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Differential impacts of rainfall and irrigation on agricultural production in Nigeria: Any lessons for climate-smart agriculture?

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ABSTRACT

The rain-fed agriculture system is vulnerable to climate change impact. However, such impact may also vary by aggregate and sub-sectoral levels of agricultural production. The impact of climate change and variability on agricultural production would engender appropriate policies and practices towards a sustainable agricultural production system. We investigated the differential impacts of rainfall and irrigation on agricultural production in Nigeria, and drew lessons for climate-smart agriculture (CSA) in Nigeria. Using time series data that spanned 43 years and econometric analytical technique, we quantified the differential impacts of rainfall and irrigation on aggregate production and sub-sectors (all crops, staples, livestock, fisheries and forestry). Irrigation had positive and significant impact on aggregate agricultural production as well as all sub-sectors of agriculture. These findings suggest the need for the minimization of the impact of climate-induced production risks through CSA which would involve complementary development of more arable land areas under irrigation in Nigeria. Irrigation would also enhance complementary agricultural water management for the development of all the sub-sectors of agriculture, thereby enhancing food security and sustainable agricultural production under prevailing climate change and variability.

1. Introduction

The agricultural production system in Nigeria is predominantly rain-fed. In such a case, extreme rainfall patterns and/or variability becomes a critical production risk. The rain-fed agricultural production system is vulnerable to seasonal variability which affects the livelihood outcomes of farmers and landless labourers who depend on this system of agricultural production (Vermeulen et al., 2012). Climate change affects rainfall through rainfall variability which is conditioned by the hydrological cycle, and observable rainfall patterns. This situation, therefore, makes climate change an important consideration for sustainable agricultural production (Easterling et al., 2007). In the event of erratic rainfall, irrigated land area is insurance for rain-fed agriculture. Similarly, land areas under irrigation are predictors of resilience of agriculture to rainfall-induced vagaries and impact of climate change (Cassman et al., 2013). Hence, it is imperative to consider and analyse the long-term impact of rainfall and irrigation on agricultural production by sub-sectors. The analyses in this paper have implications for food security (availability, accessibility, and stability) and sustainable agricultural production in Nigeria, which is the most populous nation in Africa.

The impact of climate change occurs at multiple scales (global, regional and national) and sectors (including agriculture). The latest report of the Intergovernmental Panel on Climate Change (IPCC, 2015) attests to strong evidence of global climate change and impacts. Climate change and agriculture are inextricably linked (Nwanze and Fan, 2016; World Bank, 2015, 2008). The agricultural sector and its sub-sectors are increasingly showing a high level of vulnerability and impact. Climate change across Africa is exacerbated by low levels of adaptation and mitigation (IPCC, 2015; Montpellier Panel Report, 2015). Further evidence abound on the impact of climate change and variability on specific sub-sectors of agricultural production (crops, livestock, fisheries and forestry) from across other geographical scales and countries (Gourdji et al., 2015; Craparo et al., 2015). As a result of climate change, farmers are now making changes and building resilience to vagaries of climate change (Wood et al., 2014; Kristjanson et al., 2012).

The agricultural production risk imposed by rainfall variability may be a motivation or hindrance to investment in improved agri-

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cultural technology and climate resilient agriculture. Farmers who are unable to adapt to the changing climate may find alternative livelihoods or remain impoverished. Others may become resilient by developing alternative systems of production that will help them cope with the changing climate. This situation predisposes farmers to a pseudo choice-making process that is constrained by initial endowment or capacity to innovate so as to overcome vulnerability by becoming climate-resilient through appropriate adaptation and mitigation strategies. It has been noted that any strategy to adapt agriculture and food systems to a changing climate must therefore exploit the diversified means of climate resilient strategies (Vermeulen et al., 2012), including irrigation agriculture. Variability and extreme rainfall events have the potential to transform agricultural production systems (rain-fed or irrigated) and sub-sectoral diversifications of agricultural production (including crops, livestock, forestry and fisheries) as well as downstream production activities (like processing, marketing and off-farm activities) which could help to smoothen agricultural consumption and production along the value chain (Liverman and Kapadia, 2010; Nelson et al., 2009). The ability to circumvent the negative impact of climate and weather variability in agricultural production is an important consideration for climate-smart agriculture (CSA) and for maximizing its benefits of enhancing agricultural livelihoods and economic development.

CSA is an emerging concept and practice that seeks to adapt agricultural production to climate change and weather variability, while maintaining agricultural productivity, biodiversity and the ecosystem that sustains food security, livelihoods and economic development. CSA seeks to enhance productivity, water conservation, livelihoods, biodiversity, resilience to climate stress, and environmental quality (FAO, 2013, 2010; Neufeldt et al., 2011). The overall outcome of CSA is to improve agricultural livelihood incomes, promote food security and sustainable agricultural development by ensuring that agricultural production systems are best suited to respond to the challenges of climate change and variability. The resilience of agriculture to climatic changes and variability could boost agricultural production and broadly contribute to sustainable development (Nwanze and Fan, 2016).

Contextually, CSA in Nigeria implies enhancement of agricultural livelihoods and intensification, improvement of environmental friendly agricultural systems, and sustainability of supply of agricultural water and conservation through the expansion and management of irrigation in order to cope with the vagaries of rainfall variability, flooding, drought, low productivity, and food insecurity. This paper, therefore, draws lessons for CSA (including the social, economic, and technical/environmental barriers) based on the econometric analysis of differential impact of rainfall and irrigation on agricultural production in Nigeria.

The paper builds on emerging literature on the impact of climate variability on agricultural production (Ajetomobi et al., 2015; Craparo et al., 2015; Gourdji et al., 2015). It reveals the reliance of agriculture to climate change and variability (Schlenker and Lobell, 2010; Schlenker and Roberts, 2009; Guiteras, 2009; Kurukulasuriya et al., 2006), and expand literature on the long-term impact of rainfall-induced production risks and adaptation measures (irrigation) on agricultural production in Nigeria. We found motivation to expand on the understanding provided by anecdotal research at the community and household levels that provided insight into particular adaptation strategies and impacts of climate change on agricultural production (Ajetomobi et al., 2015; Below et al., 2012; Vermeulen et al., 2011). The empirical assessment of the impact of irrigation as an adaptation measure, and complementarity with rain-fed agriculture at aggregate and sub-sectoral levels of agricultural production under long-term climate change and variability remains unclear, at least for Nigeria.

The empirical analysis of the impact of rainfall as climate-induced agricultural production risks and irrigation as a measure of adaptation to climate change for aggregate and sub-sectors of agricultural production in Nigeria is important because policies aimed at building climate change resilience and food security are typically implemented at scales (national level) greater than the individual household and community (IPCC, 2015; Gourdji et al., 2013; Dell et al., 2013; Lobell et al., 2011a,b; Easterling et al., 2007). Therefore, this paper provides empirical findings of the impact of rainfall and irrigation on agricultural production using econometric techniques. It analysed the differential impacts of rainfall and irrigation on aggregate agricultural production and sub-sectors (crops, staples, livestock, fisheries and forestry).

2. Materials and methods

2.1. Type, measurement and sources of data

Time series data were extracted from joint databases of the Central Bank of Nigeria (CBN), National Bureau of Statistics (NBS), Nigerian Meteorological Agency (NIMET) and the Food and Agriculture Organization (FAO) of the United Nations in the Statistical Bulletin of the NBS. Supplementary data on occurrence of flooding of national emergency situations were obtained from various publications. The specific data extracted included: agricultural production indices (aggregate production, all crops, staples, livestock, fishery, and forestry), incidence or occurrences of flooding in a specific year, mean annual rainfall in millilitres, proportion of land area under irrigation and value of agricultural (food) imports in million US dollars. The indices of agricultural production is the relative level of the aggregate volume of agricultural production for all sub-sectors (aggregate, all crops, staples, fishery, livestock and forestry) for each year in comparison with the base period (base year = 1990) (http://faostat.fao.org/site/362/DesktopDefault.aspx?PageID=362) (NBS, 2008).

The dataset spanned 1970–2012 (that is, 43 years). Typically, the impact of climate change is considered over a long period of time (usually more than 30 years). This condition also satisfied the econometric properties of a large sample size required for the estimation of the generalised method of moments (GMM) econometric technique (Craparo et al., 2015; Gourdji et al., 2015; Hansen, 2012).

2.2. Analytical methods

Descriptive and inferential analyses (averages, standard deviations and correlations) were used to analyse the dataset to elucidate the variables. The estimation followed an autoregressive integrated moving average (ARIMA) model style. The GMM technique was used to estimate the parameters of the model that was used for estimating the impact of rainfall and irrigation on aggregate agricultural production and by sub-sectors. The choice of parameter estimation technique was informed because the ordinary least squares parameter estimation technique (regression) might result in biased estimation which is particularly linked to spurious regression and endogeneity problems. The issue that may cause spurious regressions is the possible existence of unit roots or non-stationarity of variables in the time series data analysis. This problem was handled by differencing while the problem of endogeneity of correlated independent variables (Fan et al., 2008) was resolved with the use of instrumental variables in the GMM estimation procedures.

Following Fan et al. (2008), and Arellano and Bond (1991), the GMM estimator was stated as an autoregressive (AR) procedure as:

$$\Delta y_{it} = \sum_{e=1}^{m} a_e \Delta y_{it-e} + \sum_{e=1}^{n} \beta_e \Delta x_{it-e} + \Delta \eta_{it} + \Delta u_{it} \quad (1)$$

Table 1
Rationale/implications, hypotheses, *a priori* expectations, and relevant literature on the differential impacts of rainfall and irrigation on agricultural production.

Item	Independent variables used for the GMM estimation	
	Rainfall	Irrigation
Rationale/implications for aggregate and sub-sectors of agricultural production	Agriculture system in Nigeria is predominately rain-fed. Climate change and variability impact may result in increase or decrease in rainfall.	Irrigation serves as buffer or insurance for climate change and variability. Irrigation reduces agricultural production risks and reliance on rainfall. It is also an adaptation measure for extreme rainfall events. Irrigation is also a proxy for agro-technology, climate-smart agricultural practices, and agricultural water management strategy. Irrigation may impact agricultural production positively and profitably if well managed, or negatively if not well managed.
Hypothesis	We hypothesize that rainfall would impact on agricultural production positively or negatively. Also, rainfall may not have any significant impact since rainfall is a natural resource.	We hypothesize that irrigation would impact agricultural production positively if well-managed, or negatively if not well-managed.
A Priori expectations	Positive, negative or none	Positive, negative or none
Relevant literature	Waongo et al. (2015), Yahaya (2010), Teka et al. (2012), Harle et al. (2007), Holden et al. (2003)	Laux et al. (2010), Calzadilla et al. (2010), Connor et al. (2008), Thomas and Adams (1999)

Where y is the dependent variable; x is a set of independent variables, i = 1,. . ., N; t = time period in year; m and n are the lag (Δ) lengths sufficient to ensure that u_{it} is a stochastic error and η_i are instrumental variables. Blundell and Bond (1998) suggest that if the simple autoregressive AR(1) model is mean-stationary, the first differences Δy_{it} will be uncorrelated with individual effects.

The procedure for examining the nature of dataset for stationarity is to establish whether or not there exist a long-run relationship between the dependent variables and the independent variables using unit roots/stationarity tests. According to Engel and Granger (1987), homogenous non-stationary time series, which can be transformed to a stationary time series by differencing d times, is said to be integrated of order d. Thus, Y, (a time series variable) is integrated of order d [$Y \sim I(d)$] if differencing d times induces stationarity in Y_t. If $Y_t \sim I(0)$, then no differencing is required as Y is stationary (Jefferis and Okeahalam, 2000). The test proposed by Dickey-Fuller to determine the stationarity properties of a time series is called the Unit Root test denoted by DF. The regression equation for the DF class of unit root test is:

$$\Delta Y_t = \varphi Y_{t-1} + \varepsilon_t; \varepsilon_t \sim N(0, \sigma^2), Y_0 = 0 \quad (2)$$

The unit root test above is valid only if the series is an autoregressive, AR(1) process. The Augmented Dickey-Fuller (ADF) tests use a difference method to control for higher-order serial correction in the time series. Another alternative test for stationarity is the Phillips-Perron (PP) test. The PP test allows for individual unit root process so that the autoregressive coefficient can vary across units (Ajetomobi, 2008). The stationarity tests make a parametric correction for higher-order correlation by assuming that the Y series follows an AR(p) process and adjusting the test methodology. The ADF is identical to the standard DF regression, but augmented by k lags of the first difference of the series as follows:

$$\Delta Y_t = \alpha Y_{t-1} + \sum_{i=1}^{k} \omega i \Delta Y_{t-1} + \varepsilon_t \quad (3)$$

Where the lag k is set so as to ensure that any autocorrelation in Y_t is absorbed and that a reasonable degree of freedom is preserved, while the error term is white noise or stationary.

The GMM is widely and preferably used in applied econometric research. Zhang and Fan (2004) applied a GMM technique to empirically test the causal relationship between productivity, growth and infrastructural development using India district-level data from 1970 to 1994, while Fan et al. (2008) assessed the impact of public expenditure in developing countries.

Table 2
Description of variables used in estimating the generalised method of moment model.

Variable and measurement	Average	Std. Deviation
Index of agricultural production – aggregate	119.48	67.87
Index of agricultural production – crops	127.14	77.85
Index of agricultural production – staples	132.73	86.18
Index of agricultural production – livestock	142.60	108.72
Index of agricultural production – fishery	147.62	44.19
Index of agricultural production – forestry	109.45	43.14
Mean rainfall in ml	355.39	64.24
Proportion of arable land under irrigation	0.80	0.10
Flood occurrence (dummy)	0.42	0.50
Total agricultural (food) imports in million US dollars	2,236.47	1,971.98

2.3. Variables used for the estimation of the GMM

In estimating the ARIMA model using the GMM technique, agricultural production indices were the dependent variables while annual mean rainfall (in millilitres) and proportion of arable land under irrigation were the independent variables. The instrumental variables were incidences of flooding and annual total value of agricultural (food) imports (in million US dollars). These variables are predicted to have differential impact on aggregate agricultural production and sub-sectors of agricultural production in Nigeria. The variables on flooding and agricultural (food) imports were included as instrumental variables which enable the econometric model to run. They behave in similar ways as the other explanatory variables (rainfall and irrigation) which justifies their inclusion as suitable instrumental variables (Quian and Schmidt, 1999). The estimations were carried out with E-Views 7 econometric computer software package.

Table 1 gives the rationale/implications, hypotheses, *a priori* expectations, and relevant literature on the differential impacts of rainfall and irrigation on aggregate agricultural production and sub-sectors.

3. Results

3.1. Description of variables

Results in Table 2 show the description of variable used in the analysis. The results show that all the indices of agricultural production (aggregate, crops, staples, livestock, fishery, and forestry) are above the average for the base year (1990 = 100). This result indicates that the various sub-sectors of agricultural production increased above the base year period. On the index-by-index, the fishery and livestock sub-sectors, on the average, added more than

Table 3
Correlation matrix of variables.

Variables	Items	Aggregate agricultural production	Crops	Staples	Livestock	Fishery	Forestry	Rainfall	Flooding	Irrigation	Agricultural (food) imports
Aggregate agricultural production	Pearson Correlation	1	0.993***	0.992***	0.979***	0.401***	0.977***	−0.004	−0.111	0.929***	0.725***
	Significance		0.000	0.000	0.000	0.008	0.000	0.978	0.478	0.000	0.000
Crops	Pearson Correlation		1	0.999***	0.967***	0.366**	0.957***	−0.028	−0.146	0.947***	0.709***
	Significance			0.000	0.000	0.016	0.000	0.857	0.352	0.000	0.000
Staples	Pearson Correlation			1	0.966***	0.372**	0.952***	−0.030	−0.149	0.950***	0.704***
	Significance				0.000	0.014	0.000	0.848	0.340	0.000	0.000
Livestock	Pearson Correlation				1	0.410***	0.986***	0.027	−0.086	0.930***	0.747***
	Significance					0.006	0.000	0.862	0.584	0.000	0.000
Fishery	Pearson Correlation					1	0.431***	0.068	0.058	0.407***	0.444***
	Significance						0.004	0.664	0.710	0.007	0.003
Forestry	Pearson Correlation						1	0.029	−0.042	0.887***	0.753***
	Significance							0.856	0.790	0.000	0.000
Rainfall	Pearson Correlation							1	0.308**	−0.013	−0.234
	Significance								0.045	0.932	0.131
Flooding	Pearson Correlation								1	−0.175	−0.097
	Significance									0.263	0.536
Irrigation	Pearson Correlation									1	0.692***
	Significance										0.000
Agricultural (food) imports	Pearson Correlation										1

*Indicates 10 percent level of significance.
** Indicates 5 percent level of significance.
*** Indicates 1 percent level of significance.

40 percent over the base year for the study period. The average rainfall for the study period was 355.39 (±64.24) ml. The average proportion of arable land under irrigation was less than one percent (0.80 ± 0.10). Flooding incidences which were of national catastrophe in magnitude were recorded for an average of 42 percent for the study period. The total agricultural (food) imports in million US dollars were 2,236.47 (±1,971.98).

The results in Table 3 show the nature of the relationship (correlation) among the variables. The correlation matrix of the variables reveal that the independent variables (rainfall and irrigation are correlated with the set of dependent variables on agricultural production (see Table 3). Irrigation is positively and significantly correlated with aggregate agricultural production and other sub-sectors of agriculture. None of the considered production variables was significantly correlated with rainfall.

3.2. Results of the unit roots tests

As a necessary step for estimating times series econometric models, we examined the variables used for the GMM model for stationarity (or unit roots) using comparable standard test statistic recommended in literature (Breitung, 2002). The natural logarithms of the variables (except incidence of flooding which is a dummy variable) were tested for stationarity/unit roots using comparable test methodology of ADF and the Philips-Perron. Both tests yielded similar results (see Table 4). Only average annual rainfall and value of total agricultural (food) imports were stationary (white-noised) at level. All the variables (including, average annual rainfall and value of total agricultural (food) imports) were however, stationary at first difference which suggests that they were auto-regressive of order I (ARI) variables (Breitung, 2002), and that they are co-integrated with their past values. This result also informed the estimation of the GMM by suggesting the incorporation of appropriate lag lengths in the model estimation (Fan et al., 2008).

3.3. Differential impacts of rainfall and irrigation on agricultural production

Having established the auto-regressive order of the variables, we proceeded to estimate the differential impacts of rainfall and irrigation on aggregate agricultural production and by sub-sectors. The result of the econometric model is given in Table 5.

3.4. Impact on aggregate agricultural production

The results revealed that irrigation had positive and significant (4.3 percent) impact on aggregate agricultural production. Again, this is consistent with the result that irrigation could boost and sustain agricultural production in Nigeria. The diagnostic statistic (R-squared) of the aggregate agricultural production model showed that the independent variables explained the variation in agriculture production by as much as 74 percent. The impact of irrigation on aggregate agricultural production showed that a percentage change in arable land under would lead to 4.3 percent in aggregate agricultural production. This result also revealed that rainfall has positive but insignificant impact on aggregate agricultural production.

3.5. Impact on sub-sectors of agricultural production

Our results further reveal the impact of rainfall and irrigation on all the sub-sectors of agriculture in Nigeria. A percentage (one percent) change in the arable land under irrigation would lead to 4.99 percent in crops production; 5.37 percent in staples; 6.16 percent in livestock production; 3.11 percent in fishery production; and 2.69 percent in forestry production. The crops and staples sub-sectors have implications for food security especially for rural farming households in Nigeria. These sub-sectors comprise the cereals and legumes (rice, maize, wheat, sorghum, cowpea, soybean, roots and tuber crops (cassava, yam, potatoes and cocoyam).

Table 4
Unit roots tests.

Variable	At level (test statistic)		At first difference (test statistic)	
	Augmented Dickey-Fuller	Philips-Perron	Augmented Dickey-Fuller	Philips-Perron
Index of aggregate production	−1.0242	−1.2427	−5.9026***	−5.9026***
	(0.7359)	(0.6469)	(0.0000)	(0.0000)
Index of crops production	−1.0774	−1.3116	−5.7851***	−5.7933***
	(0.7159)	(0.6154)	(0.0000)	(0.0000)
Index of staples production	−1.0275	−1.3201	−5.5915***	−5.6066***
	(0.7347)	(0.6115)	(0.0000)	(0.0000)
Index of livestock production	−1.2919	−1.4082	−5.8757***	−5.8760***
	(0.6246)	(0.5692)	(0.0000)	(0.0000)
Index of fishery production	−2.3267	−2.4739	−7.2251***	−7.2232***
	(0.1686)	(0.1289)	(0.0000)	(0.0000)
Index of forestry production	−1.5164	−1.5549	−6.5335***	−6.5626***
	(0.5157)	(0.4964)	(0.0000)	(0.0000)
Mean annual rainfall	−4.9653***	−4.9871***	−8.9894***	−23.0233***
	(0.0002)	(0.0002)	(0.0000)	(0.0001)
Proportion of arable land under irrigation	−1.1104	−1.3873	−5.9871***	−5.9955***
	(0.7030)	(0.5794)	(0.0000)	(0.0000)
Value of total agricultural (food) imports	−3.5210**	−3.4116**	−6.5873***	−7.8971***
	(0.0122)	(0.0161)	(0.0000)	(0.0000)

*Indicates 10 percent level of significance.
** Indicates 5 percent level of significance.
*** Indicates 1 percent level of significance.

Table 5
Differential impacts of rainfall and irrigation on aggregate agricultural production and by sub-sectors.

Sub-Sector model	Variable	Coefficient	t-value	Probability	R-squared
Aggregate agricultural production	Constant	1.0265	0.1951	0.8463	0.7455
	Rainfall	0.7843	0.8877	0.3802	
	Proportion of arable land under irrigation	4.3260***	9.6783	0.0000	
Crops production	Constant	2.7294	0.5449	0.5889	0.8059
	Rainfall	0.5206	0.6194	0.5392	
	Proportion of arable land under irrigation	4.9888***	10.1583	0.0000	
Staples production	Constant	2.6379	0.4714	0.6400	0.8011
	Rainfall	0.5537	0.5898	0.5587	
	Proportion of arable land under irrigation	5.3695***	9.6597	0.0000	
Livestock production	Constant	2.4319	0.5809	0.5646	0.7723
	Rainfall	0.6283	0.8825	0.3829	
	Proportion of arable land under irrigation	6.1574***	10.1432	0.0000	
Fishery production	Constant	9.3469	1.0464	0.3018	0.8036
	Rainfall	2.5619	1.6857	0.0998	
	Proportion of arable land under irrigation	3.1134**	2.0523	0.0468	
Forestry production	Constant	2.6960	0.7787	0.4408	0.7362
	Rainfall	0.4354	0.7420	0.4625	
	Proportion of arable land under irrigation	2.6902***	8.3227	0.0000	

*Indicates 10 percent level of significance.
*** Indicates 1 percent level of significance.

4. Discussion

The results of this study have revealed the importance of agricultural water management, especially irrigation in the long-term sustainability of agricultural production in Nigeria under climatic changes.

The stationarity tests of the variables suggest the interdependence with one-year lag or past values. For instance, this result has implications for availability or retention rainfall from past year in the current year, all things being equal. But we know that soil water retention/availability is affected by many factors (Brooksbank et al., 2011), which are not captured in the present study. However, it is instructive that rainfall is needed in current agricultural production system in Nigeria, almost on a year-to-year basis. This result has implications for CSA in Nigeria because with the climate change predictions of variability in rainfall, any one year drought in Nigeria would have a negative impact on agricultural production and food security.

The impact of rainfall was positive on aggregate agricultural production and all the sub-sectors of agriculture, but the impact was not significant. Although the study did not capture rainwater retention and availability for the next farming season, the results suggest the relative dependence or reliance on rainfall, which dictates the start or end of the farming season in Nigeria. Similarly, the result suggests that, although Nigeria's agriculture is predominantly rain-fed, continued dependence on rainfall might not contribute to long-term agricultural production and food security. On the other hand, the results indicate that the sustainability of agricultural production and food security in Nigeria would rely on irrigation.

Irrigation, therefore, offers the potentials for a climate change adaptation measure and for managing extreme rainfall events (including drought). The advantages of all-year-round agricultural production, afforestation and development of ranches cannot be over-emphasized. Irrigation would assist in sustaining pasturelands, especially in the sahel and savannah areas of Nigeria, where pasturelands are critical for livestock production. This would reduce the menace of incessant conflicts between crop farmers and pastoralists due to north-south seasonal migration for pastures. The pasturelands could also contribute to reduced greenhouse gas emission and enhance carbon sinks in grazing lands and enhance grazing intensity, increased productivity, nutrient management, fire management and species introduction (O'Mara, 2012). This result underscored the potentials of existing River Basin Development Authority (RBDA) which is saddled with the responsibility of constructing large scale irrigation projects in Nigeria (Akinyosoye, 2005). Also, micro to medium scale irrigation intervention projects have been developed in low-land areas through the *Fadama* projects.

It is expensive to maintain an irrigation system in agriculture. However, the cost of irrigation system could be recouped through the production of high agricultural value commodities, especially during dry season farming. The irrigation technology could also involve drainages and channelling of flood water to reservoirs to mitigate flooding. Irrigation practices could be encouraged at both small-holder famers' level and community level. However, there are different social and economic costs of irrigation agriculture (Connor et al., 2008). These costs are often lower than the benefits (Mulangu and Kraybill, 2015) that could accrue in terms of increased agricultural productivity and diversification, economic profitability, environmental amelioration and reduction of agricultural production risks.

5. Conclusion and recommendations

The differential impact of rainfall and irrigation on agricultural production in Nigeria was assessed with implications for CSA. Time series datasets that spanned from 1970 to 2012 were used. Econometric analysis was used to estimate the differential impacts of rainfall and irrigation on agricultural production by aggregate and sub-sectors, including, all crops, staples, livestock, fisheries and forestry.

It was found that irrigation had a positive and significant impact on aggregate agricultural production as well as all sub-sectors of agriculture. The findings suggest the need for the minimization of the impact of climate-induced production risks through CSA. This would involve improving irrigation agriculture in Nigeria. Arable land areas under irrigation would ensure sustainable agricultural production and food security in Nigeria. It would also enhance the development of all subsectors of agriculture (crops, livestock, fishery and forestry). It would not only be beneficial to the crop production subsector only, but it would have beneficial impact on every other sub-sector of agriculture, thereby promoting inclusiveness and broad-based development of the agricultural economy.

Further, our findings suggest the need for a policy shift from the current agricultural production system which is predominantly based on rain-fed agricultural practices to complementary irrigation agriculture system. Such a policy shift would involve progressive scaling up of arable land areas under irrigation in Nigeria. The irrigation system of agricultural production is consistent with CSA in the face of global agro-climatic changes. The CSA supports intensive agriculture that enhances long-term sustainability of agriculture and food production.

Complementary irrigation system of agricultural production offers the potential for sustainable agricultural production practices and all-year-round agricultural production under climate change and variability. Irrigation system of agricultural production is consistent with CSA. Such agricultural practices would engender increased agricultural production (by aggregate and sub-sectors of agriculture), promote resilience through adaptation and mitigation (including beneficial impacts of forestry), and overall achievement of national food security and sustainable development goals. Hence, the opportunity for private and entrepreneurial investments in irrigation agriculture to support government large scale irrigation projects in Nigeria through the existing policy frameworks, including the River Basin Development Authority. This would also contribute to the transformation of the agricultural production system from the hitherto reliance on rainfall (which has been shown to have a high level of variability and solely unsustainable due to climate change) to climate-resilient agricultural production system that uses the irrigation system and complementarity with rainfall. Thus, we suggest appropriate agricultural production policies and practices that enhance complementary irrigation agriculture and agricultural water management (including, rainwater harvesting) since the continuous reliance on rain-fed agriculture practice, in the face of climate change and variability, would not enhance food security and sustainable agricultural production on the long-term. Hence, CSA offers complementary and sustainable agricultural production practices for Nigeria.

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