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# The Impact of Rainfall on the Yields of Staple Crops - Sorghum and Sesame in Sudan

## Research Article

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**Abstract**

This study addressed the impact of the weather change mainly rainfall on the yields for the staple crops (sorghum and sesame) in a traditional rain-fed sector in the White Nile State of Sudan. Time series rainfall and grain yield data for 10 years (2001-2010) are analyzed using Fisher Integral Model, Chebyshev Orthogonal Polynomial, and stepwise regression to estimate the meteorological yield. Our results indicate that an increased availability of water enhanced productivity in terms of grain yield. An annual increase in average rainfall to 2.62 mm during crop maturing stage (harvesting stage) resulted in sorghum and sesame yields higher to 32.31 kg/ha, and 7.64 kg/ha respectively. The main recommendation we strongly saying the possibility for early seeding for sorghum and sesame in the traditional farms of rural farmers can get high yield.

**Keywords:** Rain-fed; Metrological Yield; Integral Model; Chebyshev Orthogonal Polynomial

## Background

Agriculture is extremely vulnerable to weather changes though crop yield are affected by natural and non-natural factors. The environment is one such natural factor which plays an important role in determining the yield. Changes in yield component may be a result of plant's response to stress at various stages of plant growth and development [1]. In other hand, Mohamed studied the impact of weather change on Sudanese cereal grains and cash crops such as sesame, and groundnut and reported a higher impact of rain on yields compared to increased temperatures [2]. Despite recent technological advancements in crop improvement methods, weather remains a critical factor that determines the agricultural productivity. Jones and Thornton reported the severe impacts of change on rainfall and temperature on yields of staple crops such as maize, millet, sorghum, sesame and peanut. In other hand, higher temperatures eventually reduce yields of desirable crops while encouraging weed and pest proliferation [3]. Agricultural economics is influenced by the weather. Sudan economy primarily depended on agricultural activities which in turn is dependent on climate factors such as rainfall and variability of temperature beside varietal genetics, soil fertility, and crop management factors. In the mid-1970s and late 2000s, summer rainfall decreased by 15-20% across parts of western and southern Sudan and declines can be visualized as a contraction of the region receiving adequate rainfall for viable agricultural livelihoods which rural farmers depend on.

Mohamed and Rajaa and Abdulhamed indicated that cereal grains and oilseed crops such as. "Sesame and peanut" were domesticated in Africa for the existence of the right climate, as some cereal grains like sorghum was known in Ethiopia a long time ago since 5000 years and has moved from there to the regions of Sudan to West Africa at an early date [4,5].

Sorghum "Sorghum bicolor L. Moench" and sesame "*Sesamum indium* (L)." are main staple crops for local households in the same areas of the research (White Nile State of Sudan) because of traditional style in food and cultivation. Sorghum is the most important annual cereal grain crops for rural area in the Sudan and mainly grown in rain-fed sector in both (traditional; where small farmers owns small cultivated area in addition those farmers used production for self-sufficient also they using traditional agricultural methods e.g. seeds, land preparation. etc. And mechanized rain-fed area which consider s a big scheme farms cultivated for trade and using full technologies" [6]. This study focuses on these two widely grown major staple crops since 86.9% of sorghum and entire sesame are grown in White Nile state as shown in table 1.

## Selected Area and Data Description

**Geological Information in selected area:** White Nile State extends between longitudes (12-13.3) north and latitudes (31-33.3) east. The total area of the state is approximately equal to 44.615 thousand square kilometers (approx. about 4 million hectares), about 66% of which is under vegetation cover (FAO 2009). White Nile State is considered as one of the Sudanese States with geo-ecological diversity. The report of Ministry of Agriculture (2012) mentioned that as plains region of the natural and flat has an estimated area of 3,643,119 acres which is equivalent to about 33% of the area of the state, land area of sedimentary clay and sand area are estimated to 2,268,629 acres of which correspond to about 24% of the area of the state, area of the Nile Valley area is estimated to 945,262 acres which corresponds to about 10% of the area of the state, sub-Saharan sand area is estimated to 661,638 acres which is equivalent to about 7% of the total area of the state, quartz sandy area, estimated area to 2,363,155 acres which is equivalent to about 25% of the area of the state and rocky hills area is estimated to 94,526 acres which is equivalent to about 1% of the area of the state.

## Methodology

The Meteorological yield is a function used to estimate some of metrological factors as in rainfall, sunshine, and temperature. Fisher thought that the impact of meteorological factors on yield could be denoted in the form of the integral regression [7]. The extended Fisher integral regression model is:

$$Y = \beta * T + \int_0^{\tau} \alpha_i(t) x_i(t)\, dt \tag{1}$$

In the function (1), Y denotes the yield, T denotes the yield trend, $x_i(t)$. Denotes the meteorological factors rainfall, and $\tau$…denotes the crop growth period; while $\beta$and $a_i(t)$ are to be estimated parameters.

Usually, we used the orthogonal polynomial to approximately express $a_i(t)$ in the following function (2),

$$a_i(t) = \alpha_{ij}\varphi_{ji} \tag{2}$$

Function (2) is substituted into (1), thus the function (3) is in the following:

$$Y = \beta * T + \int_0^{\tau}\left(\sum_j \alpha_{ij}\varphi_{ji}\right) x(t)\, dt$$

$$Y = \beta * T + \sum_i \alpha_{ij}\rho_{ji} \tag{3}$$

Here, we had:

$$\rho_{ji} = \int_0^{\tau} x_i(t)\varphi_j\, dt \tag{3}$$

$\varphi_j$ could be derived from the Chebyshev-orthogonal polynomial in the following($\varphi_0$=1).

$$\varphi_{k+1}(x) = \varphi_1(x)\varphi_k(x) - \frac{k^2(n^2-k^2)}{4(4k^2-1)}\varphi_{k-1}(x) \tag{4}$$

Following the above (3) is a typical multiple linear regression equation of the stepwise regression approach to solving the equations. After several rounds of comparison, the two equations can be close to our expectations.

## Result and its Analysis

In this study, all data on meteorology and crops yield is from Ministry of Agricultural, Forest, Animal Wealth and Irrigation of White Nile State of Sudan. The CV (coefficient of variation) is which expresses the variation as a percentage of the mean is calculated as follows: CV% = (SD/Mean)*100, here SD is the Standard Deviation. The CV of yield, rainfall and temperature were studied to choose the important variable which may influence the grain yield more.

**Yield variation:** The yield of sorghum and sesame were very low 104 and 51 kg/ha in 2009 but 655 and 306 kg/ha in 2009 respectively. This variation in yield level is reflected by high CV of the yield of both the crops which were 0.57 for sorghum and 0.39 for sesame.

**Temperature variation:** The range of CV varied 0.01 to 0.06 which is very small in scale. This means that the minimum and maximum temperatures are almost stable in each month.

**Rainfall variation:** The range of CV was waving largely from 0.33 to 1.43 during the raining season. High average rainfall was observed during July and August which corresponds to vegetative growth period of the crop cycle. The fluctuations in rainfall are much greater than temperature. For the reason, we focus on rainfall as one of the important factors that determine the yield in this study. Oughan and Stoddart reported that failure of some grain sorghum seeds lines in field to germinate and emerge at very high soil temperatures reaching (45 to 50 °C), is closely has been associated with inhibition of embryo protein synthesis during the first few hours of seeds water absorption [8]. Our study shows in table 1 the high temperature is 41.72 °C and 39.99 °C in May and June respectively, which is lower than 45 °C and conducive to germination.

Now let us run the model on the relationship between yield and rainfall with the Stata software using Orthogonal Polynomial Stepwise Regression to get the significance of rainfall that can influence the sorghum and sesame metrological yield. The result shows that Rainfall co-efficiency is highly significant to the sorghum plant during the 2 stages 'vegetative growth and flowering stages' (Table 2).

According to the crops production characteristics, the lifecycle of a plant is divided into four stages: seeding, vegetative, flowering/ grain filling, harvesting. The stage wise results for rainfall- yield coefficients are in Table 3 as follows.

**Seeding stage:** The average early seeding rainfall is 7.82 mm. If



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**Table 1:** The statistic mean and coefficients of yield, rainfall and temperature for sorghum and sesame during crop cycles during 2001-2010.

| | yield | | rainfall | | | | | | temperature | |
|---|---|---|---|---|---|---|---|---|---|---|
| | sorghum | sesame | May | Jun | Jul | Aug | Sep | Oct | low | high |
| Mean | 341 | 183 | 7.8 | 16.2 | 85.7 | 87.5 | 34.2 | 2.6 | 24.6~26.7 | 35.3~41.7 |
| C.V | 0.57 | 0.39 | 1.43 | 1.33 | 0.33 | 0.37 | 0.51 | 1.19 | 0.02~0.06 | 0.01~0.06 |

Source of data: ministry of Agriculture and Irrigation, White Nile State of Sudan

**Table 2: Coef. ($\alpha_{ij}$)** and **T**explain the rainfall that influence crop yield.

| | Sorghum | | Sesame | |
|---|---|---|---|---|
| **Dependent Variables** | **Coef.** ($\alpha_{ij}$) | **T** | **Coef. ($\alpha_{ij}$)** | **T** |
| p_rf0 | 9.61 | 3.79*** | 3.29 | 3.46*** |
| p_rf1 | 2.27 | 2.25** | .69 | 1.81 |
| p_rf2 | 2.27 | 3.49*** | .87 | 3.57*** |
| p_rf3 | .84 | 1.95* | .30 | 1.82 |
| Cons | -271.90 | -1.09 | 42.19 | 0.45 |
| | F (4, 5) =3.73<br>Prob> F = 0.0905<br>R-squared = 0.7492<br>Adj R-squared = 0.5486 | | F (4, 5) = 3.50<br>Prob> F = 0.1010<br>R-squared = 0.7368<br>Adj R-squared =0.5262 | |

***denotes 1% significant degree; **denotes 5% significant degree; and * denotes 10% significant degree

**Table 3:** Sorghum yield outlook during the rainy season.

| **Life cycle** | **Months** | **C_my (kg/ha_mm)** | |
|---|---|---|---|
| | | **Sorghum** | **Sesame** |
| Seeding | May | 9.61 | 7.64 |
| | June | 0.51 | 2.42 |
| Vegetative | July | -1.74 | -0.19 |
| | August | 2.8 | -0.19 |
| Flowering & filling | September | 14.15 | 2.42 |
| Harvesting | October | 32.31 | 7.64 |

Notice: “c_my” is Coefficient Meteorological Yield

there is more rainfall, it will benefit the germination of sorghum and sesame and consequently their yields tend to increase by 9.61 kg/ha and 7.64 kg/ha. Coefficient Meteorological Yield in May month is higher for both the crops. The early seeding appears to be better than the later seeding due to increased germination and yield increase to be higher by 0.53 kg/ha and 2.42 kg/ha (Table 3).

**Vegetative growth stage:** In this stage crop grows fast and needs a lot of water. In fact, July and August are rainy seasons in Sudan; the rainfall average is 85.73 mm and 87.52 mm respectively. But the rainfall-yield coefficients are negative in July for both the crops and for sesame August. The coefficient for sorghum is positive in August (2.8 kg/ha mm). This indicates that plant response to rainfall in August is different in sorghum than sesame. It is expected since sorghum is a high biomass crop with much higher growth rate compared to sesame.

**Flowering and filling stage**: This stage starts in September when average rainfall is 34.18 mm. Coefficient Meteorological Yield indicates a rate of increase in yield trend to be14.15 kg/ha for sorghum and 2.42 kg/ha for sesame. It shows that plant needs more water in this season than the average rainfall level.

**Harvesting stage: T**his phase starts sometime in October when average rainfall is estimated to be 2.mm which is inadequate to achieve desired seed size to ensure expected yield, though grain quality will be good if harvest is in rain-free period. Our study shows that additional water supply will increase yield by 32.31 kg/ha for sorghum and 7.64 kg/ha for sesame.

## Discussion

Weather factors include temperature, sunshine duration and rainfall etc. In this study, the key weather factor is found to be rainfall as compared to the minimum and maximum temperature regimes in relation to staple crop yield. The Coefficient Meteorological Yield has revealed the influence of rainfall in predicting the response to yield increase.

The finding is that the same weather condition has different output on the yield of sorghum and sesame, for example, in July to



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September, the Coefficient Meteorological Yield of these two staple crops is similar except in August. Thus, rain is beneficial to both the crops for germination and crop growth up to July but sorghum shows differential response during August due to higher inherent capacity to produce higher biomass than sesame. At further stages, excessive rain causing water logging in sesame is injurious to it while sorghum can tolerate it upto some extent. Dabir JD has also reported that sesame is intolerant of water-logging and the rainfall late in the season prolongs growth and increases shattering losses in the harvesting period [9].

The Model only considers total rainfall as weather factor relative to the crop yields. In fact, distribution of rainfall, intensity of rainfall and number of rainy days, RH and some other weather factors such as the concentration of carbon dioxide in the air, sunshine duration, radiation intensity and wind speed also influence the yield. The effect and relationship of these factors need attention in future research.

According to the Meteorological/weather yield coefficient, the crop yield could be forecasted and the requirement of supplementary irrigation in low rainfall years may be assessed. Equitable distribution in rainfall in rain-fed areas is essential for desirable crop growth. Weather change will have varying effects in the rain-fed traditional sector which may experience large declines in yield during unfavorable years. Weather change will result in low grain production and consequently price increase of the all the agricultural crops including the major staples sorghum and sesame affecting the security in both food and cash crops. To mitigate such abnormal situation, we need to achieve different technologies to enhance the traditional farmer's grain yield ensuring irrigation potential, supply of drought tolerant/short duration improved varieties and hybrids with higher WUE, low cost input supply, improved management practices including early seeding and seedling establishment under higher temperature and skills associated with technical package to cope with weather change. In addition to this different scenarios are expected due to the climate change which will result in food deficit primarily in arid and semi-arid tropics particularly in developing countries. Mohamed B et al. [10,5,11] further elaborated agricultural production and food security under climate change in Sudan.

## Annex: Orthogonal Function

In this part of the paper we are looking to the relationship between meteorological factors "natural factors" and yield using Chebyshev Orthogonal Function as below:

$$\varphi_0(x) = 1$$

$$\varphi_1(x) = x - \bar{x}$$

$$\varphi_2(x) = (x - \bar{x})^2 - \frac{n^2 - 1}{12}$$

$$\varphi_3(x) = (x - \bar{x})^3 - \frac{3n^2 - 7}{20}(x - \bar{x})$$

$$\varphi_4(x) = (x - \bar{x})^4 - \frac{3n^2 - 13}{14}(x - \bar{x})^2 + \frac{3(n^2 - 1)(n^2 - 9)}{560}$$

$$\varphi_5 = (X - \bar{X})^5 - \frac{(5n^2 - 35)}{18}(x - \bar{x})^3 + \frac{(15n^4 - 230n^2 + 407)}{1008}(x - \bar{x})$$

$$\varphi_{k+1}(x) = \varphi_1(x)\varphi_k(x) - \frac{k^2(n^2 - k^2)}{4(4k^2 - 1)}\varphi_{k-1}(x) \quad (4)$$

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