.

D. The Empirical Results of the OLS Econometric Model

In line with the findings of the pre-estimation test and cointegration test, the study adopts the long run econometric model based on OLS for the study's analysis and interpretations of results as presented in table 4.4 below:

Table 4.4: The Summary Results of the Econometric OLS Model (Dependent Variable = foodsec)

Variables	Coef.	Std. Err.	t	P>|t|
fertintern	-1.378546	0.5467624	-2.52	0.015
tractintern	0.0050153	0.0003763	13.33	0.000
internetsub	0.074778	0.1619835	0.46	0.646
empagric	0.8534069	0.6684604	1.28	0.207
fdi	3.016793	0.7615282	3.96	0.000
hcd	0.566469	0.2038135	2.78	0.008
_cons	52.0109	34.25205	1.52	0.135

Source: Author's Computation from Available Data

Table 4.4 indicates that from the econometric regression model, fertilizer intensity (fertintern) has negative significant impact on food security (foodsec). This implies that a unit increase in fertilizer intensity significantly reduces food security by about 1.378546%. This result is surprising since it is expected that a rise in fertilizer intensity would significantly increase food production and as such, contribute significantly to food security in Nigeria. The implication of this result is that in Nigeria, fertilizer intensity reduces food security significantly due largely to the use of inorganic fertilizers which may contain some chemicals that are very harmful to the land used in the food production, microorganisms, and some crops/plants. This therefore shows that natural manure or organic fertilizer should be applied instead of inorganic fertilizer. Again, the problem of land tenure system could also militate against smart agriculture emanating from fertilizer intensity in Nigeria and as such, makes food security to fall. This finding is in consonance with the finding by Stewart & Roberts (2012), and Yousaf, Li, Lu, Ren, Cong, Fahad, & Li (2017) who found that in order to boost crop yields, numerous practices and technologies such as nutrient management practices and technologies geared towards organic fertilizer, among others, should be adopted instead of using inorganic fertilizers.

Results on tractor intensity (tractintern) revealed that it has positive significant impact on food security (foodsec). This implies that a unit increase in tractor intensity would significantly encourage food security by about 0.0050153%. This result is not surprising since it is expected that a rise in tractor intensity (tractintern) would significantly increase food production and as such, contribute significantly to food security in Nigeria. The implication of this result is that in Nigeria, the more intensive tractors are used for food production, the more food production would increase and hence, bring about significant rise in food security.

On innovation, the results on number of internet subscribers (internetsub) revealed that it has positive but insignificant impact on food security (foodsec). This implies that an improvement in innovation (internetsub) would positively but insignificantly influence food security by about 0.074778% on the average. The implication of this result is that with a continuous innovation, food security will improve in economy although, insignificantly. This study's finding is in line with the finding by Ejemeyovwi et al. (2017) who found that internet utilization is positively but insignificantly related to food security.

It was also found by the study that a percentage increase in employment in agriculture as a percentage of total employment (empagric) has positive and insignificant impact on food security (foodsec). This implies that a percentage increase in employment in agriculture (empagric) would positively but insignificantly impact food security by about 0.8534069% on the average. The implication of this result is that whenever employment in agriculture rises, food security would improve, although insignificantly.

Foreign direct investment (fdi) results also indicate that a unit increase in foreign direct investment would significantly increase food security (foodsec) by about 3.016793% on the average. This result is not surprising since it is expected that a rise in investment inflows would significantly increase food production, food inputs, and as such, contribute significantly to food security in Nigeria. The implication of this result is that in Nigeria, the inflows of foreign investments would on the average increase food security significantly.

Results on human capital development (hcd) show that a percentage improvement in human capital development (hcd) significantly increases food security (foodsec) by about 56.6469% on the average. This result is not also surprising since it is expected that an increase in the development of human capital of any economy, the more people would be more developed mentally, physically, intellectually, scientifically, agriculturally, and otherwise. This will no doubt bring about significant improvement in food security, enhanced standard of living of the people, and improved economic growth and development. Therefore, in Nigeria, enhanced in human capital development on the average, brings about significant increase in food security.

Controlling for other factors that could affect food security in Nigeria (_cons), it was found by the study that the constant term positively but insignificantly affect food security.

V. Conclusion and Recommendation

This study examined food security impact of smart agriculture and innovation in Africa using evidence from Nigeria. The study utilized time series data from 1960 – 2019, sourced from World Development Indicators – WDI (2019) and Food and Agricultural Organization of the United Nations (2020) data set and applied econometric approach based on OLS technique. With respect to smart agriculture, it was found that fertilizer intensity (fertintern) has negative significant impact on food security (foodsec) by about 1.378546% on the average, while that of tractor intensity (tractintern) revealed that it has positive significant impact on food security (foodsec) by about 0.0050153%. On innovation, the results on number of internet subscribers (internetsub) revealed that it has positive but insignificant impact on food security (foodsec) by about 0.074778% on the average. On the control variables, it was found that employment in agriculture has a positive and insignificant impact on food security (foodsec) by about 0.8534069% on the average, foreign direct investment (fdi) results indicate that a unit increase in foreign direct investment would significantly increase food security (foodsec) by about 3.016793%, while a percentage improvement in human capital development (hcd) significantly improves food security (foodsec) by about 56.6469% on the average.

Based on the findings of the study, the study recommends that:

1. Government and its agencies on food security should encourage people more to use natural manure or organic fertilizer instead of inorganic fertilizer. This can be done by boosting crop yields through numerous practices and technologies such as nutrient management practices and technologies geared towards organic fertilizer.
2. Again, government should try to solve the problem of land tenure system in a bid not to militate against smart agriculture, especially, that which emanates from fertilizer intensity in Nigeria which makes food security to fall.
3. Innovation was found to have positive but insignificant impact on food security, hence, government and all agencies responsible for food security should strive more to innovate the more in a bid to have a significant contribution from innovation on food security. This would held in increased production and a significant rise in food security.
4. Employment in agriculture was found to have positive and insignificant impact on food security, thus, there is need to mechanize agriculture, adopt improve seedling, crops that can withstand harsh climatic conditions. This would help to improve the positive effects of employment in agriculture and possibly, make it significant in affecting food security in Nigeria.
5. Foreign direct investment was found to significantly encourage food security in Nigeria, consequently, government and its agencies responsible for food security should try harder to create more conducive environment that would attract more foreign investments in the sector. However, there should be some form of controls in order to avoid some risks of unintended consequences of FDI inflows in the country.
6. Government should strive harder to enhance human capital development more through youth empowerment programmes and other agricultural grants schemes, especially to subsistence agriculturalists in the rural areas, to help improve food security the more.

REFERENCES

[1] Adamides, G. and Stylianou, A. (2013). ICT and mobile phone use for agricultural knowledge sharing by Cypriot farmers. Agris on-line Papers in Economics and Informatics. 2

[2] Adeagbo, M.O. (2012). Curbing the Menace of Food Insecurity in Nigeria's Democratic Setting. International Journal of Economic Development Research and Investment, 101-109.

[3] Agrobusiness times report (2021). How farm innovation Nigeria is giving a breath of fresh air to agriculture. Retrieved from https://www.agrobusinessngr.com/how-farm-innovation-nigeria-is-giving-a-breath-of-fresh-air-to-agriculture/

[4] Akimuda .S. S. (2014), The Role of Information and Technology on Agricultural Output in West Africa [unpublished undergraduate research work], Department of Economics and Development Studies, Covenant University, Ota, Ogun State, Nigeria

[5] Amadu, F.O. (2018). Three essays on the adoption, impact, and pathways of climate-smart agriculture: an ex-post impact evaluation of a natural resource management intervention in Southern Malawi. Retrieved 4th July 2021 from https://pdfs.semanticscholar.org/1377/41f90248813eb8b79a7957e0bcfa847dfafb.pdf

[6] Armstrong L. J., & Gandhi, N. (2012). Factors influencing the use of information and communication technology (ICT) tools by the rural farmers In Ratnagiri District of Maharashtra, India. ECU Publications Proceedings of the third national conference on Agro- infomatics and precision Agriculture. 58-63. Retrieved from: http://ro.edcu.edu.au/ecuworks2012/105

[7] Arslan, A., McCarthy, N., Lipper, L., Asfaw, S., Cattaneo, A. (2014). Adoption and intensity of adoption of conservation farming practices in Zambia. Agriculture, Ecosystems and Environment 187, 72–86.

[8] Asenso-Okyere, K., and Mekonnen, D., A. (2012), The Importance of ICTs in the Provision of Information for Improving Agricultural Productivity and Rural Incomes in Africa. United Nations Development Programme Regional Bureau for Africa. Working paper 2012 - 015

[9] Chavula, K. H., (2013). The role of ICTs in agricultural production in Africa. Journal of Development and Agricultural Economics, 7(7), 279 – 289; DOI: 10.5897/JDAE2013.0517. http://www.academicjournals.org/JDAE

[10] Chukwunonso F., Abubakhar A. & Obidi, N., (2012). The Adoption of Information and Communication Technology (ICT) in Agriculture in Adamawa State, Nigeria. African Journal of Agricultural Research and Development, 5(3), ISSN: 2141-0097.

[11] Ejemeyovwi, J., Akhigbemidu, A, Agharevba, W, Arome, V., Akaraiwe, O., Ogunlusi, T., & Owuama, I. (2017). Can ICT Adoption Aid Crop Production in Nigeria? (Smart-Agriculture). International Journal of English Literature and Social Sciences (IJELS), 2(6), 1-9. https://dx.doi.org/10.24001/ijels.2.6.1 ISSN: 2456-762

[12] EIU (2020). Global food security index (2019). Strengthening the food systems and the environment through innovation and investment. A report from The Economist Intelligence Unit.

[13] FAO., IFAD. and WFP. (2015). The state of food insecurity in the world 2015. Proceedings of the Meeting of the International Hunger Targets: Taking Stock of Uneven Progress, (HTTSUP'15), Food and Agriculture Organization of the United Nations, Rome.

[14] FAO IFAD, UNICEF, WFP, and WHO. (2018). The State of Food Security and Nutrition in the World 2018. Building Climate Resilience for Food Security and Nutrition. Technical report, FAO, Rome.

[15] Food and Agricultural Organization, United Nations (2020). FAOSTAT, Fertilizers indicators, Available Online At: http://www.fao.org/faostat/en/#data/EF

[16] Hasan, K., Desiere, S., D'Haese, M., & Kumar, L. (2018). Impact of climate-smart agriculture adoption on the food security of coastal farmers in Bangladesh, Food Secuirty: The Science, Sociology and Economics of food Production and Access to Food. Springer; the International society for Plant Pathology, 10(4), 1073-1088.

[17] Hassan, M.S., Yassin, S.M., Shaffril, H.A., Othman, M.S., Samah, B.A., & Samah A.A. (2011). Receiving the agriculture information through mass media and interpersonal sources among the rural community. American Journal of Agricultural and Biological Sciences, 6(3), 451 - 461.

[18] Idris, A., Otekunirin, O., Akinbode, S., Otekunirin, O. (2020). Food Security in Nigeria: Impetus for Growth and Development. Journal of Agriculture Economics and Rural Development, 6(2), 808-820. DOI - 10.6084/M9.FIGSHARE.12949352

[19] International Food Policy Research Institute (2002) IFPRI Annual Report.

[20] Iorliam, A, Iorliam, I.B. & Blum, S. (2021). Internet of Things for Smart Agriculture in Nigeria and Africa: A Review. International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS), 10(2), 7-12. https://www.researchgate.net/publication/349868793

[21] Islam D. and Berkes, F. (2016). Indigenous peoples' fisheries and food security: A case from northern Canada. Food Secur.;8(4):815–826.

[22] Jack, B. K. (2013). Market ine¨ciencies and the adoption of agricultural technologies in developing countries. In White paper, Agricultural Technology Adoption Initiative. Berkeley.

[23] Jaleta, M., Kassie, M., Marenya, P., Yirga, C., Erenstein, O., 2018. Impact of improved maize adoption on household food security of maize producing smallholder farmers in Ethiopia. Food Security 10(1), 81–93.

[24] Jelagat, J. (2019). Effects of Climate-Smart Agricultural Awareness on Food Security Among Smallholder Farmers: The Case of Kaptumo-Kabodi Ward, Nandi County. (Unpublished MSc Thesis in the University of Nairobi).

[25] Kabunga, N.S., Dubois, T. & Qaim, M. (2012). Yield effects of tissue culture bananas in Kenya: Accounting for selection bias and the role of complementary inputs. Journal of Agricultural Economics 63, 444–464.

[26] Mariano, M.J., Villano, R. and Fleming, E. (2012) Factors influencing farmers' adoption of modern rice technologies and good management practices in the Philippines. Agricultural System, 110, 41-53.

[27] Matemilola, S. and Elegbede, I. (2017). The Challenges of Food Security in Nigeria. Open Access Library Journal, 4: e4185. https://doi.org/10.4236/oalib.1104185

[28] Ogundiran, A. (2019). Food security, food sovereignty, and indigenous knowledge. Afr Archaeol Rev, 36,343–346. https://doi.org/10.1007/s10437-019-09349-7

[29] Osabohien, R., Osabohien, E. & Urhie, E. (2017). Food Security, Institutional Framework and Technology: Examining the nexus in Nigeria using ARDL approach. Current Nutrition and Food Science, 1-12. DOI: 10.2174/1573401313666617052513

[30] Pannell, D. J., Llewellyn, R. S., & Corbeels, M. (2014). The farm-level economics of conservation agriculture for resource-poor farmers. Agriculture, ecosystems & environment, 187, 52-64.

[31] Peixotio, M, Castro, A.C & Nasamento, P.P, (N.A). Roger's theory of diffusion of innovations and institutional changes in Brazilian Rural Advisory Services. Retrieved July 29 2021, from https://ainfo.cnptia.embrapa.br/digital/bitstream/item/216620/1/RogersTheory-of-Diffusion.pdf

[32] Ramli, N.S., Hassan, M.S., Samah, B.A., Ali, M.S., Shaffril, H.A., & Azaharian, Z.S. (2013). Problems in using agricultural information from television among farmers in Malaysia. Asian Social Science, 9(9), 70-73.

[33] Roser, M. and H. Ritchie, (2018). Hunger and undernourishment. Our World in Data. https://ourworldindata.org/hunger-and-undernourishment.

[34] Tandon S, Landes, M.,Christensen, C., LeGrand, S., Broussard, N., Farrin, K., and Thome, K., (2017) Progress and Challenges in Global Food Security, EIB-175, U.S. Department of Agriculture, Economic Research Service. Retrieved online on 4/7/2020 from https://www.ers.usda.gov/webdocs/publications/84526/eib-175.pdf?v=42944

[35] Sanz, M. J., Vente, J. de, Chotte, J. L., Bernoux, M., Kust, G., Ruiz, I., Akhtar-Schuster, M. (2017). Sustainable Land Management contribution to successful land- based climate change adaptation and mitigation. A Report of the Science-Policy Interface. Bonn, Germany.

[36] Spandana, K., & Pabboju, S. (2019). Applications of IoT for Soil Quality. In International Conference on Intelligent Computing and Communication Technologies, 277-286. Springer, Singapore

[37] Stewart, W.M. & Roberts, T.L. (2012). Food security and the role of fertilizer in supporting it, Procedia Engineering, (46):76–82, DOI: 10.1016/j.proeng.2012.09.448

[38] Sunding, D. & Zilberman, D. (2000). The Agricultural Innovation Process: Research and Technology Adoption in a Changing Agricultural Sector. Handbook of Agricultural Economics, 1-103. Retrieved on July 29 2021, from https://are.berkeley.edu/~zilber11/innovationchptr.pdf

[39] Ugboh . O. & Tibi E . U. (2008). The role of Community Based Organisations (CBOS) in Rural and Agricultural Transformation in Delta State. Retrieved from: http//:www.ajol.info/index.php/afrrev/article/download d/41009/8449. Page visited 17/01/2016.

[40] United Nations (2004). World Population to 2300. Economic and Social Affiars. United Nations, New York, NY 10017, USA. Retrieved online on 4/7/2020 from https://www.un.org/en/development/desa/population/publications/pdf/trends/WorldPop2300final.pdf

[41] Vosough, A., Eghtedari, M., & Binaian, A. (2015). Factors Affecting ICT Adoption in Rural Area: A case Study of Rural users in Iran. Research Journal of Fisheries and Hydrobiology, 10 (10), 611-616.

[42] Wekesa, B., Ayuta, O., & Lagat, (2018). Effect of climate-smart agricultural practices on household food security in smallholder production systems: micro-level evidence from Kenya.Agriculture & Food Security, 7(80).

[43] World Development Indicators – WDI (2020). World Bank Data bank, Available Online At: https://databank.worldbank.org/source/world-development-indicators

[44] Yousaf, M., Li, J., Lu, J., Ren, T., Cong, R., Fahad, S. & Li, X. (2017). Effects of fertilization on crop production and nutrient-supplying capacity under rice-oilseed rape rotation system, Scientific Reports, 7(1270): 1 – 10, DOI: https://doi.org/10.1038/s41598-017-01412-0

[45] Zhang Y., Wang L., & Duan Y. (2016). Agricultural information dissemination using ICTs: A review and analysis of information dissemination models in China. Retrieved from journal homepage: w.elsevier.com/locate/inpa; http://dx.doi.org/10.1016/j.inpa.2015.11.002.

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