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Vertical versus horizontal expansion of food security crops in Sudan: A causality analysis of 1961-2017

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This research used FAO statistical data to test the causality between production, area and yield for Sudan's three major food crops; sorghum, wheat and millet. Results indicated a sizable gap in yield between Sudan and some selected top producing countries for the selected crops. Two-way causality was observed from production to area and vice versa for sorghum crops, accentuating horizontal expansion, while the lack of causality observed from yield to output omitted the impact of vertical expansion. The non existence of any causality for wheat crops indicates the exclusion of both vertical and horizontal expansion, a result that could be explained by the unsuitability of the Sudanese climate for wheat growth. Causality results for the millet crop suggest the absence of causality between production, area and yield in all directions, which can be attributed to low yield, which is itself due to the lack of recommended technical packages required for enhanced production. The research recommends emphasis on vertical expansion to develop plans for sustainable agriculture in Sudan. Further recommendations focus on upgrading the efficiency of current agricultural production systems through the application of appropriate technological packages. Regarding the wheat crop, the study recommends in-depth integrated research on comparative advantage, developing heat-tolerant varieties and the economic feasibility of growing wheat in Sudan.

Key words: Cereals, climate change, yield gap, technological packages, sustainable agriculture, final prediction error.

INTRODUCTION

FAO (2006) defined the multidimensional nature of food security captured by availability, accessibility, food use and stability. Twenty-five of the 39 countries experiencing serious food insecurity thus requiring foreign support to overcome itare in Africa (Sudan being one of them) and 11 are in Asia. To overcome food insecurity, (FAO, 2006) emphasized rural development productivity enhancements, including improved food production by small-scale farmers.

According to FAO (2018), Africa experiences severe food insecurity; around 27.4% of the population suffered food insecurity in 2016, a rate nearly four times greater

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than any other region. Further, Africa especially sub-Saharan Africa is one of the regions where food insecurity is increasing.

Knox et al. (2012)adopted an organized review and meta-analysis of data in 52 original published articles to assess the anticipated impacts of climate change on the harvest of major crops in South Asia and Africa. The anticipated mean changeby the 2050s in the harvest of all crops, in both regions, is 8%. Across Africa, mean yield changes of 17% for wheat, 5% for maize, 15% for sorghum and 10% for millet are projected. Hence, signal of vigorous impact of climate change on crop harvest in Africa and South Asia is for wheat, maize, sorghum and millet, with an anticipated negative impact on food security.

The sources of growth in production of cereals in the state of Uttar Pradesh in India were investigated by (Sharadet al., 2018), adopting a methodology based on the dynamic nature of time and the regionalization of production, area and harvest of main cereal crops. The results indicated positive progress in the production, area and harvest of wheat, rice and maize, while other crops exhibited a mixed trend. Through the study period, variability was recognized as the highest in production, followed by harvest and area.Total production of cereals was caused by an increase in area, and its interference with other elements, thus emphasizing horizontal expansion (focusing on increases in area).Based on Sanders et al. (2019), sorghum maintains a vital role for food security in Sub-Saharan Africa. However, despite considerable research following the extreme African drought of 1968–1973, sorghum technological packages in Sub-Saharan Africa's farmers' fields were only slowly applied. The situation of sorghum was reviewed globally by Sanders et al. (2019), in the U.S. and in Sub-Saharan Africa during the period 2007-2017.The results of a 12-year program in the Sahel region of West Africa to host innovative sorghum technology were identified in Mali. The program identified innovative technologies that were provided to some farmers' associations. The Mali program was then combined with two agencies to enhance the pilot program. The pilot scheme confirmed that harvests with modest fertilization, new varieties and improved cultural practices could be increased between 50%and 100%, assuring vertical expansion (focusing on increases in yield).

Applying a world market model with short- to long-run yield response adopting available scientific research outcomes and data (Thompson et al., 2019) approximated yield elasticities that permit agricultural commodity and food policy analysis. Results highlighted substantial differences in quantity and price effects, depending on the yield elasticities. Moreover, results demonstrated the necessity of identifying yield responses to prices when evaluating impacts on food security in the face of population growth, climate change and other long-run pressures.

Liu et al. (2008) evaluated under nutrition at the national level for Sub-Saharan African (SSA) countries in order to locate regions of greatest challenge. The influence of climate change on the production of six main crops namely cassava, wheat, maize, sorghum, millet and rice was examined with a GIS-based environmental policy integrated climate model (GEPIC) with the same spatial resolution.

Upcoming hunger hotspots are estimated in the framework of predicted climate, economic, social and biophysical changes. The results indicated that some regions in Nigeria, Sudan and Angola where a large number of people currently suffer under nutrition might be able to increase their food security status through increasing purchasing power. In the near future, some regions in SSA will suffer from a low capacity to import food along with lower per capita calorie availability. Special attention should therefore be paid to these hotspot regions, Sudan being one of them, with the intention of meeting hunger alleviation goals in SSA.

Aiming to measure the impacts of temperature increase on wheat harvest, Asseng et al. (2017) constructed a grain yield–temperature response function combined with a quantification of model uncertainty using a multi-model ensemble from two irrigated spring wheat areas (Sudan and India) and applied it to irrigated spring wheat regions around the world. Wheat-growing regions with great harvest reductions as a result of increased temperatures corresponded with great poverty headcounts in southern Pakistan and southern India, indicating that these areas are forthcoming food insecurity hotspots.

The relative harvest reductions are higher in low-yielding atmospheres (for example high temperature areas in southern India, southern Pakistan and wheat-growing regions in Sudan). Farmers in the aforementioned regions are expected to be hit hardest by increasing temperatures. While Sudan could possibly produce more wheat provided irrigation is available, wheat harvests would be low owing to high temperatures, with additional temperature increases further restricting wheat production.

Sorghum, millet and wheat are considered staple food grains in Sudan. Sorghum is among the food grains spread geographically throughout Sudan. In the Northern State of Sudan, wheat is the major food grain, followed by sorghum. In eastern and central Sudan, sorghum is more dominant, while millet is the main food grain in western Sudan, followed by sorghum (Abdalla, 2016).

Mahran (2000)employed the ordinary least squares (OLS) method of analysis to evaluate the achievements of the national development strategies of medium-term plans and programs during the period 1970/1971-1992/1993. In particular, Mahran examined achievements as they relate to meeting the objective of national self-sufficiency in food through vertical and horizontal

expansions infood production. An exponential function was used for estimating the trends in area, production and productivity for the major staple food crops sorghum, wheat and millet, applying annual time series data during the period 1970-1995. Results indicated that vertical expansion alone does not increase output. Hence, policies should emphasize enhancing agricultural productivity through the production of new varieties and assured application of technical packages. Further, the research emphasized the importance of increased productivity to food security as a mean of paving the way for industrial growth.

The impact of meteorological drivers on crop yields and the effects of herbicide application on farm productivity were examined (Fahmiet al., 2017)at two locations in Sudan, namely El Dali and El Mazmum, for ten successive years, from 2001-2010. Analysis of time series annual and monthly precipitation and yields of sorghum, millet and sesame were undertaken using the Mann-Kendall test and Sen's slope estimator methodologies. Results indicated that variation in crop yields is caused mainly by inter-annual variations in precipitation and insufficient agricultural practices.

Based on Reynolds et al. (2016), wheat, rice, sorghum, millet and maize provide more than half of globally needed food calories. To preserve global food security constrained by the climate change challenge, there is an increased necessity to utilize prevailing genetic variability and evolving cultivars with higher genetic harvest potential. Hence, the prospect of sharing knowledge between researchers and recognizing priority traits for further research could enhance breeding effects and help to detect the genetic focus that regulates adaptation. A globally harmonized path to crop phenotyping and modeling, combined with operative sharing of knowledge, data and facilities, will enhance cost effectiveness and help to implement genetic benefits forall staple crops, resulting in a higher yield of food security crops.

Using descriptive and regression analysis, Elmulthumet al. (2011) provided some insightful forecasts concerning food security for the period 2009-2020, assuming exponential growth over time. Results proved self-sufficiency in cereals of less than 100% during the period 1986-2009, while forecasts for the production and consumption of cereals indicated that food insecurity would persist during the period 2009-2020. Research findings recommend the adoption of clear and sound agricultural policies to ensure the accessibility and availability of food crops at all times. Thus, agricultural strategies could encourage producers of food crops to boost food crop harvests.

Emphasizing the importance of food security for Sudan, the present research aimed to examine the causality between production, area and yield for the major staple food crops in Sudan: sorghum, wheat and millet.

METHODOLOGY

Based on Granger (1969), testing the causality between two variables, for example Y and X, involves estimating the following regression equations:

$$Y_t = \sigma + \sum_{i=1}^{n} \mu_i Y_{t-i} + \sum_{j=1}^{h} \pi_j X_{t-j} + \pounds_t \tag{1}$$

$$X_t = \alpha + \sum_{i=1}^{k} \emptyset_i Y_{t-i} + \sum_{j=1}^{q} \partial_j X_{t-j} + \epsilon_t \tag{2}$$

Where,$\pounds_t$ and ϵ_t denote white-noise errors, n, h, k and q denote the number of lagged variables in undertaken regressions. Granger methodology is based on calculating the ordinary least square estimates of regression parameters in the above equations and applying the Wald F statistical test of joint statistical significance. For detecting the existence and direction of causality, three cases are distinguished. First, unidirectional causality implicates two cases: causality from X to Y and vice versa. Causality from X to Y is proved if the coefficients of the lagged X variable in equation 1 differ significantly from zero ($\sum \pi_j \neq 0$), while the coefficients of the lagged Y variable in equation 2 are not statistically different from zero ($\sum \emptyset_i = 0$)). Unidirectional causality from Y to X occurs when the calculated coefficients of the lagged X variable in equation 1 are not significantly different from zero as a group$\sum \pi_j = 0$), while the calculated coefficients of the lagged Y variable in equation 2 are significantly different from zero ($\sum \emptyset_i \neq 0$)). Bilateral causality occurs if the coefficients of the lagged Y and X variables are significantly different from zero in both estimated regression equations. More properly, causality from X to Y co-occurs with causality from Y to X when the hypotheses of ($\sum \pi_j \neq 0$)and ($\sum \emptyset_i \neq 0$) are statistically accepted for equations 1 and 2. Independence of the two variables is advocated when the coefficients of the lagged X and Y variables are not significantly different from zero, accepting null hypotheses of $\sum \pi_j = 0$)and and$\sum \emptyset_i = 0$). It has been a common exercise in causality research to adopts Granger (1969) methodology to select the lag order on an ad hoc basis and to use the same lag order in all regressions. According to (Thornton and Batten 1985) and Hsiao (1979, 1981), the Granger procedure may give rise to misleading results. Based on the above (Hsiao 1979), (Hsiao 1981) proposed an alternative methodology combining the Granger (1969) test of causality and the final prediction error measure developed by Akaike (1969). Based on Akaike (1969), the final prediction error (FPE) statistic is a minimum for the optimum lag for the model and has solved the identical problem of determining the correct order of an autoregressive model for the data.

The proposed methodology has the advantage of allowing the data to define the optimum lag order for each variable. Based on Hsiao's (1979, 1980) methodology adopted by (Mahran, 2003), the Y variable is first assumed as the only output of the system. A series of auto-regressive regressions on Y variable starting from one lag, and adding one more lag in succeeding regressions were run. For each of the succeeding auto-regressive regressions, the final prediction error is estimated using the following equation:

$$FPE(h) = \frac{(T+h+1)}{(T-h-1)*((\frac{RSS(h)}{T})} \tag{3}$$

Where, T denotes the number of observations and RSS(h) the residual sum of squares with h lags. The optimum lag number h* is the one matching the autoregressive equation with the least FPE (h*). The equation with the least FPE (h*) is then regressed with lagged values of X, adding one more lag in each regression. The final prediction error is then calculated for each regression using the following formula:

$$FPE(h*, m) = \frac{(T + h + + m + 1)}{(T - h - - m - 1) * ((\frac{RSS(h*, m)}{T}))} \qquad (4)$$

The optimum lag order (m*) from these regressions is defined as the one which leads to the lowest FPR (h*,m*). Hence, testing for causality comprises a comparison between FPE(h*) and FPE (h*,m*). The test is now straightforward using the following criteria:

FPR (h*, m*) < FPR (h*)   X Granger causes Y
FPR (h*, m*) > FPR (h*)   X does not Granger cause Y

To test whether Y Granger causes X, or vice versa, the above methodology is repeated using X as a controlled variable and Y as the manipulated variable.

Akaike whose final prediction error (FPE) statistic is a minimum for the optimum length model, solved the identical problem of determining the correct order of an autoregressive model for the data. Since causality tests require stationarity of data, the Dickey-Fuller test was used to test the null hypothesis that the autoregressive model has a unit root(Cheung and Lai, 1995).

RESULTS AND DISCUSSION

This section starts with some descriptive statistics, comparing the yield of selected food crops in Sudan to the yield of the same crops in some of the top producing countriesincluding Nigeria, Egypt and Indiafor one decade. Comparisons indicated a recognized gap, where the yield of sorghum, wheat and millet in Sudan was 52, 33, and 30% ofNigeria, Egypt and India, respectively (Table 1).

Results of the Dickey-Fuller test proved the non-stationarity of the data for the three selected food crops.To determine the lag structure of all variables, one-dimensional autoregressive regressions were estimated using an upper limit of five lags for each variable. The estimated final prediction error for the results for sorghum, wheat and millet are reported in Tables 2, 4 and 6, respectively. The next step was to fix the number of lags in the controlled variables determined in the first step and regress with lagged manipulated variables added successively to determine the final prediction error of bivariate regressions. Results of the final prediction error for the bivariate regressions for sorghum, wheat and millet are reported in Tables 3, 5 and 7, respectively.

All estimated autoregressive and bivariate equations were significant, as indicated by F-statistic. In addition, Durbin-Watson statistics suggested the absence of autocorrelation for autoregressive and bivariate estimated equations.

In view of the results for the sorghum crop shown in Tables 2 and 3, a two-way causality from production to area and vice versa is acknowledged. Further, results indicated that production Granger-causes yield while yield does not Granger-cause production. The above results indicate that the increase in production is influenced by the increase in area, leading to a further increase in area, hence emphasizing horizontal expansion

for Sudan's dominant food crop. In addition, the large fluctuation in the output of the sorghum crop may contribute to an unforeseen impact of yield on output, excluding the impact of vertical expansion. The yield of sorghum is around 50% of the yield of one of the top producing countries, Nigeria (Table 1). The above results could be further explained by large areas cultivated for the sorghum crop, the main staple food crop in Sudan, together with conventional ways of crop production, in which the majority is grown byadopting low technical packages in rain-fed areas. The results in relation to sorghum are in line with(Mahran, 2003) regarding causality from production to area; however, the other causality results contradict the results of (Mahran, 2003). This contradiction could be explained by the length of time series and the dependence of policy makers on increasingly large areas for the required level of sorghum production to meet increasing demand.

Regarding the wheat crop, the results shown in Tables 4 and 5 proved the nonexistence of causality between production and area grown in any direction. The results also point to the absence of causality between production and yield in both directions. Results in relation to wheat may be explained by the unsuitability of environmental conditions for the planting of wheat in those areas where the crop is grown. Thus, according to policy makers, neither vertical nor horizontal expansion will pay off or motivate farmers to grow wheat. A sizable gap in the yield of wheat was observed when comparing the yield of Sudan to the yield of Egypt, one of the top ten wheat producing countries. The above results are in line with (Asseng et al., 2017), who argued that, despite the potential to grow more wheat in Sudan assuming the availability of irrigation water, crop yield would be low owing to high temperatures, with forthcoming rises in temperature limiting further production. Hence, farmers are expected to be hard hit by these increased temperatures.

Causality results for millet, reported in Tables 6 and 7, suggest the absence of causality between production and area in all directions. Reasons for this could be attributed to observed negative growth of production and area for the millet crop for most years of the study period (calculated from FAO statistics). In addition, the majority of the population does not consume millet, which is widely grown and consumed by the local population in western Sudan.

Results also indicated the nonexistence of causality for yield and production of millet in either direction, a result that could be explained by the low yield of millet compared to India, one of the top ten millet producing countries, where the millet yield was only 30% of Indian yield during the last decade (Table 1). The above results could also be attributed tothe problems facing women as the main producers of food crops in western Sudan (where the majority of millet is grown and consumed),

Table 1. Yield of selected crops relative to high yield countries (hg/ha).

Sudan as % of highest yield	Country	Highest yield average 2008-2017	Sudan average 2008-2017	Crop
30	India	11218	3357.8	Millet
52	Nigeria	11838	6180.4	Sorghum
33	Egypt	64205	21326	Wheat

Source: authors' calculations based on FAO statistics.

Table 2. Final prediction error of one-dimensional autoregressive processes for area (A), production (P) and yield (Y) of sorghum.

Final prediction error (FPE) of controlled variable			
h	A	P	Y
1	4.96079E-07	4.04101E-06	4.50472E-06
2	3.62588E-07*	1.48751E-06	2.09627E-06
3	3.67046E-07	1.23406E-06*	1.95255E-06
4	3.96381E-07	1.3E-06	1.8178E-06*
5	4.31087E-07	6.14083E-05	2.07833E-06

Source: Authors' calculations; asterisks denote the minimum FPE of autoregressive process; h denotes the lag number.

Table 3. Sorghum causality results.

Controlled variable	Manipulated variable	FPE (h*)	FPE (h*,n*)	Causality results
A (2)	P(3)	3.62588E-07	3.1763E-07	Production causes area
P(3)	A (2)	1.23406E-06	7.22573E-07	Area causes production
P(3)	Y (1)	1.23406E-06*	1.29884E-06	Yield does not cause production
Y(4)	P(1)	1.8178E-06*	4.32247E-08	Production causes yield

Source: Author's calculation. Figures in brackets are the optimum lag orders of variables.

Table 4. Final prediction error of one-dimensional autoregressive processes for area (A), production (P) and yield (Y) of wheat.

Final prediction error (FPE) of controlled variables			
h	A	P	Y
1	0.000164*	3.64E-05*	6.129E-08
2	0.000181	3.89E-05	5.59103E-08
3	0.000199	4.16E-05	5.69077E-08
4	0.000227	4.47E-05	5.19165E-08*
5	0.000242	4.56E-05	5.87051E-08

Source: Authors' calculations; asterisks denote the minimum FPE of autoregressive process; h denotes the lag number.

as indicated by (Ibnouf 2011). The main problem, however, is a lack of the full package of enhanced production methods, including upgraded seeds, fertilizers, recent farming methods, pesticides, credit services,

Table 5. Wheat causality results.

Controlled variable	Manipulated variable	FPE (h*)	FPE (h*,n*)	Causality results
A (1)	P (1)	0.000164*	0.000168	Production does not cause area
P(1)	A (1)	3.64E-05*	3.77E-05	Area does not cause production
P(1)	Y (1)	3.64E-05*	3.75687E-05	Yield does not cause production
Y(4)	P (3)	5.19165E-08*	5.77E-08	Production does not cause yield

Source: author's calculation. Figures in brackets are the optimum lag orders of variables.

Table 6. Final prediction error of one-dimensional autoregressive processes for area (A), production (P) and yield (Y) of millet.

	Final prediction error (FPE) of controlled variables		
h	A	P	Y
1	7.31E-08	1.79E-06*	1.74E-08*
2	6.89E-08	9.93E-07	2.02E-08
3	6.23E-08*	7.05E-07	2.51E-08
4	6.9E-08	7.42E-07	3.11E-08
5	7.59E-08	6.47E-07	3.17E-08

Source: Authors' calculations; asterisks denote the minimum FPE of autoregressive process; h denotes the lag number.

Table 7. Millet causality results.

Controlled variable	Manipulated variable	FPE (h*)	FPE (h*,n*)	Causality results
A (3)	P (1)	6.23E-08*	3.39451E-06	Production does not cause area
P(1)	A (3)	1.79E-06*	3.97E-05	Area does not cause production
P(1)	Y (4)	1.79E-06*	7.86E-05	Yield does not cause production
Y(1)	P (3)	1.74E-08*	1.07E-06	Production does not cause yield

Source: author's calculation. Figures in brackets are the optimum lag orders of variables.

proper technologies and marketing services.

Conclusion

The present research results indicate an emphasis on horizontal expansion for the major staple food crop in Sudan, while neither horizontal nor vertical expansion is proved for either millet or wheat. The main policy lesson derived from the above causality results concerning food crops in Sudanespecially sorghum and milletis to focus more on vertical expansion in developing strategies for sustainable agricultural development. The most economical and practical method to attaining a large increase in yield lies in improving the efficiency of the current agricultural economyadvances in the quality of inputs together with the application of recent technological packages. Regarding the wheat crop, the study recommends further comprehensive research on comparative advantage, developing heat-tolerant varieties and the economic viability of growing wheat in Sudan.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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