Supply Response of Field Crops to Price and Environmental Factors in Traditional Rainfed Agriculture

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Abstract*: This study aimed to estimate supply response crops, i.e., sesame, groundnut, sorghum, and millet, in traditional rainfed agriculture, in North Kordofan State, Sudan, from 1990 to 2015. The response is estimated as the yield and area responses to prices, temperature, and rainfall. The study depended mainly on secondary data obtained from the records of the Ministry of agriculture and animal resources, Elobied Crops Market, and Elobied Airport Metrological Station. The co-integration and vector error correction approaches were applied to estimate the response. The results found that the estimated responses of crop yield in the long run to price were negative and inelastic for sesame, groundnut, and elastic for sorghum. It was positive and inelastic for yield millet yield. The estimated responses of crop area to price in the long run were negative and inelastic for sesame, sorghum, millet, and elastic for groundnut. The estimated responses of crop yield in the long run to temperature were negative and elastic for all crops and ranged from-24.01 to -197.83. The estimated responses of crop area in the long run to temperature were positive and elastic and ranged from 37.121 to 411.747.The estimated responses of crop yield to rainfall index, in the long run, were positive and elastic for groundnut (2.357), sorghum (4.667), and millet (1.142), but it is inelastic for sesame (0.509). The responses of crop area to rainfall index were negative and elastic and ranged from -13.745 to -1.086. The study concluded that rainfall index and temperature factors are the most dominating factors influencing yield and area behavior in the long-run, hence farmers' decisions.

***Keywords*: Kordofan, rain-fed, supply, response, error correction model**

I. INTRODUCTION

The traditional rain-fed agriculture is one of the three major production systems in Sudan, representing more than 50% of the total cultivated area. The rain-fed farming system is characterized by small farm size, labor-intensive cultivation techniques employing hand tools, low input levels, and poor yields.

Traditional rain-fed crop production is predominant in western Sudan and most other parts of Sudan. The average contribution of this sector to the total national production of millet, sorghum, sesame, and groundnut is about 93%, 27%, 39%, and 60%, respectively. However, the low productivity attributed to traditional technology, lack of rural savings and credit institutions, poor access to marketing services, inadequate infrastructure, and lack of safe water resources (Issam, 2010).

The most influential factors affecting the production of agricultural crops in Kordofan are climatic factors (rainfall and temperatures) and prices of crops in the market. So, the traditional agriculture sector in Kordofan region is highly exposed to climate change and, consequently, to its risks. The climate risk is capable of altering other risks such as asset depletion (damage and loss to assets as a result of extreme climate events), price risks (risk of falling or rising prices) and financial risk (from possible increase of interest rates). It is known that, risk refers to a probability that can be expected analyzing former information, while uncertainty applies to circumstances in which probability cannot be expected. Both risks and uncertainties have a contribution to the choice of appropriate practices to be applied in the farm. It is easily knowable there, how variation and annual weather and changing climate may affect production and growth of food and cash crops in kordofan. The effect on traditional agriculture and its consequences on society in kordofan are likely to differ locally depending on the type of climate change that has taken place in that area and the alternatives available to the producers. In long run climate change could affect crops produced in traditional production in kordofan in several ways such as change in productivity. Change in productivity appear in terms of quantity and quality of crops through changes in agricultural practices, in particular in relation of frequency and intensity of soil drainage (leading to nitrogen leaching), soil erosion, reduction of crop diversity through the loss of previously cultivated lands, land speculations, land renunciation, and hydraulic amenities.

Utmost of the research on the supply response in agriculture in developing countries was linked to how farmers respond to changes in the relative prices of various agricultural products. Nerlove (1958) and Krishna (1963) studied the relative price changes' effect on acreage. According to Binswanger (1989), supply response in developing countries is explained as the instability of agricultural output and cultivated area typically due to disparity in general prices; the literature on the supply response has focused on the short and long-term supply response of individual crops to changes in (relative) output and input prices since much of the agrarian price policy is made on a commodity-by-commodity base.

A typical supply response means that the higher the price level, the greater the output level offered for sale and vice versa. If food prices , were lowered, farmers would preserve more and market less out of a given food grain production. To conclude, traditional farmers respond positively to variations in food prices (Krishna 1963).

In the Sudan context, empirical estimations of agricultural supply responses in Sudan have revealed diverse findings. According to Medani (1970), Ali (1978), and Kabalo (1984), there were variances in the degree of response to prices, but the individual crops responded positively to the price change.

The general aimed of the study Supply Response under North Kordofan Environment in field crops production through:

- Estimating supply response to price and non-price factors.
- Estimating the impact of environmental factors on field crop production.

Depending to methodology the hypotheses of the study were

- Price of previous year has positive effects on productivity and areas of food and cash crops in North Kordofan State.
- Rainfall has positive impact on productivity and areas of food and cash crops in North Kordofan State
- Annual temperatures have negative impact on productivity and areas of food and cash crops in North Kordofan State.

II. METHODOLOGY

2.1 Model of analysis

In the literature, generally, two types of methods are found to be used in analyzing the farmers supply response behavior in agriculture, namely, the first is the Nerlovian direct reduced form approach and second is the indirect structural form approach which shows the supply function derived from the profit-maximizing framework. The studies using this approach have extensively surveyed by Just (1993) and Sadoulet and de Janvry (1995) . Nevertheless, the majority of studies follow the Nerlovian reduced form approach. The Nerlovian model is built to examine farmers' output reactions depending on price expectation and partial adjustment (Nerlove, 1958). It is also flexible enough to incorporate non-price factors. It can be computed regarding yield, area, or output response. The model is expressed as the desired yield or area of agriculturalproduce in period t is a function of expected relative prices P and exogenous shifters Z, which can be written as equation (1):

$$A_t^* = \alpha_1 + \alpha_2 P_t^* + \alpha_3 Z_t + u_t \qquad (1)$$

Where A^*_t is the desired yield/area in period t; P_t^* is the expected relative prices of the crop and other competing crops; Z_t is a set of other explanatory variables, involving the climatic, physical, and institutional factors. The u_t takes into account those unobserved random factors affecting the area under cultivation. Therefore, α_s (s =1, 2, 3) are long-run coefficients to be estimated which is the long-run coefficient of supply response. Partial Adjustment and Adaptive Expectation Farmers' response is constrained by factors like small land holding combined with the need to diversify production to minimize risk, credit constraint, and lack of availability of inputs (Moula, 2010). In addition, apprehension regarding the uncertainty of weather plays an important role. Thus, a complete adjustment in the desired position within a short period is subject to those constraints. So as to incorporate that possibility in the cultivation process, it is assumed in Nerlovian tradition that the change in yield between two periods happens in proportion to the difference between the expected output for the current period and the actual output in the previous period. Thus, the equation can be written as given below:

$$A_t - A_{t-1} = \delta(A_t^* - A_{t-1}) + \epsilon_t; 0 \le \delta \le 1 \qquad (2)$$

$$A_t = \delta Y_t^* + (1-\delta)A_{t-1} + \epsilon_t \qquad (3)$$

Generally, the price farmers expect to prevail at the harvesting time cannot be observed. Therefore, one has to form expectations based on actual and past prices. In Nerlovian tradition, adaptive expectation implies that the farmer revises his expectations by some proportion of the extent to which his expectation in the previous period varied from actual (Lahiri and Roy, 1985). Thus, the equation can be written as given below:

$$P_t - P_{t-1} = \lambda(P - P_{t-1}) + \varepsilon_t; 0 \le \lambda \le 1 \qquad (4)$$

$$P_t = \lambda P_t^* + (1-\lambda)P_{t-1} + \varepsilon_t \qquad (5)$$

Where P^*_t is the expected relative price at t, P^*_{t-1} is the relative price at t-1 and Pt-1 is the actual price in the previous period. Therefore, λ is the adjustment coefficient. If λ is one, it becomes a static expectation where the current year's expected price equals the preceding year's price. Now the unobservable A^*_t and P^*_t are eliminated from the system by substituting equations (1) and (5) into (3), and with algebraic handling, the final resulted reduced form equation as follows:

$$A_t = \beta_1 + \beta_1 P_{t-1} + \beta_3 A_{t-1} + \beta_4 A_{t-2} + \beta_5 Z_t + e_t \qquad (6)$$

Where
$\beta_1 = \alpha_1\delta\lambda: \beta_2 = \alpha_2\delta\lambda; \beta_3 = (1-\delta) + (1-\lambda); \beta_4 = (1-\delta)(1-\lambda); \beta_5 = \alpha_3\delta$

and $e_t = \epsilon_t - (1-\lambda)\epsilon_{t-1} + \delta u_t - \delta(1-\lambda)u_{t-1} + \alpha_2\delta\varepsilon_t$.

This estimatable reduced form equation is called the distributed lag model with the lag dependent variable as an exogenous variable. The β coefficients, apart from that of lagged endogenous variable display short-run elasticities if taken in logarithm form. Long-run elasticities are attained by dividing the short-run elasticities by an adjustment coefficient, to be precise, one minus coefficient of the one-lagged dependent variable (1- β_3). Estimation Technique: Cointegration and Vector Error Correction Mechanism 6. The Nerlovian mechanism presumes that the adjustment coefficient (δ) is minus than one. So the variation in the expected output level is less than the fluctuation observed 6. The methodology of co-integration and error correction mechanisms are found in the research work by Engle and Granger (1987), Banerjee *et al*. (1993), Hallam and Zanoli (1993), Hwang (2002), Deb (2003), and Awosola *et al*.(2006). The production level such that the actual change in harvest level between period *t* and *t-1* is only a portion of the change essential to achieve the expected output level. In this case, the only condition for observing significant differences between short-run and long-run Elasticities is introducing a nonstatic assumption. Consequently, it is biased, and the researches make use of this mechanism have generally found low values, at times even zero, for long-run elasticities (Awosola *et al*., 2006). Accordingly, the Cointegration and Error Correction Mechanism (ECM) methodology is favored over the ordinary least square (OLS) estimation method of the Nerlovian framework. Aside from this, the OLS technique uses time series data, which are often suspected to be nonstationary since most economic data series have unit root problems. So the statistical significance of the *t-test*, and *F-test*, lose relevance (McKay *et al*., 1998). However, the advanced time series methodology of Cointegration can be used with nonstationary data to evade spurious regression (Banerjee *et al*., 1993). When linked with this, the ECM, considering the partial adjustment and adaptive expectation of farmers, which are essential in the analysis of agricultural supply response, gives different long-run and short-run elasticities among variables (Townsend and Thirtle, 1995). Furthermore, the partial adjustment model is nested within the error correction mechanism.

2.2 Source of data

The study depended mainly on secondary time series data, so data for the analysis were collated from various secondary sources from 1990 to 2015. Where there were gaps in the early years in official data, estimates were substituted from other sources. Environmental variables data for instance, rainfall and temperature, were taken from Elobied airport. Crop production data were taken from the Economic Survey Reports of the Ministry of Agricultural and Animal resource, Department of Economic Planning and Development. Numerous estimates were made to fill in data gaps. Still, most of the domestic production data were taken from the Ministry of Agriculture and Forests and the Ministry of Animal Resources, which were additionally used to obtain wholesale prices of sorghum, millet, groundnut, and sesame. The Elobied crop market was vital in providing early statistics on local quantities and sales of sorghum, millet, groundnut, and sesame and prices in different markets.

III. RESULTS

III.1 Test of Stationary

Table1 shows the summary of the unit root test of the series used in estimations. Calculated ADF statistics for series of yield, area, and price for sesame; groundnut; sorghum, and millet indicated that these series were all integrated of 1(1) Calculated ADF statistics for series of temperature and indicated that they were stationary, so they were all integrated of order 1(0). The first lag difference of each series was tested for the presence of a unit root by estimating an Augmented Dickey-Fuller (ADF) equation with intercept.

III.2 Test of Co-integration between Variables

Given that in economics, variables time series often exhibit nonstationary stochastic processes. The econometric specification is achieved in a framework that allows for nonstationary but potentially co-integrated variables. The unit root test results are described in Table1. As shown by the ADF test, the null hypothesis did not reject that a random walk process generated the level of each series except for the series with a 1(0) order of integration. Nevertheless, the hypothesis of a random walk in the first difference of those series was rejected. It implies that the standard OLS technique cannot estimate the series integrated of order one, and VEC is the better option in this regard. However, before employing the VEC model, it is needed to ensure that the series of the same order of integration are co-integrated. Hence, Johansen's (1988) co-integration test was applied before applying the VEC model. The co-integration test also provides the long-run equilibrium relationship and the long-run supply response elasticity. The co-integration results for area equations were reported in Tables 2 to9. When only one co-integrating vector exists, its parameters could be interpreted as estimates of the long-run co-integrating relationship between the variables. Thus the yield/area models had one co-integrating vector according to the Johansen procedure with maximum Eigenvalues. The normalized co-integrating equation for the area of crops is explained under the tables of the co-integration test.

III.3 Error correction models for yield and area

Table10 shows the ECM estimates of supply response of crop yield to price and area, temperature, and SPI. The model fits better for sesame, groundnut, sorghum, and millet as the adjusted R-squared were 0.54, 0.35, 0.59, and 0.72 for four crops, respectively. F-statistics were also well above the 5% significance level. It could be observed from the result that the price coefficients were significant above the 10% significance level and had a negative effect on the yield of groundnut and millet. The price coefficients were not significant in cases of yield sesame and sorghum. The area coefficients were significant at a 5% level for the yield of sesame and groundnut. The insignificance effect of this coefficient appeared incased of the yield of sorghum and millet. The coefficient of temperature was significant at a 1% level showing how significantly temperature influences on yield of sorghum.

Nevertheless, on the other hand, it did not influence the yield of the rest of the crops because its significance level is less than 10%. SPI had a positive and significant impact on groundnut, sorghum, and millet yield, which was greater than 5%. As expected, negative error correction coefficients (-0.08 and -0.19 for yields of groundnut and sorghum) suggest that about 8% and 19% of deviation from long-run equilibrium were made up within one time period for yields of groundnut and sorghum. It also implied that the speeds with which the yield of these crops adjusted from short-run disequilibrium to changes in explanatory variables to attain long-run equilibrium were 8% and 19% for the yield of both crops within one year. However, it was not significant for groundnut yield. The estimated short-run coefficients ECM of millet yield presented in Table (4.10) shows that the error correction term is statistically significant at the 1% level with a negative coefficient. If the value of the coefficient of the lagged error correction term is between -1 and -2, afterwards the lagged error correction term produces diminished fluctuations in millet yield (Narayan and Smyth, 2006). The lagged error correction term in the short-run model appeared with a coefficient of -1.38, which implies that instead of monotonically converging to the equilibrium path directly, the error correction process fluctuate around the long-run value in a reducing manner. However, once this process is complete, convergence to the equilibrium path is rapid. A positive and insignificant error correction coefficient was found with sesame yield, which may imply autocorrelation or some specification problem.

Similarly, the ECM results for area response are depicted in Table11. The coefficients of independent variables were not significant except for the coefficients of price in the sesame area model and temperature and rainfall in the sorghum area model. The models seem not to fit well since the adjusted R-squared values were very low, as well as the F-statistics. However, the error correction coefficient showing the speed of adjustment towards the long-run equilibrium is negative as expected and not significant.

III.4 Supply response, short-run and long-run elasticities of yield, and area of crop in North Kordofan

The coefficients of the ECM model indicate short-run elasticities, and the coefficients of estimated co-integrated equations represent long-run elasticities. Table12 revealed the short-run and long-run elasticities of both yield and area function. The short-run elasticities of environmental factors were higher in comparison to price and other non-price factors in both functions though they were comparatively lower in magnitude in the case of area function.

IV. DISCUSSION

The issue of agricultural supply response is a critical one as it has an impact on growth, poverty, and the environment. Low supply response means that farmers' aim is not to maximize profit. One reason attributable to it is that farmers in North Kordofan are predominantly subsistence farmers. Since75% of farmers are small and marginal farmers in North Kordofan so, finally, we can say that subsistence farming is one of the causes of the low supply response. Supply function analyses provide exciting insights into farmers cropping decisions. The regression analyses of ECM suggest that, in general, North Kordofan farmers do not adjust crop area allocation in response to crop prices. Alternatively, the study reveals that farmers respond to environmental factors. Farmers' supply response to price varies depending on their physical conditions. In the rainfed agriculture of North Kordofan, yield and area behavior have been price inelasticity of supply in the short and long run. However, weather factors are the most dominating factor influencing yield and acreage behavior in the short-run and long-run. The study emphasized that farmers' decisions are influenced by weather and climate. Specifically, farmers in North Kordofan increase crop supply when temperature and precipitation conditions become more favorable. Conversely, farmers decrease crop supply and switch to other crops and activities when temperature and precipitation become less fortunate. Farmers with limited alternative activities options compensate for losses in yield, according to the bad weather condition of production, by making more efforts in fieldwork and reallocating areas between crops.

V. CONCLUSION

It was inferred that price was not a significant factor explaining supply response. The analysis confirmed that temperature and rainfall were more critical for higher supply response, which supports the argument that environmental factors could be vital in supply response analysis, particularly in the case of traditional North Kordofan agriculture**.** The estimates of elasticities of different variables presented in this study can be a valuable addition to the repository of knowledge about the supply elasticity of various agricultural commodities in the traditional subsector in North Kordofan. This knowledge is highly required in implementing adaptation policies that concern climate change and agricultural production projects, including strategic research, demonstration of field technology, capacity building, etc., to ensure food security for alleviating poverty under climate change conditions.

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Table1: Unit Root Test for the Data Series using Augmented Dickey-Fuller Test

Crop	Series	level	1st difference	Conclusion
Sesame	Yield	0.261211	-3.496562**	1(1)
	Area	-2.566894	-5.03087***	1(1)
	Price	-0.426220	-3.426802**	1(1)
Groundnut	Yield	-3.624752**	-----------	1(0)
	Area	-2.799080	-3.447025**	1(1)
	Price	2.29024	-4.138901***	1(1)
Sorghum	Yield	-3.718872**	-----------	1(0)
	Area	-3.806658***	-----------	1(0)
	Price	-4.222169***	-----------	1(0)
Millet	Yield	-4.157740***	-----------	1(0)
	Area	-2.692941	-5.641814***	1(1)
	Price	-0.977058	-3.707868**	1(1)
Temperature	Celsius	-3.667798**	--------------	1(0)
Rainfall	mm	-3.655288**	--------------	1(0)

Notes:

- *** And ** denote rejection of the hypothesis of a unit root at 1% and 5% level, respectively.
- The value of k is determined by using Akaike's AIC criterion.
- Instead of t-statistics, Mackinnon critical values denoted by M-Values have been applied here.
- Including intercept in Augmented Dickey-Fuller Test Equation

Table2: Co-integration test of variables in sesame yield model

Eigenvalue	Likelihood Ratio	5 Percent Critical Value	1 Percent Critical Value	Hypothesized No. of CE(s)
0.871074	104.2898	68.52	76.07	None **
0.717944	55.12551	47.21	54.46	At most 1 **
0.608934	24.74991	29.68	35.65	At most 2
0.088222	2.216843	15.41	20.04	At most 3
9.32E-06	0.000224	3.76	6.65	At most 4

Notes:

- *(**) denotes rejection of the hypothesis at a 5% (1%) significance level
- L.R. test indicates 2 co-integrating equation(s) at 5% significance level
- Test assumption: Linear deterministic trend in the data
- Lags interval: 1 to 1
- Series in LN form: yield; price; area; and temperature. Rainfall in standardized precipitation index (SPI)
- Equation of co-integration model:

YIELD = 141.7550+ 0.026637 PRICE -2.497AREA-29.319TEMPERATURE + 0.509SPI

T-values (0.03784) (0.3772) (6.5662) (0.1995)

Table3: Co-integration test of variables in groundnut yield model

Eigenvalue	Likelihood Ratio	5 Percent Critical Value	1 Percent Critical Value	Hypothesized No. of CE(s)
0.825754	95.06368	68.52	76.07	None **
0.722989	53.12884	47.21	54.46	At most 1 *
0.432444	22.32009	29.68	35.65	At most 2
0.280737	8.726105	15.41	20.04	At most 3
0.033487	0.817441	3.76	6.65	At most 4

Notes:

- *(**) denotes rejection of the hypothesis at a 5% (1%) significance level
- L.R. test indicates 2 co-integrating equation(s) at 5% significance level
- Test assumption: Linear deterministic trend in the data
- Lags interval: 1 to 1
- Series in LN form: yield; price; area; and temperature. Rainfall in standardized precipitation index (SPI)
- Equation of co-integration model:

YIELD = 530.263+ 0.383PRICE+0.809AREA-152.051TEMPERATURE + 2.357SPI

T-values (0.2290) (0.8130) (63.7413) (1.07054)

Table4: Co-integration test of variables in sorghum yield model

Eigenvalue	Likelihood Ratio	5 Percent Critical Value	1 Percent Critical Value	Hypothesized No. of CE(s)
0.806627	84.50065	68.52	76.07	None **
0.630618	45.06541	47.21	54.46	At most 1
0.396336	21.16325	29.68	35.65	At most 2
0.296582	9.049540	15.41	20.04	At most 3
0.024944	0.606255	3.76	6.65	At most 4

Notes:

- *(**) denotes rejection of the hypothesis at a 5% (1%) significance level
- L.R. test indicates 1 co-integrating equation(s) at 5% significance level
- Test assumption: Linear deterministic trend in the data
- Lags interval: 1 to 1
- Series in LN form: yield; price; area; and temperature. Rainfall in standardized precipitation index (SPI)
- Equation of co-integration model:

YIELD = 762.4425+ 0.593PRICE-4.809AREA-197.83TEMPERATURE + 4.667SPI

T-values (0.7918) (5.573) (213.849) (5.465)

Table5: Co-integration test of variables in millet yield model

Eigenvalue	Likelihood Ratio	5 Percent Critical Value	1 Percent Critical Value	Hypothesized No. of CE(s)
0.848374	93.05197	68.52	76.07	None **
0.610345	47.77984	47.21	54.46	At most 1 *
0.375453	25.15998	29.68	35.65	At most 2
0.365284	13.86251	15.41	20.04	At most 3
0.115760	2.952635	3.76	6.65	At most 4

Notes:

- *(**) denotes rejection of the hypothesis at a 5% (1%) significance level
- L.R. test indicates 2 co-integrating equation(s) at 5% significance level
- Test assumption: Linear deterministic trend in the data
- Lags interval: 1 to 1
- Series in LN form: yield; price; area; and temperature. Rainfall in standardized precipitation index (SPI)
- Equation of co-integration model:

YIELD = 94.03382-0.0405PRICE-0.420AREA-24.013TEMPERATURE + 1.142SPI

T-values (0.04943) (0.2497) (6.5997) (0.24783)

Table6: Co-integration Test of variable in the sesame area model

Eigenvalue	Likelihood Ratio	5 Percent Critical Value	1 Percent Critical Value	Hypothesized No. of CE(s)
0.760533	74.55973	47.21	54.46	None **
0.602339	40.25559	29.68	35.65	At most 1 **
0.509379	18.12388	15.41	20.04	At most 2 *
0.042164	1.033895	3.76	6.65	At most 3

Notes:

- *(**) denotes rejection of the hypothesis at a 5% (1%) significance level
- L.R. test indicates 3 co-integrating equation(s) at 5% significance level
- Test assumption: Linear deterministic trend in the data
- Lags interval: 1 to 1
- Series in LN form: area; price; and temperature. Rainfall in standardized precipitation index (SPI)
- Equation of co-integration model:

AREA = -187.2038- 0.179PRICE+ 49.448TEMPERATURE -1.697SPI

T-values (0.0599) (15.218) (0.6004)

Table7: Co-integration Test of variable in the groundnut area model

Eigenvalue	Likelihood Ratio	5 Percent Critical Value	1 Percent Critical Value	Hypothesized No. of CE(s)
0.679579	57.34004	47.21	54.46	None **
0.522225	30.02518	29.68	35.65	At most 1 *
0.381231	12.29841	15.41	20.04	At most 2
0.031891	0.777843	3.76	6.65	At most 3

Notes:

- *(**) denotes rejection of the hypothesis at a 5% (1%) significance level
- L.R. test indicates 2 co-integrating equation(s) at 5% significance level
- Test assumption: Linear deterministic trend in the data
- Lags interval: 1 to 1
- Series in LN form: area; price; and temperature. Rainfall in standardized precipitation index (SPI)
- Equation of co-integration model:

AREA = -1458.260-1.445PRICE+411.75TEMPERATURE -13.74458SPI

T-values (3.1772) (63.7413) (32.5255)

Table8: Co-integration Test of variable in the sorghum area model

Eigenvalue	Likelihood Ratio	5 Percent Critical Value	1 Percent Critical Value	Hypothesized No. of CE(s)
0.775735	64.24176	47.21	54.46	None **
0.409595	28.36350	29.68	35.65	At most 1
0.343233	15.71677	15.41	20.04	At most 2 *
0.208985	5.626535	3.76	6.65	At most 3 *

Notes:

- *(**) denotes rejection of the hypothesis at a 5% (1%) significance level
- L.R. test indicates 3 co-integrating equation(s) at 5% significance level
- Test assumption: Linear deterministic trend in the data
- Lags interval: 1 to 1
- Series in LN form: area; price; and temperature. Rainfall in standardized precipitation index (SPI)
- Equation of co-integration model:

AREA = -165.1592- 0.200PRICE+ 43.324TEMPERATURE-1.086SPI

T-values (0.0746) (10.924) (0.3414)

Table9: Co-integration Test of variable in the millet area model

Eigenvalue	Likelihood Ratio	5 Percent Critical Value	1 Percent Critical Value	Hypothesized No. of CE(s)
0.765374	63.86449	47.21	54.46	None **
0.473326	29.07022	29.68	35.65	At most 1
0.393750	13.68207	15.41	20.04	At most 2
0.067254	1.670942	3.76	6.65	At most 3

Notes:

- *(**) denotes rejection of the hypothesis at a 5% (1%) significance level
- L.R. test indicates 1 co-integrating equation(s) at 5% significance level
- Test assumption: Linear deterministic trend in the data
- Lags interval: 1 to 1
- Series in LN form: yield; price; area; and temperature. Rainfall in standardized precipitation index (SPI)
- Equation of co-integration model:

AREA= -143.5170 - 0.133PRICE+37.021TEMPERATURE-1.467SPI

T-values (0.0729) (8.6142) (0.3260)

Table 10: Results of ECM of yield for all crops

Error Correction:	D(sesame yield)	D(groundnut yield)	D(sorghum yield)	D(millet yield)
CointEq1	0.175 (0.1459)	-0.081 (0.0685)	-0.195*** (0.0418)	-1.384*** (0.2281)
D(YIELD(-1))	-0.543** (0.1912)	-0.021 (0.1803)	-0.488** (0.1828)	0.340 (0.206)
D(PRICE(-1))	-0.009 (0.1631)	-0.651* (0.3400)	0.119 (0.340)	-1.076** (0.5282)
D(AREA(-1))	-0.492** (0.2260)	0.585** (0.2504)	-0.127478 (0.32717)	-0.275 (0.2057)
D(TEMPERATURE(-1))	-4.198 (3.9690)	-2.324 (7.2102)	-16.691*** (5.526)	-7.38 (5.0948)
D(RAINFALL(-1))	0.004 (0.1239)	0.667*** (0.2144)	0.6426** (0.21533)	0.585** (0.2262)
C	0.178 (0.1486)	0.294 (0.2031)	0.031019 (0.18018)	0.208 (0.1829)
R-squared	0.6628	0.527	0.698	0.787
Adj. R-squared	0.544	0.359	0.591	0.712
Sum sq. resids	6.994	13.059	8.743	9.859
S.E. equation	0.641	0.876	0.717	0.761
F-statistic	5.571	3.154	6.546	10.491
Log likelihood	-19.25	-26.752	-21.94	-23.379
Akaike AIC	2.188	2.813	2.411	2.532
Schwarz SC	2.531	3.156	2.755	2.875
Mean dependent	0.077	0.132	0.063	0.0016
S.D. dependent	0.949	1.095	1.122	1.419

Notes: *; ** and *** denotes rejection of the null hypothesis at 10%, 5% &1% significance level

Table11: Results of ECM of area for all crops

Error Correction:	D(sesame area)	D(groundnut area)	D(sorghum area)	D(millet area)
CointEq1	-0.077 (0.0871)	0.012(0.0230)	-0.450**(0.163)	-0.370(0.2812)
D(AREA(-1))	0.225 (0.1378)	-0.382*(0.219)	0.035(0.205)	-0.399(0.255)
D(PRICE(-1))	0.243**(0.0992)	-0.194(0.2854)	-0.321(0.2861)	-0.056(0.523)
D(TEMPERATURE(-1))	1.742(2.4430)	2.400(5.8192)	12.129**(4.2527)	6.120(6.054)
D(RAINFALL(-1))	-0.124(0.1171)	0.274(0.249)	-0.314*(0.178)	-0.413(0.305)
C	-0.038(0.0908)	0.175(0.1729)	0.122(0.157)	0.039(0.214)
R-squared	0.388	0.279	0.368	0.392
Adj. R-squared	0.218	0.079	0.193	0.224
Sum sq. resids	2.848	10.067	7.125	15.69
S.E. equation	0.398	0.748	0.629	0.934
F-statistic	2.283	1.393	2.100	2.325
Log likelihood	-8.477	-23.629	-19.481	-28.960
Akaike AIC	1.206	2.469	2.123	2.913
Schwarz SC	1.501	2.764	2.418	3.208
Mean dependent	0.079	0.095	0.014	0.028
S.D. dependent	0.450	0.779	0.700	1.060

Notes: *;** and *** denotes rejection of the null hypothesis at 10%; 5% &1% significance level

Table12: Short- and long-run elasticities of yield and area for field crops in North Kordofan, 1990–2015

	Yield response				**Area response**			
	sesame	groundnut	sorghum	millet	sesame	groundnut	sorghum	millet
Short-run elasticities								
Price	-0.009	-0.651	0.119	-1.076	0.243	-0.194	-0.321	-0.056
Area	-0.492	0.585	-0.127	-0.275				
Temperature	-4.198	-2.324	-16.691	-7.376	1.742	2.400	12.129	6.119
rainfall	0.004	0.667	0.643	0.585	-0.124	0.274	-0.314	-0.412
Long-run elasticities								
Price	0.027	0.383	0.594	-0.04	- 0.179	-1.445	- 0.2	-0.133
Area	-2.497	0.808	-4.809	-0.419				
Temperature	-29.31	-152.051	-197.83	-24.01	49.448	411.747	43.32	37.021
rainfall	0.509	2.357	4.667	1.142	-1.697	-13.745	-1.086	-1.467