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Effect of Carbon Dioxide Concentration on Cereal Yield in Sudan

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Effect of Carbon Dioxide Concentration on Cereal Yield in Sudan

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Abstract

To estimate the long-term effect of carbon dioxide (CO₂) emission on cereal yield in Sudan, we employed an autoregressive distributed lagged (ARDL) bound test for cointegration analysis. The ARDL results reveal evidence of cointegration between the dependent variable (cereals yield) and two independent variables (CO₂ emission) and agricultural GDP. The estimation results of the error correction model indicate that change in CO₂ has a positive and significant impact on the cereal yield in the long and short terms, as 1% increase in CO₂ leads to a cereal yield increase by 3% in the short term and by 0.7% in the long term. This result adds two important findings to the existing literature: First, the positive impact of CO₂ on cereal yield in Sudan supports previous research findings in other countries of warm and arid climates. Second, the effect of CO₂ on cereal yield differs from short to long term, as our finding indicates that CO₂ has a greater positive effect in the short term compared to that in the long term, implying that the effect of CO₂ on cereal yields is not linear, as commonly perceived, but it decreases as time duration extends to longer periods. This may be due to the CO₂ effect on global warming that emanates from cumulative CO₂ concentration, which leaves a disproportionate impact on crops over time.

Keywords: Cereal yield; Emission; Carbon dioxide; Sudan.

1. INTRODUCTION

Changes in climatic conditions have a significant impact on agricultural production and productivity in developed as well as in developing economies (Zaied, 2013).¹ More specifically, the effect of climate change on agriculture productivity is becoming more important as researchers recently have indicated that crop yield and the type of crops to grow are influenced by climate change (Deryng *et al.*, 2016; Mendelsohn *et al.*, 1994; Fischer *et al.*, 2001). The increasing role of agricultural sector in the economies of underdeveloped economies, including food security, employment opportunity, raw material provision for the industrial sector, and a source of foreign exchange via the supply of export product, makes the research on the impact of climate change on agricultural sector even more important.

Alam (2013) indicated evidence of slower growth rate of agricultural sector over the years due to climate change, and indicated that the situation becomes more worrisome given fast ongoing demographic changes of urbanization and population growth rates worldwide. As in developing economies, such as in Sudan, agriculture is largely affected by the climatic condition; there is a need to examine empirically the effect of climate changes on agriculture so that the right adaptation policy could be adopted to ensure food security.

Applied research (Deryng *et al.*, 2016; Zaid, 2013; Blanc, 2011) indicates that carbon dioxide (CO₂) plays an important role in crop yield enhancement as CO₂ plays the role of fertilizer in the growth of crops

¹ Change in climate conditions includes increased frequency of climate extreme events, altered precipitation, higher temperatures, and elevated CO₂ concentration.

classified as C3 and C4 crops.² These research findings indicate that CO₂ has both direct and indirect effects of crops yield by increasing photosynthesis, which stimulate growth, and reducing the amount of water the crops lose because of transpiration.³

According to Blanc (2011), "greater CO₂ concentration enhances CO₂ assimilation by crops. This results in faster stomata closures and ultimately lower transpiration rates (i.e., crops lose less water). Therefore, CO₂ concentration increases are most beneficial in sudano-sahel, which has a warm and arid climate." The consequence of this result is that crop yield is expected to have a positive link with CO₂ emissions, especially cereal crops, which is the subject matter of this research.

2. LITERATURE REVIEW

The empirical findings on the effects of climate change on agricultural productivity can be viewed in various papers including Deryng *et al.* (2016), Blanc (2011), Wang *et al.* (2011), Lippert *et al.* (2009), Alam (2013), Kimball *et al.* (2002), Adams *et al.* (1998), Adams *et al.* (1995), Lobell and Field (2008), Lang (2007), Schlenker *et al.* (2006), Derner *et al.* (2003), Tubiello and Ewert (2003), and Fischer *et al.* (2002).

Deryng *et al.* (2016) indicated that increased CO₂ concentrations in the atmosphere may reduce the utilization of water in crops and alleviate significantly the yield losses due to climate change; however, Alam (2013) states that the increasing concentration of CO₂ may cause a decline in agricultural productivity and "will act as a fuel to the higher prices of goods and services in the economy." However, Blanc (2011) shows that CO₂ concentration has significant long-run and short-run effect on millet yield but not on cassava and maize yields and has an insignificant impact on sorghum yields. Other researchers such as Lobell and Field (2008) also indicated that CO₂ fertilization has a positive impact on cereal plant yields in the Northern Hemisphere countries. Similar results reported by Cure and Acock (1986) who revealed evidence of a positive relationship between maize yields and CO₂ fertilization. However, de Tafur *et al.* (1997) indicated that there is a negative association between CO₂ and cassava yields, and similarly Fuhrer (2003) states that "Warming accelerate plant development and reduces nutrients efficiency use, and favors C4 weeds over C3 crops." In another study, Adams (2007) show evidence of positive plant yields from CO₂ fertilization.

To sum up, a significant number of empirical research support the evidence that more CO₂ concentration reduces plant transpiration and improves the water-use efficiency of plants. This result accentuates the importance of CO₂ concentration on cereal yield in regions of warm and arid climate where the efficiency of water use is essential. Deryng *et al.* (2016) conclude that there have been very few studies analyzing the impact of CO₂ concentration on crops yield in dry and warm climate regions, where efficient utilization of water is very essential. This paper aims to fill this void of research gap by investigating the impact of CO₂ concentration on cereal crops in the distinctive warm and arid climate of Sudan. Currently, Sudan is a major regional producer of a number of cereal crops including sorghum, millet, sesame, and wheat. The findings in this paper on the impact of global warming on food safety in underdeveloped countries have been added to the existing literature.

3. GLOBAL WARMING AND AFRICA

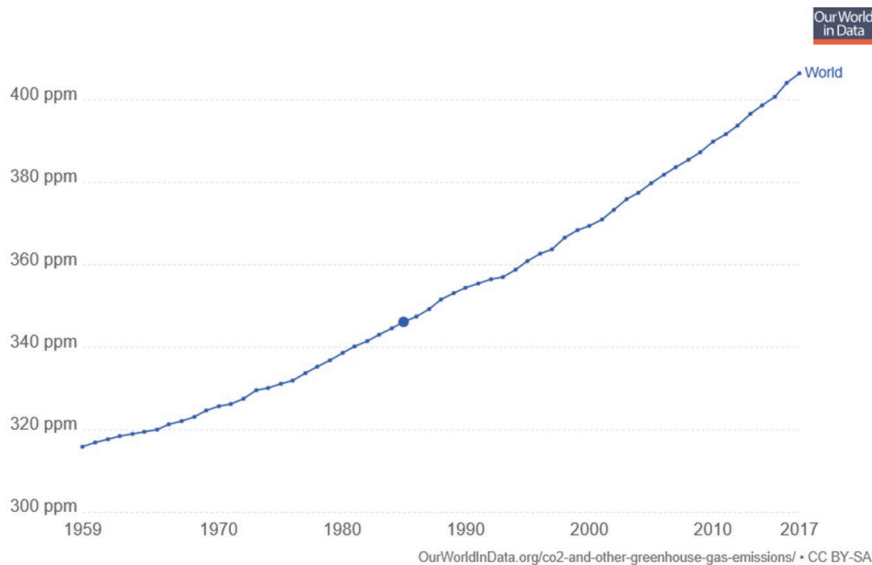
Despite all African countries listed among the least contributors to CO₂ emission worldwide, less than 1% of global emission (Figure 1), but still regarded as vulnerable to the global warming effect caused by the fast increasing cumulative CO₂ emission, from 300 ppm in 1959 to 450 ppm in 2017 (Figure 2). As a result, in general, global warming is expected to affect negatively the African countries in the coming 30 years (5th Intergovernmental Panel on Climate Change (IPCC) report). Global warming is expected to leave adverse potential effects on health and crops in Africa due to extreme weather events causing floods, droughts,

² C3 plants are beans, rice, wheat, and potatoes; C4 plants are corn and sugarcane.

³ The CO₂ fertilization effect or carbon fertilization effect suggests that the increase of carbon dioxide in the atmosphere increases the rate of photosynthesis in plants. The effect varies depending on the plant species, the temperature, and the availability of water and nutrients.

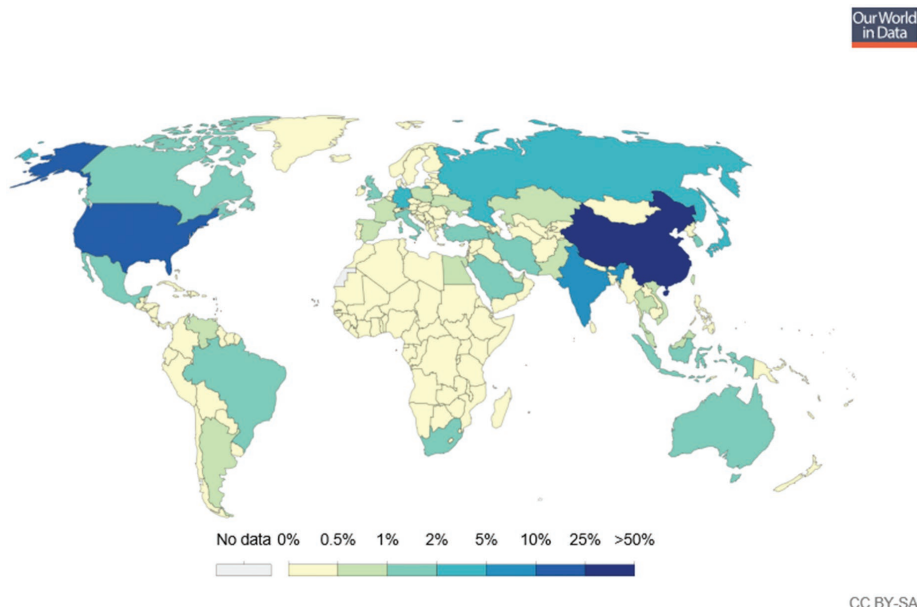
storms, and heat waves. Thus, climate severity and volatility expected to severely impinge on agricultural production, causing food shortage and demographic change in the continent. If this is the case, then the impact of cumulative CO₂ concentration on crops and plants expected to have disproportionate effects in the long terms compared to short term, depending on the speed of global CO₂ concentration over time.

Figure 1. Global CO₂ Atmospheric Concentration



Global mean annual concentration of carbon dioxide (CO₂) measured in parts per million (ppm).
 Source: NOAA/ESRL (2018).

Figure 2. Annual share of global CO₂ emissions, 2016



Each country's share of global carbon dioxide (CO₂) emissions. This is measured as each country's emissions divided by the sum of all countries' emissions in a given year; this does not include international aviation and shipping (known as 'bunkers') and 'statistical differences' in carbon accounts.

Source: Our World in Data based on Global Carbon Project (2017).

4. METHODOLOGY

Since our primary aim in the current study is to assess the long-term association between CO₂ emission levels and the yield of cereal crops, to determine the appropriate cointegration model, we need to investigate first the order of integration of each variable included our estimation process. This requires estimation of the unit root for each variable to determine the order of integration of variables, which is a prerequisite for the proper choice of cointegration model.

Before we start, let's recall what a conventional ECM (error correction model) for cointegrated data looks like. It would be of the form:

$$\Delta y_t = \beta_0 + \sum_0^p \beta_i \Delta y_{t-i} + \sum_1^{q_1} \gamma_j \Delta x_{1,t-j} + \sum_1^{q_2} \delta_k \Delta x_{2,t-k} + \varphi z_{t-1} + e_t \quad (1)$$

Here, z , the "error-correction term," is the ordinary least squares (OLS) residuals series from the long-run "cointegrating regression" specified as:

$$y_t = \alpha_0 + \alpha_1 x_{1,t} + \alpha_2 x_{2,t} + v_t \quad (2)$$

We can use unit root tests to check that none of the series we're working with are $I(2)$, since the ARDL model cannot work with $I(2)$ or a higher order of integration.

For ease of exposition, substituting Equation 2 in Equation 1, we get the unrestricted ECM specification:

$$\Delta y_t = \beta_0 + \sum_0^p \beta_i \Delta y_{t-i} + \sum_1^{q_1} \gamma_j \Delta x_{1,t-j} + \sum_1^{q_2} \delta_k \Delta x_{2,t-k} + \theta_1 x_{1,t-1} + \theta_2 x_{2,t-1} + \theta_0 y_{t-1} + e_t \quad (3)$$

The difference here is that we've now replaced the error-correction term, z_{t-1} with the terms y_{t-1} , $x_{2,t-1}$.

The basic assumption in the ARDL model is that the error terms in Equation 3 should be serially uncorrelated. To test for serial independence of the error terms, we can use the lagrange multiplier (LM) test to test for the null hypothesis that the errors are serially uncorrelated, against the alternative hypothesis that they are serially correlated. To perform the ARDL cointegration test on Equation 3, we compute the F-test to check the hypothesis $H_0: \theta_0 = \theta_1 = \theta_2 = \theta$ against the alternative that H_0 is not true. We do this to infer the absence of a long-run equilibrium relationship between the variables. This absence can be tested by testing for zero coefficients for y_{t-1} , $x_{1,t-1}$ and $x_{2,t-1}$ in Equation 3. A rejection of H_0 reveals the presence of a long-run relationship.

A problem that has been addressed in the ARDL model is that the exact critical values for the F-test are not applicable for a mix of cointegration orders of $I(0)$ and $I(1)$ variables. However, constructed upper and lower bounds of critical values for the F-test, where the lower bound critical values assume all variables are $I(0)$ and the upper bounds assume all variables are $I(1)$. As a matter of fact, the truth can lie in between the two bounds. So, if the computed F- statistic is below the lower bound, we would deduce that the variables are $I(0)$, and if the computed F-statistic exceeds the upper bound, we would conclude that we have cointegration. If the F-statistic falls between the two bounds, the test is inconclusive.

Alternatively, we can also perform the ARDL bound test by testing t-test of $H_0: \theta_0 = 0$ against $H_1: \theta_0 < 0$. If the t-statistic for y_{t-1} in Equation 4 is greater than the "I(1) bound" tabulated by Pesaran et al. (2001, pp. 303-304), we conclude a cointegration, which implies a long-run relationship between the variables. If the t-statistic is less than the "I(0) bound," we conclude that the data are all stationary, and that there is no cointegration.

If the results of the ARDL conclude cointegration, we can estimate the long-run relationship between the variables:

$$y_t = \alpha_0 + \alpha_1 x_{1,t} + \alpha_2 x_{2,t} + v_t \quad (4)$$

as well as the usual error correction model (ECM):

$$\Delta y_t = \beta_0 + \sum_0^p \beta_i \Delta y_{t-i} + \sum_1^{q_1} \gamma_j \Delta x_{1,t-j} + \sum_1^{q_2} \delta_k \Delta x_{2,t-k} + \varphi z_{t-1} + e_t \tag{5}$$

where $z_{t-1} = (y_{t-1} - a_0 - a_1 x_{1,t-1} - a_2 x_{2,t-1})$ and the a s are the OLS estimates of the α s in Equation 5.

We can deduce long-run coefficient values from Equation 3 and noting at a long-run equilibrium $\Delta y_t = 0, \Delta x_{1,t} = \Delta x_{2,t} = 0$, we see that the long-run coefficients for x_1 and x_2 are $-(\theta_1/\theta_0)$ and $-(\theta_2/\theta_0)$, respectively.

5. EMPIRICAL ANALYSIS

Equation (1) specifies cereal yield (kg per hectare) as a function of CO₂ emissions (from liquid fuel consumption, kt) and the GDP value added by agricultural sector during the sample period from 1961 to 2016.⁴ The data have been collected from World development Indicators, 2017 edition. To assess the long-term association between cereal yield and the explanatory variables mentioned earlier, we employed an ARDL bound test for cointegration analysis.

We employed the conventional PP (Phillips-Perron) test, which is a test for the null hypothesis of a random walk, to test the unit root in the data. The ARDL cointegration test requires each variable either integrated of order 0, or 1 (i.e., I(0) or I(1)) but not I(p) for $p > 1$, as the test result becomes inconclusive for $p > 1$. As the results of unit root test included in Table 1 indicate that some variables are I(1) and others are I(0), we can apply the ARDL specification as implied in equation (3) to assess the long-run association between the dependent variable and the set of the independent variables.

The calculated F-statistic is equal to 19.24, which is greater than the upper bound critical value (3.79) at 5% significance level. This result rejects the null hypothesis of no cointegration between the variables. Evidence of long-term association of cereal yield, CO₂ emission, and contribution of the agriculture sector in GDP justify the use of ECM specification as represented in equation (3). Table 2 presents the estimation results of ECM specification and indicates that the change in CO₂ has a positive and significant impact on cereal yield in Sudan in the long and short terms, as 1% increase in CO₂ increases the cereal yield by 3% in the short term but by 0.7% in the long term.

Table 1. Unit Root Tests.

Level	PP test statistics	Order of integration
y	10.7*	I(0)
x_1	2.9	I(1)
x_2	2.3	I(1)
First difference		
y	67.5*	I(0)
x_1	24.5*	I(1)
x_2	14.7*	I(1)

*Significant at 5% significance level.
 y = cereal yield; x_1 = CO₂ emission; x_2 = agriculture value added (%GDP).

⁴ Cereal crops in Sudan include beans, wheat, corn, and millet.

Table 2. ECM Specification.

	Coefficient	p-Value
Δy_{t-1}	-0.18**	0.08
$\Delta x_{1,t-1}$	0.03*	0.01
$\Delta x_{2,t-1}$	3.36	0.42
y_{t-1}	-0.59	0.46
$x_{1,t-1}$	0.004*	0.03
$x_{2,t-1}$	7.40*	0.00
Constant	37.51	0.82

*Significant at 5% significance level;

**Significant at 10% significance level.

y = cereal yield; x_1 = CO₂ emission; x_2 = agriculture value added (%GDP).

6. CONCLUSION

To assess the impact of CO₂ emissions on cereal yield in Sudan in this study, we specify yield as a function of CO₂ emissions and value added of the agriculture sector to GDP during the period 1961-2016. The total agricultural production variable is taken here, beside the CO₂ variable, to control all the factors that influence cereal yield other than CO₂ emissions.

To estimate the long-term association between cereal yield and the explanatory variables mentioned earlier, we employed an ARDL bound test for cointegration analysis.

The ARDL test results reveal evidence of cointegration between the dependent variable (cereals yield) and the two independent variables (CO₂ emission) and agriculture GDP. Evidence of long-term association of cereal yield and CO₂ emission justifies the use of ECM. The estimation results of ECM specification indicate that a change in CO₂ has a positive and significant impact on cereal yield in Sudan in the long and short terms, as 1% increase in CO₂ increases the cereal yield by 3% in the short term, but by 0.7% in the long term.

This result contributes to the existing literature in two ways: First, confirmation of the positive impact of CO₂ concentration on cereal yield indicated in the empirical literature. Second, the result that the effect of CO₂ on cereal yield differs from short to long term. Our findings indicate that CO₂ has a greater positive effect in the short term compared to the long term, implying that the effect of CO₂ on cereal yields is not linear, as commonly perceived, but it decreases as time span extends to longer periods. This may be because the CO₂ effect on global warming emanates from cumulative CO₂ concentration, which leaves a disproportionate impact on crops over time.

An important limitation of the current study is the error bounds of global CO₂ emission estimates arising from the exclusion of fuels supplied to ships and aircrafts in international transport.

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