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Impact of Meteorological Factors on Rice Growth Stages and Yield

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ABSTRACT

Weather variability poses threats to rural crop producers in Tanzania. This research aimed to find the impact of weather variation on the growth stage and yield of rice in Tanzania. The analyses were done using rice yield data and weather variables from 1981-2017. The approaches used were; decomposing rice yields into yield tendency and yield weather, stepwise integral regression for identification of significant yield model, and applied Fisher's meteorological regression and Chebyshev polynomial function to compute coefficients for weather factors. From the results, other than the non-natural factors, rainfall, maximum and minimum temperature, and sunshine significantly affect rice yield from sowing to harvest stage. The effect of rainfall, sunshine, maximum and minimum temperature coefficients on the rice yield differ by growth stage. An increase of 1 millimeter of rainfall at the sowing-seedling stage increased rice yield by 2.7 kg/ha. In the sowing-seedling stage, the temperature had a stronger positive influence on the rice yield as with every 1°C in average maximum temperature increased the rice yield by 674.1 kg/ha. The minimum temperature coefficient had stronger influences in the vegetative, tillering –booting stages, thus, with 1°C increase in average minimum temperature, the rice yield increased by 70.1 kg/ha and 420.7 kg/ ha respectively. In the flowering –grain formation stage, the maximum temperature had a greater influence on rice yield, that is, as 1°C increased, the rice yielded increased by 674.7 kg/ha. The sunshine duration had a higher influence on the harvesting stage.

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Increased 1-hour duration of sunshine increased rice yield by 495.95 kg /ha. Finally, a meteorological rice model, which could be used for rice yield forecasting in the region, was developed.

Keywords: Meteorological factors, natural and non-natural factors, rice, weather, yield

INTRODUCTION

Weather factor variations have significant impacts on most agricultural crop productions as already witnessed by the farming communities (Vaghefi et al., 2013). Changes and variations of the common meteorological factors such as precipitation, maximum and minimum temperature, sunshine, and humidity pose threats to crop performances, from the growth stages to the expected outputs; thus, they have direct cause to food insecurity all over the world (Thi et al., 2015). Rice is among the crops that are sensitive to any weather variations particularly with water, light, and heat (Shannon & Motha, 2015). It should be noted that rice crop requires more water than any other crop. Water is needed at the time of transplanting and much water is needed during the growing period. In addition to water, rice cultivation needs an average temperature and sunlight, especially during the ripening period.

In Tanzania, rice production is mainly dependent on rainfall (Adhikari et al., 2015; Katengile et al., 2018). About 71% of rice produced in the country is under the rain-fed system, however, the system has been vulnerable to weather shocks. Only a small portion of rice is produced through irrigation water (Katambara et al., 2016). The continuous dependence on rain-fed production substantiates the existing high relationship between rice production and weather factors (Ngailo et al., 2016). Although many studies continue to urge scientists to carry out more researches because of the existing relationships between rice crop and the influences of weather factors on the phenological progresses, studies on the weather-crops relationship are few in Tanzania (Hat & Prueger, 2015; Islam et al., 2016; Johansson et al., 2015; Lizumi & Ramankutty, 2015; Siebert et al., 2017). The available studies have centered on the impacts of climate change on crops. The few recent studies have focused only on the long effects of the climatic change to other cereal crops other than rice (Mkonda, 2014; Mkonda & He, 2017; Msongaleli et al., 2017; Mtongori, et al, 2016). Other studies have focused on the impact of weather variability on agricultural crop production and economic activities. These studies range from agriculture (Dell et al., 2014), infrastructures (Gelete & Gokcekus, 2018; Moretti & Loprencipe, 2018), investment, political, export and imports (Chatzopoulos et al., 2019), industrial products and conflicts (Peter, 2014). From these studies, the influence of weather on production emerges. For example, it was reported that for each 1°C rise in temperature reduced agricultural export in developing countries by 2.0 to 2.7% (Benjamin et al., 2012) and that for each increase of 1^{o}C reduced industrial outputs between 2.0 to 2.6 percent (Hsiang, 2014). Similarly, it was revealed that rainfall and temperature variability had a significant negative impact on crop growth and output level especially in developing countries (Burke, 2010; Dell et al., 2014). On an interesting note, it was reported that the rise in temperatures and decrease in rainfall had negative influences in political stability and conflicts which generally affected economic performances in Sub-Saharan Africa (Bruckner & Ciccone, 2011; Zhao et al., 2017).

Several studies that have shown the relationship between the cumulative influences of climatic factors on crop production. For example, Zhao et al. (2017) established the relationship between the maximum and minimum temperatures, and the rice yield in China. Similar studies in China concluded that weather had positive and negative contributions on peanut yield in Hebei on winter wheat in Weishan County (Wen et al., 2014; Yu et al., 2015). Mirzabaev (2013), who assessed the effect of weather variability on agricultural revenue in Central Asia, found that weather variability had a relatively high negative impact.

Rice crop undergoes several growth stages that help to identify its life cycle. Scholars generally agree that rice growth is separated into stages that are associated with either vegetative or reproductive development (Sridevi & Chellamuthu, 2015; Weng et al., 2017). The relationship between weather-related factors and their variability at each rice growth stage has a worth impact on rice yield. This is, however, made possible by analyzing the yield contributed by weather fluctuation (Y_w) as deduced from the difference between actual rice yield (Y_a) and trend yield (Y_t). Basically, *Yt* is the yield from other attributes other than natural ones such as technological progress, seeds, management practices, and government policies. As a subject of concern to crop specialists, the weather is known as an input in crop production (Paltasingh, 2012). However, while it is possible for researchers to quantify and measure other production inputs, it has not been possible for weather variables (Abdul-rahaman & Ebenezer, 2017). Therefore, the main objective of this study was to determine the influence of weather-related factors including the rainfall, maximum and minimum temperature, and sunshine on the rice growth cycle. Most of the previous cited empirical approaches used the Ricardian and Hedonic models on estimating impacts of weather on crop production. Nevertheless, the Ricardian models are mostly used to explain the variations of values of land per ha across different geographical conditions including very few weather parameters and are limited for the permanent crops (Mamane & Malam, 2015). On similar views, most of the studies involving the uses of the Hedonic models rely on analyzing variables on sale prices for land allocations and its produces as well as some environmental attributes (Salman et al., 2016). In the real sense, the aforementioned models used the temperature and rainfall variables to estimate the aggregate impact of weather variables on crop production and to the entire economy. In the current study, we have determined the impact of the respective weather variables and the resulting weather yield at each rice growth stage by using the econometric methods based on Fisher's (1925) ideas and Chebyshev Polynomial Function.

MATERIALS AND METHODS

The study used secondary data pertaining to rice production and weather statistics. A collection of rice yield data series from the study region for the past 36 years (1981-2017) was obtained from different sources that include the Tanzania government agencies namely; Tanzania Ministry of Agriculture, Food Security and Cooperative (MAFC), Ministry of Industry and Trade (MOIT), and National Bureau of Statistics (NBS). Meteorological data that include the average monthly rainfall (mm), monthly maximum and minimum temperature (^{o}C), and sunshine (Hours) for 36 years, were obtained from the Tanzania Meteorological Authority (TMA).

Profile of the Study Region

Mbeya is among the oldest regions situated in the Southern Highlands of Tanzania. It is situated between latitude 70 and 90 31' to the south of equator and Longitude 320 and 350 east of Greenwich. The region is among the leading regions in terms of agricultural outputs in Tanzania. It has a tropical climate that supports the growth of many cereal crops such as rice, maize, wheat, and sorghum. The region's annual rainfall ranges from 650 - 1200 mm with the experience of a dry and cold spell between June and September. The tropical climate, rainfall distribution, and variations in temperature favor rice production. Rice cultivation is undertaken in a large area of the region including Mbarali and Kyela Districts.

Research Method

In this research, the traditional classical production function was used where the dependent variable rice yield *Ya* is a function of a set of various independent variables (Dell et al., 2014). The assumption is *Ya* is the result of natural factors such as (weather variables; rainfall, sunshine, maximum and minimum temperature), and non-natural factors including change in technology, farm management, fertilizer application, seed varieties, pesticides, policy and labor. Therefore, in this study, the statistical relationship between the rice yield and the two components; natural and non-natural factors were considered.

This study accommodated previous concepts from different researchers including Yu et al. (2015) and Zhao et al. (2017). It also reviewed a recent study by Jiayu et al. (2018) who had reported on the existing statistical relationship between meteorological factors and crop yield. The study further stressed on to detach weather yield from the actual yield as yield due to weather variations. In addition, the actual yield is defined as the sum of the trend yield which is a measure of technology advancement and management, and weather yield due to weather factors variation. In accordance with that, accommodating a similar approach in this research, weather yield was computed from the difference between actual yield and linear trend-yield. This study's central idea was to establish a significant statistical relationship between weather yield and weather-related yield coefficients and weather factors as opposed to previous findings cited in this paragraph that used only the weather factors to explain their impact on crop yield. Owing to the idea that in the study region rice is transplanted in early January and matures in July of the same year, therefore, the study considered a total of seven 7 months and five growth stages.

Actual, Trend, and Meteorological Yield Model Setting

The actual yield Y_a (Equation 1) was computed from crop production and weather factors in time series data which enabled the researchers to set up the required model. More so, the actual yield was obtained from traditional classical production function as a combination of natural factors (Y_w) and non-natural factors (technology advancement, farm managements, fertilizer application, seed varieties, pesticides, policy and labor) at a specified duration of time. Henceforth, the trend yield is refered to as a yield due to the effect of the non-natural factors including farmers' interventions and technological application with time (Zhao et al., 2017). Likewise, Paltasingh (2012) and Jiayu et al. (2018) defined weather yield as the yield realized from the relative contribution of weather factors on crop performance. Therefore, the relationship was developed as follows (Equation 1, 2 and 3):

$$Y_a = Y_T + Y_w + \mu \tag{1}$$

Where Y_a is the actual rice yield, Y_T is the trend yield, Y_w is the weather yield, and μ is an error term.

$$Y_T = f(t) \tag{2}$$

Where f(t) shows the function of a particular year t

$$Y_w = \sum_{q=0}^{n} \sum_{p=0}^{m} f(w_{p,q}) \tag{3}$$

Therefore q is the growth stages of the rice plant, p is the weather factors (in this study we denoted as x1= rainfall (rf), x2= maximum temperature (tmax), x3=minimum temperature (trmin), and x4=sunshine (ss), $w_{p,q}$ is the weather variable by growth stage, and $f(w_{p,q})$ is the function of weather variables and respective yield variations.

In order to calculate the variations in different yield, we introduced the concept of initial yield or the Standard yield, and the relationship could be derived as follows (Equation 4, 5 and 6):

$$Y_{a0} = Y_{T0} + Y_{w0} + \mu \tag{4}$$

$$Y_{T0} = f(t_0) \tag{5}$$

$$Y_{w0} = \sum_{q=0}^{n} \sum_{p=0}^{m} f(\overline{w}_{p,q}) \tag{6}$$

Whereas Y_{a0} denote the base or standard rice crop yield, Y_{T0} denote the base trend yield or is the yield contributed by the non-natural factors, and Y_{w0} is the weather yield which is the result of the average weather variables.

Fisher Integral Regression Model

Fisher (1925) gave a respectable statistical regression model that could be used to compute the relationship between weather- yields and weather factors at different crop growth stages. In addition, he provided the possibilities for ascertaining the quantitative relationship among variables and their coefficients in the model. This study applied Fisher's regression model to establish the quantitative relationships between the weather yield as a dependent variable on weather-related attributes. The model requires to have the following Equation 7 which is the advancement of Equation 4:

$$\begin{aligned}\hat{y}_{pt} = \alpha_0 + \int_0^\tau a1j\ (t)x_1(t)dt + \int_0^\tau a2j\ (t)x_2(t)dt \\ + \int_0^\tau a3j\ (t)x_3(t)dt + \int_0^\tau a4j\ (t)x_4(t)dt\end{aligned} \quad [7]$$

Where, $\hat{y}\,pt$ = Weather yield, a_0= Constant, τ = growth stage of rice as it count from 0 as sowing stage with j[th] independent period, a_1, a_2, a_3, and a_4, are the regression coefficients of explanatory variables (x_1=rainfall, x_2=maximum temperature, x_3=minimum temperature, x_4=sunshine respectively) , t= is time, τ = is (the rice 'jth' growth durations), and $x_n(t)$ denote the function of independent variable in the model.

From Equation 7, the effect of each weather factor was computed from the sowing stage to the harvest stage. Thereafter, we acknowledged the Chebyshev-orthogonal polynomial function to solve regression coefficients in linear function form as in Equation 8:

$$a_i(t) = \sum_j \alpha_{ij}\varphi_{ji} \quad [8]$$

Whereby φ_{ij} is j = 1, 2, 3,…5. and α_i(t) is a regression coefficient of x_n, as a functional form of rice growth stage and time, which is approximated by Chebyshev polynomial as in Equation 9:

$$\hat{y} = \alpha_0 + \sum_i \sum_j \alpha_{ij} p_{ji} \quad [9]$$

This resulted in Equation 10 for independent variable effect on yield:

$$p_{ji} = \int_0^\tau x_i(t)\varphi_j dt \quad [10]$$

Since the intention was to solve φ, the Chebyshev polynomial matrix was used to consider the total rice growth stages as given in Equation 10.

RESULTS

Descriptive Analyses

Table 1 describes the statistical behavior of the rice yield earned, rainfall, the maximum and minimum temperature and sunshine for the period of 1981-2017. The mean rice yield is 2748.2 kg/ha. However, the results show significant variations among seasons as portrayed by the yield range (7785.3 kg/ha) which is the difference between the maximum and minimum yield (Yan et al., 2018).

Table 1
Descriptive statistics of the rice yield, rainfall, sunshine, maximum and minimum temperatures

Statistics	Rice yield (kg/ha)	Rainfall (mm) from January-July						
		Jan	Feb	Mar	Apr	May	Jun	Jul
Mean	2783.2	152.3	129.3	202.1	152.0	135.7	77.6	13.8
SD	1276.3	73.5	50.8	76.8	67.4	82.4	59.4	19.2
CV	0.5	0.5	0.4	0.4	0.4	0.6	0.8	1.4
Minimum	666.7	40.3	54.1	76.3	19.3	2.8	0.0	1.0
Maximum	852.0	340.4	237.9	451.3	363.9	329.7	192.1	72.2
Range	7785.3	300.1	183.8	375.0	344.6	326.9	192.1	72.2
Statistics	Rice yield (kg/ha)	Sunshine (hr) from January-July						
		Jan	Feb	Mar	Apr	May	Jun	Jul
Mean	2783.2	6.5	7.0	6.9	7.2	8.2	9.3	9.6
SD	1276.3	1.5	1.7	1.0	1.0	0.8	0.8	0.7
CV	0.5	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Minimum	666.7	2.9	2.8	4.5	4.6	6.5	7.6	7.9
Maximum	852.0	9.4	9.5	8.6	9.1	9.7	10.4	10.8
Range	7785.3	6.5	6.7	4.1	4.5	3.2	2.8	2.9
Statistics	Rice yield (kg/ha)	Temperature maximum (°C) January-July						
		Jan	Feb	Mar	Apr	May	Jun	Jul
Mean	2783.2	23.7	24	24.1	23.4	22.8	22.2	22.1
SD	1276.3	0.8	0.9	0.6	0.6	0.6	1.1	0.7
CV	0.5	0	0	0	0	0	0.1	0
Minimum	666.7	22	21.8	22.9	22.2	21.9	20.8	20.6
Maximum	852	25	25.6	26	24.5	23.8	27	23.7
Range	7785.3	3.0	3.8	3.1	2.3	1.9	6.2	3.1

Table 1 *(Continued)*

Statistics	Rice yield (kg/ha)	Temperature minimum (°C) January-Jul						
		Jan	Feb	Mar	Apr	May	Jun	Jul
Mean	2783.2	14.5	14.4	14	12.6	9.8	6.7	5.9
SD	1276.3	0.6	0.6	0.7	0.8	0.8	1.8	1.2
CV	0.5	0	0	0.1	0.1	0.1	0.3	0.2
Minimum	666.7	13.2	13.1	12.7	9.6	8.1	4.2	3.3
Maximum	852	15.9	16.2	15.5	14	11.2	15.1	7.8
Range	7785.3	2.7	3.1	2.8	4.4	3.1	10.9	4.5

Source. Tanzania Meteorological Authority (TMA)

The rainfall data attest to have noticeable variations among the months. For instance, the mean rainfall was the lowest in July with 13.8 mm and the highest with 202.1 mm in March. Basing on the differences, the rainfall range was 375 mm and 72.2 mm for July and March respectively which portray a significant difference not only between months but also within months. In order to understand the degree of variability among the weather variables, the authors calculated the corresponding coefficients of variability (CV) as a ratio of the standard deviation (SD) to the mean. Therefore, 0.4 as a minimum CV was obtained for the month of February, March and April and 1.4 as maximum CV the month of July. Henceforth, it reveals that from February to April the degree of rainfall variation was relatively low compared to other months while the highest rainfall variability was in July. Regarding sunshine, the minimum variability was observed during February (2.8 hrs) while the maximum was in July with (10.8 hrs). Based on temperature variability minimum temperature was observed on 3.3°C in June and the maximum was 27°C in July.

Trend Yield Determination

The trend yield is sparing of important as it shows the level of technological advancement and acceptance and other non-natural attributes including (farm management, fertilizer application, seed varieties, pesticides, policy, labor) which increase rice yields with time. As a result, trend yield was obtained from the regression equation (Equation 2) of rice yield in kg/ha obtained from Tanzania as a function of time in years from 1981-2017 as presented in Table 2. The result in Tables 2 implies that the time in years (t) was significant positively to explain the linear trend yield at 5% probability level. Therefore, there was an increment of the line of yield increase by 44.6 multiplied by time t in years as calculated for the period of years 1981-2017.

Table 2

Regression results of rice yield over time (years) y=f (t (years))

yield	Coef.	Std. Err.	t	P>t
time	44.601	20.243	2.2	0.035**
_cons	1990.01	400.29	4.97	0.000***

*** 1% significant level, ** 5% significant level

Thus, from the regression results in Table 2, we could obtain Equation 11 as our true linear trend yield model as shown below.

$$Y_t = 1990 + 44.60 * t \qquad [11]$$

Where Y_t is the intended linear trend yield showing the linear incremental of yield over time, the value 1990 is the constant of the model equation, and t is the time in years.

Therefore by solving the Equation 11 which resulted from the regression Table 2, Figure 1 shows the behavior of the actual yield and the yield for the period from 1981 to 2017 was obtained. The result is similar to the trend established in (Paltasingh, 2012). The difference between the actual yield and trend yield as explained in this work is what we refer to as weather yield that is a function of weather or meteorological factors.

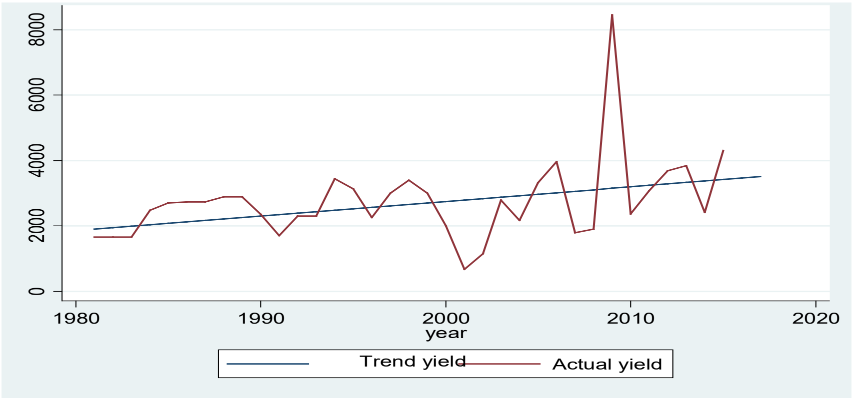

Figure 1. Actual yield and linear trend yield from the year 1981-2017

Determination of Coefficients of the Variables

Table 3 illustrates the regression results of the rice growth stages with respect to the weather factors. The regression summary demonstrates that the rainfall, maximum and minimum temperatures, and the sunshine have a significant influence on various rice growth stages. Further, it shows that the R^2 is 53%, this means that the weather factors including rainfall, temperature maximum, and sunshine explained well the variation in rice growth stages.

Table 3

Regression results for the weather- yield with weather factors on the growth stage

s/n	Growth stage	Predictor Variables	Coef	Std. Err	t	P>|t|
1	Sowing - seedling	rf0	2.708**	1.261	2.150	0.041
		tmax0	137.947**	61.571	2.240	0.033
2	Late seedling - tillering	ss1	71.845**	27.284	2.630	0.014
3	Jointing - booting	ss2	56.078**	23.320	2.400	0.023
4	Flowering - grain formation	tmax3	-89.367***	20.455	-4.370	0.000
5	Maturity - harvesting	tmin4	5.844***	1.595	3.660	0.001
		Constant	-22209.89**	10655.530	-2.080	0.046

*** P<0.01, **P<0.05, *P<0.1; F=0.001, R^2=0.53, Adj R^2=0.42, DW=2.4 Rainfall stage 1= rf0, Maximum temperature stage1= tmax0, Sunshine stage 2=ss1, Sunshine stage 3=ss2, maximum temperature stage 4=tmax3 minimum temperature stage 5=tmin4,

From Table 3, Equation 12 was obtained as a yield weather model for the study region. Also, we solved for Chebyshev yield coefficients (φij) by using the coefficients of significant variables and the resulting yield coefficients are presented in Table 4.

$$Yw = -22209.890 + 2.708 * rf0 + 137.947 * trmax0 + 71.845 * ss1 + 56.078 * ss2 - 89.367 * trmax3 + 5.844 * trmin4 \quad [12]$$

Table 4

The yield coefficients for weather-related factors on rice yield by growth stage from the Chebyshev Polynomial function

Month	Growth stage	Rainfall (kg/ha/mm)	Sunshine (kg/ha/hr)	Temperature minimum (kg/ha/°C)	Temperature maximum (kg/ha/°C)
Jan	Sowing-Seedling	2.7	64.9	210.4	674.1
Feb			-143.7	-490.9	-398.3
Mar	Vegetative		-240.1	70.1	-398.3
Apr	Tillering - booting		-224.3	420.7	137.9
May	Flowering-Grain formation		-96.4	70.1	674.1
Jun	Maturity -		143.7	-490.9	674.1
Jul	Harvesting		495.9	210.4	-398.3

DISCUSSION

This study aimed to establish the relationships between weather factors -yield coefficients on the rice yield by growth stages in the Mbeya region. Thus based on the results, a discussion on how coefficients of weather factors affected rice yield on various growth stages is presented in this section. As a preamble, while all other significant weather factors demonstrate to vary with growth stages (Belloumi, 2014; Zhao & Fitzgerald, 2013), the rainfall yield coefficient influenced rice yield on only sowing-seedling stage. In our findings, rainfall demonstrated to have a significant effect at the sowing - seedling stages. It was found that each 1 mm increase of the average rainfall could increase 2.7 kg/ha of the rice yield. This result indicates that any deviation from this amount can lead to a negative impact on rice yield. This finding echoes (Zhao & Fitzgerald, 2013) observation in their study of climate change and its implications to edible rice yield.

Sowing to the Seedling Stage

Rainfall. In the study areas, rice planting is done from early January. This month experience the mean rainfall of 152.3 mm (Table 1), thus, enough to support seedling development. The result in (Table 4) shows that the rainfall yield coefficient was 2.7 kg/ha/mm implying that, every 1 mm increases of rainfall at the sowing –seedling stage, the rice yield increased 2.7 kg/ha. These findings are consistent with the findings of Jiayu et al. (2018) conducted in China, and also Vaghefi et al. (2013).

Sunshine. Sunshine is essential to balance water through evaporation. Conversely, moderate sunshine is required by rice plants at different growth stages for optimal output. Table 4 shows that the sunshine yield coefficient influence rice yield positively in the sowing-seedling stage. This implied that as sunshine duration increased by 1-hr during the sowing-seedling stage the rice yield increased 64.9 kg/ha. This fact goes in line with our expectations that rice seed requires warm moisture to support seed rapture and emerging at the early stages of germination. This is similar to Opin et al.'s (2015) observations that optimum sunshine is required to catalyze seeds metabolism and create a reasonable environment for seeds germination. However, it was illustrated that increased sunshine duration in hours was disadvantageous for late planting because it reduced rice yield by 143.7 kg/ha.

Minimum and Maximum Temperatures. Both minimum and maximum temperatures appear to be essential for rice growth especially at the early stages of planting and germination. The results indicate that their positive yield coefficients of 210.4 kg/ha/ ^{o}C and 674.1 kg/ha/ ^{o}C benefited rice yield respectively. Also, as demonstrated in Table 4, each 1^{o}C increase of the minimum and maximum temperature enhances rice yield by 210.4 kg/ha and 674.1 kg/ha respectively from planting to the seedling. Both minimum and maximum temperatures are essential because rice grows well in an area with a temperature between 20°C to 27°C which is a characteristic of the tropical climate. Our findings concur with the findings by Krishnan et al. (2011) who found that rice survived up to 6 days under a low temperature below 15°C, and 2 days at the maximum between 27°C -37°C, while, there was no germination at the temperature above 45°C. In the case of the delayed planting, the rice yield decreased by 490.9 kg/ha and 398.3 kg/ha for each increase of 1⁰C in minimum and maximum temperature respectively. Generally, it implied that in the sowing-seedling stage the maximum temperature yield coefficient had a relatively stronger influence on rice yield than the other weather factors.

Vegetative Stage

Sunshine. The findings have revealed that excess sunshine duration at the vegetative stage is detrimental to rice development. This implies that as sunshine duration increased by 1 hour in the vegetative stage decreased rice yield by 240.1 kg/ha. In line with these findings, Opin et al. (2015) upheld that during the vegetative stage plants needed sunshine for development. However, if sunshine duration exceeded the required level, the plant lost color and hibernated on the ground, that is, if the situation prolongs it can cause delayed plant growth and or plant death.

Minimum Temperatures. The minimum temperature yield coefficient in the vegetative growth stage influenced rice yield positively (Table 4). The analyses indicate that if the minimum temperature was increased by 1°C during the vegetative stage, therefore, the rice yield increased 70.1 kg/ha. A similar claim was reported by Yaoje et al. (2017) as they narrated that the minimum temperature benefited rice with steady growth and enough nutrients. Henceforth, among the weather variables, the minimum temperature had a stronger influence in the vegetative growth stage to influence rice yield positively.

Maximum Temperatures. It was demonstrated that as the maximum temperature increased by 1°C during the vegetative stage decreased rice yield by 398.3 kg/ha. The current finding is contrary to the findings of (Ajetombi & Binuomote, 2014; Yaojje et al., 2017) at different times reported that higher temperatures during the early vegetative stage facilitated faster rice growth and yields.

Tillering and Booting

Sunshine. The influence of the sunshine yield coefficient on rice yield at this stage was negative. It was indicated that as sunshine duration increased by 1-hour in March decreased rice yield by 224.3 kg/ ha. It is apparently proven that at this stage, rice demands extra water for growth and for preparing the plant for the flowering process. Due to a negative but strong correlation between sunshine and rainfall, therefore, rainfall is required to benefit rice yield. Further, since at this stage the average rainfall was 152.04 mm (Table 1), scholars (Zhao et al., 2017) insisted that care should be taken here as rice did not demand too much water. They recommended at least 2.5 cm height of rainfall water which was sufficient to support the tillering and booting stage.

Minimum and Maximum Temperature. On the one hand, the minimum temperature yield coefficient was positive (420.7 kg/ha/°C), which had a stronger influence on the rice yield in the tillering and booting stage. This means an increase in average minimum temperature by 1°C in the tillering and booting stage increased rice yield by 420.7 kg/ha. Consequently, an increase in maximum temperature by 1°C would increase the rice yield by 137.9 kg/ha. Therefore, these findings declared that in the tillering and booting stage the average minimum temperature had more influence on the rice yield than the other weather factors. As illustrated in Figure 2 and the minimum and maximum temperatures had almost similar behavior. That is, while the minimum temperature was increasing, the maximum temperature was curving upward from negative to the positive quadrant. Our findings agree with Yu (2016) who reported a similar scenario in Hainan-China. The behavior demonstrated by the maximum temperature benefits the flowering stage. This current finding is similar to Oh-e et al. (2007) and Kaur and Attwal (2017) observation that the variations of maximum and minimum temperature had different responses in terms of crop yields in China and India respectively.

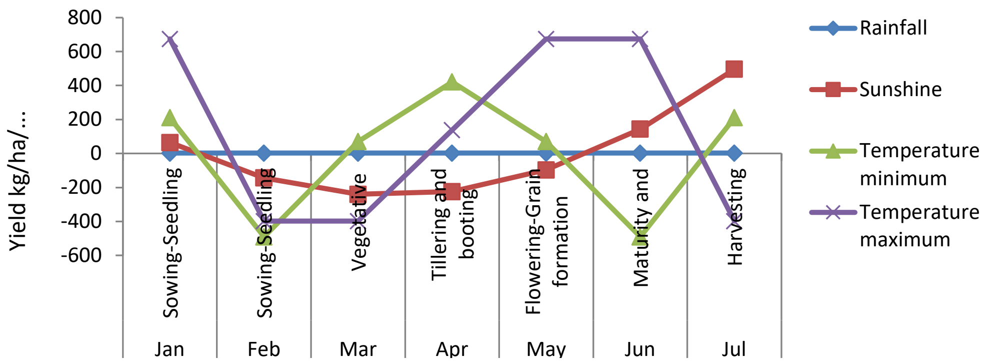

Figure 2. Impact of the yield coefficients of the rainfall (kg/ha/mm), sunshine (kg/ha/hr), maximum and minimum temperatures (kg/ha/°C) on rice yield by growth stage.

Flowering - Grain Formation Stage

Sunshine. The yield coefficient of average sunshine in the flowering stage was negative (Table 4). It indicated that having a longer sunshine duration at this growth stage could reduce rice yield by 96.4 kg/ha. Under normal circumstances, high sunshine at this stage precludes normal flowering as it induces stress to the rice plant, and hence fewer grains formation. This finding concurs with Li-quan et al. (2016) who revealed that minimum day sunshine was conducive in early stages to support photosynthesis and flowering development. However, it is advantageous for the late flowering stage where an increase of sunshine duration will increase yield by 143.7 kg/ha.

Minimum and Maximum Temperature. The positive yield coefficient of minimum temperature indicates that an average increase by 1°C could facilitate flowering and grain formation for enhanced rice yield up to 70.1 kg/ha at flowering and early grain formation stage. Meanwhile, an increase of 1°C in an average maximum temperature increased rice yield by 674.1 kg/ha at flowering and grain stage especially from April, and by 674.1 kg/ha in May. Although rice plants can relatively tolerate an increase in temperature at the flowering stage, this increase had a positive impact on grains formation and increased rice yield 674.1 kg/ha. This observation contradicts the earlier findings of Hat and Prueger (2015) and Chaturvedi et al. (2017) who reported that high temperature was detrimental during the grain formation stage of plant development.

Maturity - Harvest Stage

Sunshine. The sunshine yield coefficients were positive in maturity and harvesting stages which benefited the rice yield. As is shown, in (Figure 2), sunshine exhibits a sharp increase from June and reaches a peak in July. Therefore, the sunshine was very necessary at maturity because the grain is characterized by a full of moisture, thus, adequate sunshine is required to decrease the moisture as rice grains are ready for harvesting. Also, as it was shown in Table 4, an increase of 1 hour of sunshine duration would increase rice yield 495.9 kg/ha (harvesting stage) in July. Additionally, in this final stage (harvesting stage) sunshine was a major rice yield determinant than the other weather factors due to a relatively higher yield coefficient (495.9 kg/ha/hr). In a similar study, Dunand and Saichuk (2012) maintained that sunshine was crucial during seeds maturity and pre-harvesting seed since rice needs to attain 15 to 18% and 18 to 21% of moisture content of grain on the main stem and crop grain respectively.

Minimum Temperature. Furthermore, the rice yield coefficients for minimum temperature were negative in the maturity stage but positive in the harvesting stage. It was demonstrated that an increase of 1°C minimum temperature was detrimental to the grain's maturity, thus, decreased rice yield 210.4 kg/ha in June. The impact was contrary to the harvesting stage as a similar increase of 1°C benefited rice yield 210.4 kg/ha. This indicates essentiality for the minimum temperature to facilitate normal grains ripening and maturity. A similar trend was commented by Jiayu et al. (2018), although, they added the situation could differ depending on locations.

Maximum Temperature. The results indicate that rice yield increased by 674.1 kg/ha at each average increase of 1°C maximum temperature at the maturity stage. However, in the harvesting month of July, the maximum temperature reduced rice yield by 398.3 kg/ha at each 1°C increase of maximum temperature. This is similar to Oh-e et al. (2007) and also Zhao and Fitzgerald (2013) assertion. In practice, it is very obvious that high temperatures has a significant negative impact on rice yield from flowering to maturity. For example, Fankhauser and McDermott (2016) observed that high temperatures during the final stages of rice growth could disrupt both morphology and biochemical status of rice grains.

CONCLUSION

The study has revealed that the previous weather data (rainfall, sunshine, maximum and minimum temperatures) have significantly influenced the rice yield in the Mbeya Region. The results from the Fisher Regression Model and Chebyshev Polynomial Function have confirmed that different weather factors have affected rice yield at different rice growth stages. In addition, the developed weather rice yield model from this study could be useful for regional rice yield forecasting. At this end, the study recommends necessary efforts to curb the impacts of weather variability on rice crop yield to be taken. The efforts involve; planning for water harvesting, investing in irrigation technology, and investing in the local community awareness of weather-driven impacts on rice production. Also the introduction of crop risk awareness and management at local levels. Since this study focused on the few meteorological factors namely; the rainfall, sunshine duration, and temperatures, we recommend further studies on other meteorological factors to be undertaken to rice crop and other agricultural crops in Tanzania.

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REFERENCES

Abdul-rahaman, I., & Ebenezer, O. (2017). Climate variability and sustainable food production. *Ghana Journal of Geography, 9*(2), 80-83.

Adhikari, U., Nejadhashemi, A. P., & Woznicki, S. A. (2015). Climate change and eastern Africa: A review of impact on major crops. *Food and Energy Security, 4*(2), 110-132.

Ajetombi, J., & Binuomote, S. (2014). An investigation of the effect of climate change on selected cereal crops yield in Nigeria: A ricardian analysis. *Continental Journal of Agricultural Science, 8*(3), 38-48.

Belloumi, M. (2014). Eastern and Southern African countries investigation of the impact of climate change on agricultural production in eastern and southern African countries. *Classification Q54; Q18, 54*(July), 1-29.

Benjamin A. O., Dell, M., & Benjamin, F. J. (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal, 4*(3), 66-95.

Bruckner, M., & Ciccone, A. (2011). Rain and the democratic window of opportunity. *Econometrica, 79*(3), 923-947.

Burke, P. J. (2010). Do output contractions trigger democratic change? *American Economic Journal of Macroeconomics, 2*(4), 124-157.

Chaturvedi, A. K., Bahuguna, R. N., Shah, D., & Singh, M. P. (2017). High temperature stress during flowering and grain filling offsets beneficial impact of elevated CO_2 on assimilate partitioning and sink- strength in rice. *Scientific Reports, 7*(8227), 1-14.

Chatzopoulos, T., Pérez, I., Zampieri, M., & Toreti, A. (2019). Climate extremes and agricultural commodity markets: A global economic analysis of regionally simulated events. *Weather and Climate Extremes, 27*, 1-14.

Dell, M., Benjamin, F. J., Benjamin, A. O., & Muqaddimah, G. (2014). What do we learn from the weather? The new climate–economy literature. *Journal of Economic Literature, 52*(3), 740-798.

Dunand, R., & Saichuk, J. (2012). Rice growth and development. InJ. Saichuk (Ed.), *Louisiana rice production handbook* (pp. 41-53). Baton Rouge, Louisiana: Louisiana State University Agricultural Center.

Fankhauser, S., & McDermott, T. K. J. (2016). *The economics of climate –resilient development*. Cheltenham, UK: Edward Elgar Publishing.

Fisher, R. A. (1925). Statistical methods for research workers. In S. Kotz & N. L. Johnson (Eds.), *Breakthroughs in statistics* (pp. 66-70). New York, NY: Springer.

Gelete, G., & Gokcekus, H. (2018). The economic impact of climate change on transportation assets. *Journal of Environmental Pollution and Control, 1*(1), 1-6.

Hat, J. L., & Prueger, J. H. (2015). Temperature extremes: Effect on plant growth and development. *Weather and Climate Extremes, 10*(2015), 4-10.

Hsiang, S. M. (2014). Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America. *Proceedings of the National Academy of Sciences, 107*(35), 15367-15372.

Islam, S., Cenacchi, N. T. B., Sulser, S., Gbegbelegbe, G., Hareau, U., & Kleinwechter, K. W. (2016). Structural approaches to modeling the impact of climate change and adaptation technologies on crop yields and food security. *Global Food Security, 10*(2016), 63-70.

Jiayu, Z., Shiwei, X., Ganqiong, L., Yongen, Z., Jianzhai, W., & Jiajia, L. (2018). The influence of meteorological factors. *Crop Science, 852*(April), 837-852.

Johansson, R., Luebehusen, E., Morris, B., Shannon, H., & Meyer, S. (2015). Monitoring the impacts of weather and climate extremes on global agricultural production. *Weather and Climate Extremes, 10*(2016), 65-71.

Katambara, Z., Mng, M., Chambi, C., & Malley, Z. (2016). Characteristics of rice produced under direct and indirect SRI practices in Chimala area in Mbarali District. *Journal of Agriculture and Sustainability, 9*(1), 15-30.

Katengile, R. J., Ngelenge, H. S., & Busindeli, I. M. (2018). Socio-economic and field performance evaluation of different rice varieties under system of rice intensification in Morogoro, Tanzania. *Agricultural Research and Technology, 17*(2), 1-5.

Kaur, K., & Attwal, K. (2017). Factors affecting paddy pant at different growth stages. *International Journal Advanced Technology in Engineering Science, 4*(5), 193-199.

Krishnan, P., Ramakrishnan, B., Reddy, K. R., & Reddy, V. R. (2011). High-temperature effects on rice growth, yield, and grain quality. *Advances in Agronomy, 111*(December), 87-206.

Li-quan, J., Yan-zhen, W. U., Shi-teng, Z., Yun-xia, W. Z., Jian-guo, H. U., & Yu-long, W. (2016). Effects of CO_2 enrichment and spikelet removal on rice quality under open-air field conditions. *Journal of Integrative Agriculture, 15*(9), 2012-2022.

Lizumi, T., & Ramankutty, N. (2015). How do weather and climate in fluence cropping area and intensity ? *Global Food Security, 4*(2015), 46-50.

Mamane, B. G. H., & Malam, M. M. N. (2015). A ricardian analysis of the impact of temperature and rainfall variability on agriculture in Dosso and Maradi regions of Niger Republic. *Agricultural Sciences, 6*, 724-733.

Mirzabaev, A. (2013). Impacts of weather variability and climate change on agricultural revenues in central Asia. *Journal of International Agriculture, 52*(2013), 242-246.

Mkonda, M. Y., & He, X. (2017). Yields of the major food crops: Implications to food security and policy in Tanzania's semi-arid agro-ecological zone. *Sustainability, 9*(8), 7-15.

Mkonda, M. (2014). Rainfall variability and its association to the trends of crop production in Mvomero District, Tanzania. *European Scientific Journal, 10*(20), 15-18.

Moretti, L., & Loprencipe, G. (2018). Climate change and transport infrastructures: State of the art. *Sustainability, 10*(11), 1-18.

Msongaleli, B. M., Tumbo, S. D., Kihupi, N. I., & Rwehumbiza, F. B. (2017). Performance of sorghum varieties under variable rainfall in central Tanzania*. International Scholarly Research Notices, 2017*, 1-10.

Mtongori, H. I., Stordal, F., & Benestad, R. E. (2016). Evaluation of empirical statistical downscaling models' skill in predicting Tanzanian rainfall and their application in providing future downscaled scenarios. *Journal of Climate, 29*(9), 3231-3252.

Ngailo, J. A., Mwakasendo, J. A., Kisandu, D. B., & Tippe, D. E. (2016). Rice farming in the southern highlands of Tanzania: Management practices, socio-economic roles and production constraints. *European Journal of Research in Social Sciences, 4*(3), 5-11.

Oh-e, I., Saitoh, K., & Kuroda, T. (2007). Effects of high temperature on growth, yield and dry-matter production of rice grown in the paddy field. *Plant Production Science, 10*(4), 412-422.

Opin, C., Potuschak, T., & Bachmair, A. (2015). Seedling germination: Seedlings follow sunshine and fresh air cell migration: Recoiling from an embrace. *Current Biology, 25*, 565-566.

Paltasingh, K. (2012). Measuring weather impact on crop yield using aridity index: Evidence from Odisha. *Agricultural Economics Research Review, 25*(13), 205-216.

Peter, H. G. (2014). Water, drought, climate change, and conflict in Syria. *American Meteorological Society, 6*(2014), 331-340.

Salman, K., Ghaffar, A., Syed, A. S., Abbas, U. J., Dawood, J., & Fayaz, M. (2016). A hedonic analysis of agricultural land prices in Pakistan's Peshawar District. *Asian Journal of Agriculture and Rural Development, 6*(4), 59-67.

Shannon, H. D., & Motha, R. P. (2015). Managing weather and climate risks to agriculture in North America, central America and the Caribbean. *Weather and Climate Extremes, 10*(2015), 50-56.

Siebert, S., Webber, H., & Rezaei, E. E. (2017). Weather impacts on crop yields - searching for simple answers to a complex problem. *Environment Research Letters, 12*(2017), 5-8.

Sridevi, V., & Chellamuthu, V. (2015). Impact of weather on rice – A review. *International Journal of Applied Research, 1*(9), 825-831.

Thi, N., Jintrawet, A., & Promburom, P. (2015). Impacts of seasonal climate variability on rice production in the central highlands of Vietnam. *Italian Oral Surgery, 5*(2015), 83-88.

Vaghefi, N. M., Nasir, S., Radam, A., & Rahim, K. A. (2013). Modeling the impact of climate Change on rice production: An overview. *Journal of Applied Sciences, 13*(24), 5649-5660.

Wen, Y., Shiwei, X., Liu, S., Ahamed, A., & Wang, Yu. (2014). Meteorological impact on the winter wheat yield in weishan China*.* *Journal of Applied Science, 13*(14), 2740-2742.

Weng, F., Zhang, W., Wu, X., Xu, X., Ding, Y., & Li, G. (2017). Impact of low-temperature, overcast and rainy weather during the reproductive growth stage on lodging resistance of rice. *Nature Publishing Group, 2017*(April), 1-9.

Yan, M., Liu, P., Zhang, C., Zheng, Y., & Wang, X. (2018). Quantitative research on the relationship between yield of winter wheat and agroclimatological resources. *Earth and Environmental Science, 108*(2018), 4-11.

Yaojie, C., Min, L., Wenzhong, W., Minglu, M., & Yaoxiu, F. (2017). Effects of climate change on winter wheat yield in Wenshui County. *Journal of Arid Land Resources and Enviroment, 7*(2017), 6-15.

Yu, W. (2016). Could rice yield change be caused by weather ? *Journal of Agricultural Chemistry and Environment, 5*(01), 31-37.

Yu, W., Shiwei, X., Wen, Y., Ahmed, A. G., & Guogang, X. (2015). Application of modified fisher integral model on the influence of meteorological factors on peanut yield in Hebei of China. *International Journal of Agricultural and Food Research, 4*(2), 3-7.

Zhao, C., Liu, B., Piao, S., Wang, X., Lobell, D. B., Huang, Y., … & Durand, J. L. (2017). Temperature increase reduces global yields of major crops in four independent estimates. *Proceedings of the National Academy of Sciences, 114*(35), 9326-9331.

Zhao, X., & Fitzgerald, M. (2013). Climate Change: Implications for the yield of edible rice. *PLoS ONE, 8*(6), 1-9.