Rice meteorological yield model on growth stages in Mbeya region of Tanzania

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ABSTRACT

This study intended to determine the exact impact of weather variables on each rice growth stage in Mbeya region. Rice yield data and weather variables from 1981-2017 were employed for analysis. The study includes the following approaches: decomposition of rice yield into yield tendency and yield weather; applications of a Stepwise integral regression to obtain significant yield weather-related variables to establish yield Model in the study area; and applications of Fisher’s Meteorological regression and Chebyshev polynomial function to compute respective weather factors’ coefficients from the yield model. Rice yield in the region apart from the non-natural factors, also rainfall, maximum and minimum temperature, and sunshine showed greater impact on rice yields from sowing to harvest stages. However, their impacts differ for each stage and respective months in the farming season. Additionally, rainfall seems to have an averagely uniform impact at each stage, and an increase of 1mm rainfall at each growth stage could result in 2.7 kg/ha. Sunshine duration had a negative impact on rice yield and was found to reduce rice yields up to 1087 kg/ha from February-May. Maximum temperature had a negative impact on February, March, and May. More so, the minimum temperature had a negative impact during February and June. Finally, the meteorological rice yield model was established for the Mbeya region.

Key words: Meteorological yield, rice yield, regression, growth stages, weather, Mbeya.

INTRODUCTION

Rice is among the three major crops grown in Tanzania and is ranked second after maize (Makoi, 2016). It is utilized as food and cash generating crop for most rural families (Wilson and Lewis, 2015). Statistically, Tanzania is ranked second to Madagascar in term of production among the Eastern and Southern Africa countries (FEWSNET, 2016; Rugumamu, 2014a; Adhikari et al., 2015). Its share in the world account for 0.4% and is ranked 22 (Mirzabaev and Tsegai, 2012). Significantly, Tanzania is rich in rice production potentials (Mbilinyi and Kazi, 2013) including; rain-fed rice eco-system in the lowland and uplands, and the irrigated rice eco-system. In most areas of the country, rice is planted beginning from either late December or early January after first rains and harvested from late May to July depending on weather variations (Sunshine and precipitation) and also seed variety (Mbilinyi and Kazi, 2013). Currently, about 71% of rice produced in the country is under the rainfed system (Call, 2017); however,
the system has been vulnerable to weather shocks (Suit and Choudhary, 2015). In fact, high rain fed dependency (Ngailo et al., 2016) substantiates the existence of a high relationship between rice production and weather factors in Tanzania. In addition, in Tanzania studies on the weather-crops relationship are few, and even the available studies have centred on the impacts of climate change on crops. The few recent studies (Mtongori et al., 2016; Mkonda, 2014; Mkonda and He, 2017) focused only on the long effects of the climatic change to others cereal crops other than rice.

At present, many researchers outside Africa have so far tried to establish a relationship between meteorological factors and agricultural crops production. For example Chen et al.(2014) tried to establish the relationship between maximum and minimum temperature and the weather rice yield in China. Their finding shows the existence of both positive and negative relationship on rice growth stages in different counts of China. A similar study in China concluded on having positive and negative contributions (Yu et al., 2015) on peanut yield in Hebei and also (Yu et al., 2015) on winter wheat in Weishan county. Appreciating its vitality to Tanzania population, the government has been working hard to intensify rice production. This is due to inadequate production and low productivity which is threatening rice subsector and the population at large (Rugumamu, 2014a; Zhao et al., 2017). The current research opens a new approach to Tanzania rice subsector intensification especially in the study region of which later could be adapted to the other areas of the country. The relationship between weather-related factors and their variability at each rice growth stage have a worth impact to disclose on rice yield. This is, however, made possible by analysing the yield contributed by weather fluctuation (yp) as deduced from the difference between actual rice yield (ya) and trend yield (yt). Basically, yt is the yield from other attributes rather than natural ones such as technology progress, seeds, management practices, government policies etc. As a subject of concern to crops specialists, the weather is known as an input in crop production, however, while it is possible to specialists to quantify and measure other inputs it had not been so for weather (Paltasingh, 2012). This brings up the main objective of this study, that is, to determine the influence of weather-related factor on weather-yield, by building the relationship between weather yield and weather-related factors as yield impelling variables. The authors employed the idea of Fisher (1925) by accounting the impacts of weather-related factors at each rice growth stages.

**METHODOLOGY**

**Type of data and data sources**

The three important secondary data pertaining to rice production are included in the current research. First, the authors obtained rice yield data series from the study region for the past 36 years (1981-2017). Yield data was sourced from the Tanzania government agencies including Tanzania Ministry of Agriculture, Food security and Cooperative (MAFC), Ministry of Industry and Trade (MOIT), and National Bureau of Statistics (NBS). Second, the Meteorological data including average monthly rainfall (mm), monthly maximum and minimum temperature (°C), and sunshine (Hours) for 36 years were obtained from Tanzania Meteorological Authority (TMA).

**Profile of the study region**

Mbeya is among the oldest region situated in the Southern Highlands of Tanzania. It situated between latitude 70 and 90 31’ to the south of equator and longitude 320 and 350 east of Greenwich. The region is the leading regions in term of agricultural outputs in Tanzania. The climate is hugely affected by both physiology and altitudes. It has a tropical climate which many cereal crops including rice are farmed. The region receives rainfall which varies between 650 and 1200mm, though it also experiences dry and cold spell between June and September. The tropical climate, rainfall distribution, and variations in temperature favour rice production. Rice cultivation is undertaken in the large area of the region including Mbarali and Kyela Districts.

**Descriptive analyses**

Table 1a and b describe the statistical behaviour of the yields earned, rainfall, sunshine, maximum and minimum (Yan et al., 2018) temperature for the period of 1981-2017. The mean rice yield is 2748.23 kg/ha. However, the results showed significant variations among seasons as portrayed by the yield range (7785.3Kg per ha) which is the difference between maximum and minimum yield. Among the months, rainfall data showed noticeable variations. Between months, the mean rainfall was lowest in July with 13.79 mm and highest with 202.06 mm in March. Based on the differences, the rainfall range was between 375 and 72.2mm, respectively which shows significant difference not only between months but also within months. 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, the authors obtained 0.39 and 1.39 as minimum and maximum CV for March and July, respectively.

The mean maximum temperature was highest in March (24.11°C) and lowest in July (22.10°C), whereas, the range between maximum and minimum temperature was 3.10°C for both two months. In addition, the mean minimum temperature was found to be 5.90°C as lowest in July and
was relatively high (14.51°C) in January. Also the average sunshine duration was 9.59 (hours) in July and lowest was 6.54 (hours) in January. Moreover, the sunshine duration range was between 2.7 (hours) in July and 6.5 (hours) in January. However, the data show that C.V of sunshine ranged from 0.24-0.07 in both February and July, respectively.

### Research method

In this research began by employing traditional classical economic production function where the dependent variable rice crop yield \( y_a \) is a function of a set of independent variables; (technology, capital, labour) denoted as q and weather factors (w) as shown in Equation (1):

\[
y_a = f(q, w)
\]

Where \( y_a \) = actual yield \\
q = Combined production factors; technology, labour, and capital \\
w = weather or meteorological factors.

Therefore, the authors of the present study accommodated the ideas of different scientists including Yu et al. (2015) and Zhao et al. (2017) who have managed to extend the existing statistical relationship between meteorological factors and crop yield. Furthermore, they went on to detach weather yield as yield due to weather variations. To add up, actual yield is defined as a yield due to yield tendency as a measure of technology advancement and management, and meteorological yield due to weather factors variation. In line with that, in this research, accommodating similar approach yield weather was computed from the difference between actual yields trend-yield. In addition, the authors' central idea was to establish the worthwhile statistical relationship between weather yield and weather-related factors by considering the different rice growth stages, and the time from sowing to harvest. In the study region, rice is grown in early January and matures in July of the same year. So, the study

**Table 1:** Descriptive statistics of variable.

### (a) Rice yield kg/ha, Rainfall (mm) (Jan-Jul), Sunshine (Jan-Jul)

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2748.23</td>
<td>152.30</td>
<td>129.27</td>
<td>202.06</td>
<td>152.04</td>
<td>135.67</td>
<td>77.66</td>
<td>13.79</td>
<td>6.54</td>
<td>7.01</td>
<td>6.91</td>
<td>7.15</td>
<td>9.29</td>
<td>9.59</td>
</tr>
<tr>
<td>SD</td>
<td>1276.25</td>
<td>73.51</td>
<td>50.83</td>
<td>76.75</td>
<td>67.44</td>
<td>135.67</td>
<td>77.66</td>
<td>13.79</td>
<td>6.54</td>
<td>7.01</td>
<td>6.91</td>
<td>7.15</td>
<td>9.29</td>
<td>9.59</td>
</tr>
<tr>
<td>CV</td>
<td>0.46</td>
<td>0.48</td>
<td>0.39</td>
<td>0.38</td>
<td>0.44</td>
<td>0.61</td>
<td>0.77</td>
<td>1.39</td>
<td>0.23</td>
<td>0.24</td>
<td>0.15</td>
<td>0.09</td>
<td>0.08</td>
<td>0.07</td>
</tr>
<tr>
<td>Minimum</td>
<td>666.70</td>
<td>40.30</td>
<td>54.10</td>
<td>76.30</td>
<td>19.30</td>
<td>2.80</td>
<td>0.00</td>
<td>0.00</td>
<td>2.90</td>
<td>2.80</td>
<td>4.50</td>
<td>6.50</td>
<td>7.60</td>
<td>7.90</td>
</tr>
<tr>
<td>Maximum</td>
<td>8452.00</td>
<td>340.40</td>
<td>237.90</td>
<td>451.30</td>
<td>363.90</td>
<td>329.70</td>
<td>192.10</td>
<td>72.20</td>
<td>9.40</td>
<td>9.50</td>
<td>8.60</td>
<td>9.10</td>
<td>9.70</td>
<td>10.40</td>
</tr>
<tr>
<td>Range</td>
<td>7785.3</td>
<td>300.1</td>
<td>183.8</td>
<td>375</td>
<td>344.6</td>
<td>326.9</td>
<td>192.1</td>
<td>72.2</td>
<td>6.5</td>
<td>6.7</td>
<td>4.1</td>
<td>4.5</td>
<td>3.2</td>
<td>2.8</td>
</tr>
</tbody>
</table>

### (b) Temperature maximum (°C) (Jan-Jul), Temperature minimum (°C) (Jan-Jul)

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD</td>
<td>0.77</td>
<td>0.90</td>
<td>0.59</td>
<td>0.55</td>
<td>0.57</td>
<td>1.07</td>
<td>0.74</td>
<td>0.57</td>
<td>0.60</td>
<td>0.67</td>
<td>0.78</td>
<td>0.78</td>
<td>1.76</td>
<td>1.17</td>
</tr>
<tr>
<td>CV</td>
<td>0.03</td>
<td>0.04</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.05</td>
<td>0.03</td>
<td>0.04</td>
<td>0.04</td>
<td>0.05</td>
<td>0.06</td>
<td>0.08</td>
<td>0.26</td>
<td>0.20</td>
</tr>
<tr>
<td>Minimum</td>
<td>22.00</td>
<td>21.80</td>
<td>22.90</td>
<td>22.20</td>
<td>21.90</td>
<td>20.80</td>
<td>20.80</td>
<td>13.20</td>
<td>13.10</td>
<td>12.70</td>
<td>9.60</td>
<td>8.10</td>
<td>4.20</td>
<td>3.30</td>
</tr>
<tr>
<td>Maximum</td>
<td>25.00</td>
<td>25.60</td>
<td>26.00</td>
<td>24.50</td>
<td>23.80</td>
<td>23.70</td>
<td>23.70</td>
<td>15.90</td>
<td>16.20</td>
<td>15.50</td>
<td>14.00</td>
<td>11.20</td>
<td>15.10</td>
<td>7.80</td>
</tr>
<tr>
<td>Range</td>
<td>3.00</td>
<td>3.80</td>
<td>3.10</td>
<td>2.30</td>
<td>1.90</td>
<td>3.10</td>
<td>3.10</td>
<td>2.70</td>
<td>3.10</td>
<td>2.80</td>
<td>4.40</td>
<td>3.10</td>
<td>10.90</td>
<td>4.50</td>
</tr>
</tbody>
</table>

Source: Tanzania Meteorological Authority (TMA).
considered a total of seven months and five growth stages.

**Yield model setting**

**Actual, trend, and meteorological yield model setting**

The actual yield $ya$ (Equation 2) is computed from crop production time series data which enabled the researcher in setting up the intended model. More so, the actual yield was obtained from traditional classical production function as a combination of natural factors, technology, management, and weather elements [Yu et al., 2015]. Therefore, using equation 2, we could differentiate yield weather from actual yield:

$$ya = yt + yp \quad (2)$$

Where, $ya$ is Actual rice yield, $yt$ is production trend or tendency yield, and $yp$ is weather yield.

As a matter of fact, $yp = f(rf, trmax, trmin, ss)$ indicates $yp$ as a function of weather variables (rainfall ($rf$), maximum temperature ($trmax$), minimum temperature ($trmin$), and sunshine ($ss$) equation 3.

$$yp = f(rf, trmax, trmin, ss) \quad (3)$$

Hence, by combining the classical production function, we can have a new rice production function as shown in Equation 4:

$$ya = yt + f(rf, trmax, trmin, ss) \quad (4)$$

In addition, yield tendency $yt$ as referred to in this study is a function of non-national production attributes including progress in technology, seeds, land, management practices, policy issues etc. In reality, to measure $yt$ is not simple but we attempted to do so. In this regard, the present study considered $yt$ as a function of time $t$ from year 1981 to 2017. Others researchers have applied the moving average method by denoting to a specific sliding window. The yield trend is economically important as it shows the level of technology acceptance and other non-national attributes. As a result, yield trend could be obtained from the regression equation as presented in Table 2.

Thus from the regression results in Table 2, we could obtain Equation 5 for yield trend:

$$yt = 1900 + 44.60 * t \quad (5)$$

Where, $yt$ = yield trend in question
$c$ = constant
$t$ = time trend

Therefore, by solving the Equation (5), Figure 1 is obtained showing how actual yield and yield trend behave for the period of 1981-2017. Basically, the difference between the two as was explained in this work is what we refer to as yield weather as a function of meteorological factors.

**Application of fisher integral regression model**

Fisher had given a respectable statistical regression model to enable solving the relationship between weather-related yields and weather factor’s influence at different growth stages of crops in question. In addition to that, it makes possible to ascertain the quantitative relationship among variables and their coefficients in the model. The regression model was used to establish the quantitative relationships between the weather yield as a dependent variable on weather-related attributes. Hence, according to Fisher, the model requires obtaining the following (Equation (6)):

$$\hat{y}_p = \alpha_0 + \int_0^t a_1(t)x_1(t)dt + \int_0^t a_2(t)x_2(t)dt + \int_0^t a_3(t)x_3(t)dt + \int_0^t a_4(t)x_4(t)dt \quad (6)$$

Where, $\hat{y}_p$ = Weather yield, $\alpha_0$ = Constant, $t$ = growth stage of rice as it count from 0 as sowing stage with jth 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), $t$ = time, $\tau$ = is (the rice ‘jth’ growth durations), and $x_a(t)$ denote the function of independent variable in the model.

From Fisher integral of Equation (6), we computed the effect of each weather factor from sowing stage to mature or harvest stage. Thereafter, we acknowledged the Chebyshev – orthogonal polynomial to solve regression coefficients in linear function form:

$$a_j(t) = \sum_j \alpha_j \varphi_{ji} \quad (7)$$

Whereby $\varphi_{ji}$ is $j = 1, 2, 3,...5.$ and $a_j(t)$ is the regression coefficient of $x_n$ as a functional form of rice growth stage and time, which is approximated by Chebyshev polynomial shown in Equation (8):

$$\hat{y} = \alpha_0 + \sum_i \sum_j \alpha_j p_{ji} \quad (8)$$

Therefore, we ended up having equation for independent variable effect on yield:

$$p_{ji} = \int_0^t x_i(t) \varphi_j dt \quad (9)$$

Since, the intention was to solve $\varphi,$ the Chebyshev
Table 2: Regression of yield with time (years) results.

<table>
<thead>
<tr>
<th></th>
<th>Yield</th>
<th>Coef.</th>
<th>Std. Err.</th>
<th>t</th>
<th>P&gt;t</th>
</tr>
</thead>
<tbody>
<tr>
<td>t</td>
<td>44.601</td>
<td>20.243</td>
<td>2.2</td>
<td></td>
<td>0.035**</td>
</tr>
<tr>
<td>_cons</td>
<td>1990.007</td>
<td>400.287</td>
<td>4.97</td>
<td></td>
<td>0.000***</td>
</tr>
</tbody>
</table>

Prob > F = 0.0347  R-squared = 0.1282  Adj R-squared=0.1018

*** denote 1% significant level and ** denote 5% significant level.

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

Table 3: Chebyshev orthogonal table.

<table>
<thead>
<tr>
<th></th>
<th>φ_0(x)</th>
<th>φ_1(x)</th>
<th>φ_2(x)</th>
<th>φ_3(x)</th>
<th>φ_4(x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>-3</td>
<td>5</td>
<td>-6</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>-2</td>
<td>0</td>
<td>6</td>
<td>-84</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>-1</td>
<td>-3</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>0</td>
<td>-4</td>
<td>0</td>
<td>72</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1</td>
<td>-3</td>
<td>-6</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>-6</td>
<td>-84</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>36</td>
</tr>
</tbody>
</table>

The polynomial matrix was used by considering the total rice growth stages which in this work is five (5).

RESULTS

Determination of coefficients of the variables

From the Chebyshev polynomial matrix function, we calculated the coefficient of the respective variables as shown in Table 3. Therefore, from Table 3, Equation (10) was obtained for yield weather model.

\[
\gamma_w = -22209.890 + 2.708 \cdot \text{RH} + 137.397 \cdot \text{tmax} + 71.845 \cdot \text{ss1} + 56.078 \cdot \text{ss2} - 09.367 \cdot \text{tmax} + 5.844 \cdot \text{tmin4} 
\]

(10)

Figures 2 to 5 show how each individual weather factor influence rice weather yield from sowing to maturity.

DISCUSSION

The study intended to establish the relationships between weather rice yield and weather-related factors in Mbeya region. So, based on the results, we could have discussed on how rice is affected by each weather variable at various
growth stages. As a preamble, while all other significant weather factors did vary with growth stages, rainfall was found uniformly distributed among all the stages. This signifies that for each 1mm increase of rainfall, approximately 2.7 kg/ha in each of rice growth should be added. More so, based on this result, any deviation from this amount will have a negative impact on rice yield.

Sowing to the seedling stage

Rice is sown from early January in most area of the study region. In the early stages of sowing to germination (January–February), sunshine is an important attribute to forecast future rice yields. From Figure 3 and Table 4, it is shown that an increase in average 1 hof sunshine increase up to 64.9 kg/ha of rice yield. This fact goes in line with the researcher’s expectations since rice seed does require warm moisture to support seed rapture and emerging. Another fact is, in the study region, rainfall is experienced from early December and reach to the peak in March (Table 1a), so sunshine is essential to balance water through evaporation, also catalyse plants metabolism, and create reasonable warm soil moisture for seeds to germinate.

On the other hand, both minimum and maximum temperatures appear to be essential for rice growth
especially at early stages of sowing and germination. The positive yield coefficients, of 210.4 and 674.1, respectively

Table 4: Step-wise regression results for yield-weather factors.

| s/n | Growth stages                        | Predictor variables | Coef   | Std. Err | t     | P>|t| |
|-----|-------------------------------------|---------------------|--------|----------|-------|-----|
| 1   | Sowing to Seedling                   | rf0                 | 2.708**| 1.261    | 2.150 | 0.041|
|     |                                     | tmax0               | 137.947** | 61.571  | 2.240 | 0.033|
| 2   | Late seedling to Tillering          | ss1                 | 71.845** | 27.284  | 2.630 | 0.014|
| 3   | Jointing to booting                 | ss2                 | 56.078** | 23.320  | 2.400 | 0.023|
| 4   | Flowering to grain formation        | tmax3               | -89.367*** | 20.455  | -4.370| 0.000|
| 5   | Maturity to 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=0.52590, Adj R^2=0.42430, DW=2.375777.

Rainfall stage 1= rf0, Maximum temperature stage1= tmax0, Sunshine stage 2=ss1, Sunshine stage 3=ss2, Temperature maximum stage 4=tmax3, Temperature minimum stage 5=tmin4.

Table 5: The yield coefficient for weather related factors.

<table>
<thead>
<tr>
<th>Month</th>
<th>Rainfall</th>
<th>Sunshine</th>
<th>Temperature minimum</th>
<th>Temperature maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>2.7</td>
<td>64.9</td>
<td>210.4</td>
<td>674.1</td>
</tr>
<tr>
<td>Feb</td>
<td>2.7</td>
<td>-143.7</td>
<td>-490.9</td>
<td>-398.3</td>
</tr>
<tr>
<td>Mar</td>
<td>2.7</td>
<td>-240.1</td>
<td>70.1</td>
<td>-398.3</td>
</tr>
<tr>
<td>Apr</td>
<td>2.7</td>
<td>-224.3</td>
<td>420.7</td>
<td>137.9</td>
</tr>
<tr>
<td>May</td>
<td>2.7</td>
<td>-96.4</td>
<td>70.1</td>
<td>674.1</td>
</tr>
<tr>
<td>Jun</td>
<td>2.7</td>
<td>143.7</td>
<td>-490.9</td>
<td>674.1</td>
</tr>
<tr>
<td>Jul</td>
<td>2.7</td>
<td>495.9</td>
<td>210.4</td>
<td>-398.3</td>
</tr>
</tbody>
</table>

in Table 5, demonstrate that for each 1°C increase also add rice yield by 210.4 and 674.1 kg, respectively. The two variables are essential from the fact that the study area is in the tropical region of which a temperature of 20 – 27°C can support rice growth. In addition, rainfall seemed to have a vital effect at this stage because rice needs enough moisture for seedling development and balance the environmental temperature. More so, each increase in 1mm of rainfall increases rice yield by 2.7 kg/ha.

and relatively negative impact on yield; however, the minimum temperature appears to benefit rice with steady growth and enough nutrients.

Jointing and booting stage

The influence of rice sunshine yield coefficient at this stage is negative. It is shown that as sunshine duration increase by one hour from March, rice yield decreases by 240.1 kg/ha. It is apparent that at this stage, rice demands extra water growth and prepares the plant for flowering. Due to a negative but strong correlation between sunshine and rainfall, rice yield benefit is expected. As shown in Figures 3 and 4, both minimum and maximum temperatures had almost the similar behaviour. While the minimum temperature was increasing at the same time maximum temperature was also curving upward from negative to the positive quadrant. At first, the rice yield coefficient on minimum temperature was positive, indicating that as it increases by 1°C, the yield also increases by 210.4 kg/ha. Contrary to that, increase in maximum temperature by 1°C will have a negative impact on rice yield which results in a loss of 398.3 kg/ha. Additionally, the behaviour shown by maximum temperature with the curve in Figure 4 has future benefit for the flowering stage. Thus, would have a

Late seedling to tillering stage

Tillering is an important and also very sensitive stage of rice plant development. Meteorological factors play a great role as well, from the analysis in Table 5, it shows that yield coefficient of sunshine starts from 0 in February going to negative (-240.1) in March. This stage is the period where developing seedling is becoming delicate and every increase of one hour of sunshine will decrease rice yield by 240.1 kg/ha. Consequently, coefficients of rice yield are positive for minimum temperature and when is increased by 1°C can increase yield by 70.1 kg/ha, contrary to maximum temperature which was found to decrease yield by 398.3 kg. Practically, with higher temperatures at early stages of rice development could facilitate faster growth
severe impact as shown to lower yield by 398.3 kg/ha. However, rice yield increased by 70.1 kg/ha for each increase of 1°C of minimum temperature. The result of this study is in line with the findings reported by Yaojie et al. (2017) that variations of maximum and minimum temperatures have both positive and negative influences on crops yields in China.

Flowering and grain formation stage

The yield coefficient of an average sunshine during the flowering stage was negative. It indicates that having a longer sunshine duration at this stage will reduce rice yield by 224.3 kg/ha (From April). Under normal circumstances, receiving high sunshine preclude normal flowering as it induces stress to rice plant, and hence fewer grains formation. So, minimum day sunshine was conducive at early stages so as to support photosynthesis and facilitate flowering development. The yield coefficient of minimum temperature was positive, indicating that average increase by 1°C facilitates flowering and grain formation for better rice yield of 420.7 kg/ha. Moreover, an increase in average maximum temperature increased rice yield by 137.9 kg/ha especially from April and by 674.1 in May.

Maturity and harvest stage

This stage provides the outcomes of the previous stages. The yield coefficient of sunshine was positive in June to complete maturity of the rice grains. Thus depict that, an increase of 1 h of sunshine duration increase rice yield by 143.7 and 495.9 kg/hain both June and July, respectively. To conclude this, it is shown by exhibiting a sharp increase in sunshine duration from June and reached its peak in July, as shown in Figure 3 and Table 5. The sunshine behaviour is also shown in Table 1a having a small range of between 2.9 and 2.9 h for both June and July, meanwhile, the average sunshine was high in all months (9.29 h in June and 9.59 h in July). In addition, from flowering, grain formation, and ripening, sunshine exhibited a gradual and sharp increase to enhance maturity and later harvesting process. As a result, rice yield coefficient for minimum temperature was positive which indicate essentiality for minimum temperature to facilitate normal ripening and maturity. Therefore, increases of average minimum temperature of 1°C decreased rice yield by 490.9 kg/ha in July but increased by 210.4 kg/ha during seeds maturity. As opposed to minimum temperature, rice yield seem to have a negative yield coefficient of maximum temperature. This indicates that rice yield was increased by 674.1 kg/ha at each increase of 1°C maximum temperature during June. However, in harvesting month of July, increases in maximum temperature by 1°C decreased rice by 398.3 kg/ha, so maximum temperature is rudimental to rice yield possibly due to high humidity which may affect rice yield.

In practice, it is very obvious that high temperatures have a significant negative impact on rice yield starting from flowering to maturity. A Similar result was reported by Ohe et al. (2007) in their study on the effect of high temperature on rice production. Thus they reported that temperature upsurge in final stages of rice can disrupt both morphology and biochemical status of the grains.

Conclusion

This research was courteously undertaken for Tanzania rice production subsector especially in Mbeya region. The authors used secondary data including rice yields and meteorological factors such as average monthly rainfall, monthly sunshine, and minimum and maximum temperatures for the study region to derive statistical but economic relationship among variables. They managed to decompose actual rice yield into tendency yield and weather yield and later detached weather yield by the aid of trend yield. Furthermore, the relationship between weather yield and weather factors including rainfall, sunshine, maximum, and minimum temperatures were obtained from the stepwise regression analysis. We managed to design the rice yield model with the help of actual rice yield and yield tendency. The established model could be employed for rice yield forecasting in Mbeya region. Finally, it is recommended that further studies be undertaken in Tanzania for different crops so as to increase crops yields, whereby people’s livelihoods can be improved.

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