Effect of Meteorological Factors on Maize Yield in Comoros

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Abstract: Understanding the effects of climatic factors on maize yield will benefit tactical decisions for future agricultural forecasting. In this study, the relationship between maize yield and meteorological factors has been estimated on the basis of daily meteorological data during the growing season and maize yield observation data from 1970 to 2022 on the island of Nguazidja. The specific maize growth stages most sensitive to meteorological factors were divided into six stages: emergence, jointing, tasseling, flowering, filling and harvesting. First, a simple regression is carried out with the tendency model. Yield and years are included. We then analysed the effect of meteorological factors on each stage of maize growth using the orthogonal Chebyshev polynomial regression. It was found that rainfall has a generally positive influence on yield growth. Temperature has a significant negative effect on yield during the emergence and filling stages. The key point is that meteorological factors have an effect on maize yield throughout the growth season. The degree of impact of each meteorological factor during the growing season is not the same. The first step is to understand that maize needs higher temperatures, especially during the emergence period. On the other hand, rainfall sometimes provides more water than is needed. The aim of this research is to provide clear information on the impact of climatic factors on maize yields. This is a study that has not yet been carried out in the country. And the results are important for forecasting maize yields in the Comoros.

Keywords: Maize Yield; Meteorological Fators; Orthogonal Polynomials and Interal Regression; Comoros

1. Introduction

Agricultural production depends on meteorological factors, excluding material inputs. This is especially true for cereal crops, which are very sensitive to climate and its changes. In terms of changes, the increase in temperature has been shown to be the most likely to have a negative impact on crop yields [1]. It is imperative for farmers to understand the importance of thoroughly analysing how meteorological factors affect crop yields, in particular maize. Let's also add the adoption of better crop and soil management practices; in fact, we are talking about the technology with which the competent farmer can generally reach 80% of the yield potential [2]. However, it is important to apply yourself and learn about the methods of technological practice to avoid any kind of climate change. Studies have shown that the expansion of irrigation in regions with low rainfall can lead to an attenuation of a warming induced by greenhouse gases [3]. To highlight any agricultural production is also to know the importance and the benefits it brings. In sub-Saharan Africa, maize production is very useful insofar as, apart from the contribution to cereal consumption, it is also used in industry.

In our present case, In this case, the research is based on the Comoros, a tropical country with a climate and cultivated areas that are generally suitable for crops such as maize. However, it is important to carefully study the environment, the working area, in order to identify, for example, the crop varieties (here we can therefore mention maize) that are suitable for the environment [4]. In addition, it is known that with good crop management and a good maize breeding programme, it is obvious to have an increase in yield potential in tropical areas [5]. There is even more emphasis on the need to adopt maize varieties, the need to properly target varieties where they are best suited and most beneficial, because that is where the key to increasing maize yield in tropical environments lies [6].

Knowing the impact of meteorological factors on maize production will allow farmers to choose the most favourable periods for planting, for example. For instance, if drought stress occurs during flowering, it is too late for farmers to adjust management and the season is too advanced to consider planting [7]. Maize production is of great importance globally, but it is also the most important staple food in sub-Saharan Africa. Therefore, it is essential not only for food security but also for monitoring its growth by analysing all the factors that depend on it [8]. Thus, this type of research allows us to better understand and adapt to current and future climate events. The achievement of high crop yield potential is a challenge for any agricultural producer [9].

2. Materials and Methods

2.1. Field Site and Data

Comoros lies north of the Mozambique Channel between 110 20′ and 130 04′ south latitude and 430 11′ and 450 19′ east longitude. It is equidistant from the African continent and Madagascar. Its total area is 2,034 square kilometres, divided as follows Grande Comore (Ngazidja) 1,025 km2 (with Moroni, the capital); Mohéli (Mwali) 211 km2; Anjouan (Nzuani) 424 km2 and Mayotte (Maore) 374 km2. The maximum distance between two islands does not exceed 75 kilometres. The average air temperature is 27℃ (November to April) with a maximum of 31℃ and a minimum of 23℃. During the dry season, from June to September, the average temperature is 23 to 24℃. The maximum is around 28℃ and the minimum is 4 to 5℃ higher than in the warm season.Our research will focus particularly on the island of Moheli, where most of the maize is grown. The soil type in this region is known for its fertility and ability to retain water (clay soils that can retain water).

This study uses yield data expressed in kg/h and meteorological data such as temperature, rainfall, sunshine and wind. The yield data come from the official statistics website of the Food and Agriculture Organisation of the United Nations (which contains various yields of crops of different varieties and over several years), statistical archives covering the 3 islands, yield data were collected from 1970 to 2021, covering all the arable areas of the Comoros, and the daily meteorological data come from the private website www.meteoblue.com. Overall, the data are very detailed and cover all months of each selected year.

2.2. Meteorological Data Descriptions

Comoros Meteorological data spanning from 1980 to 2022 were graphed to provide insights. The descriptions are presented as follows:

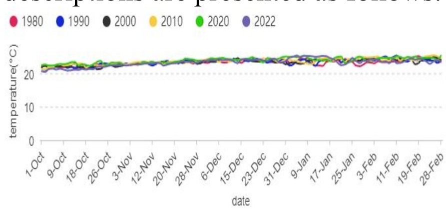

Figure 1. Average Daily Temperature for the Year 1980-2022

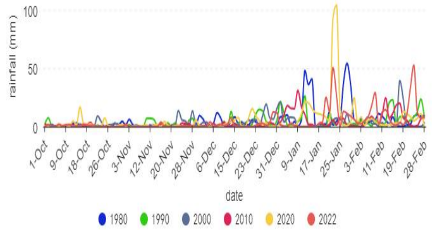

Figure2. Average Daily Precipitation for the Year 1980-2022

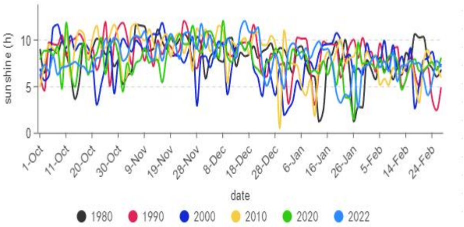

Figure 3. Average Daily Sunshine for the Year 1980-2022

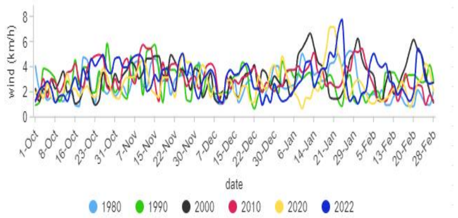

Figure 4. Average Daily Wind for the Year 1980-2022

Figure 1 illustrates the average temperature. Notably, temperatures consistently surpass 20℃, fluctuating between 21℃ and 24℃ from October to February, coinciding with the maize growing season. Figure 2 depicts precipitation trends. It conspicuously low precipitation levels at the commencement of the growing season (October to November) across all years. However, from December onward, precipitation significantly increases, particularly in January, as observed in the abundant precipitation during the filling stage in 2020. Figure 3 illustrates the sunshine hours. At the onset of the growing season (October), the curve of the graph exhibits fluctuations, ranging between 4 to 12 hours of total sunshine. This trend is observed in almost all the observed years. During the raining season (December to February), the hours of sunshine occasionally decline to 2 hours or less. Figure 4 presents the wind patterns. Overall, the wind speed throughout the growing season remains moderate ranging between 0.8 to 7km/h.

2.3 Yield Data Description and Technological Factors

Maize yield of Comoros was subjected to graphical analyses spanning from 1987 to 2021. Figure 5 visually represents the yield trends over the years, revealing a gradual decrease. Notably, the year 1998 stands out prominently (highlighted by a red circle), signifying a substantial decline during that specific period. In Figure 6, year 1998 was intentionally excluded to create a more coherent curve, facilitating a clearer analysis. It presents a more explicit depiction of maize yield patterns, allowing for a refined examination without the influence of the distinctive value observed in 1998.

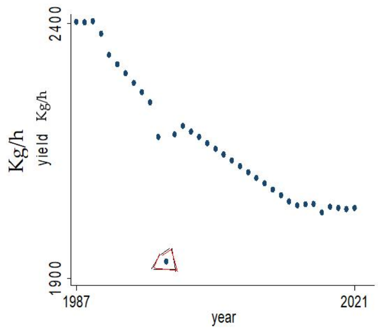

Figure 5. Maize Reel Yield with the Year 1998

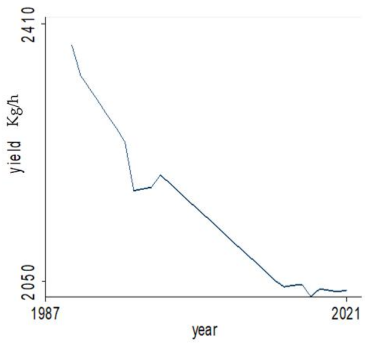

Figure 6. Maize Reel Yield Without the Year 1998

The real yield experiences an annually decline, with brief stability observed only from 2017 to 2021. Several factors may contribute to this trend. Despite the fertility of the soil, it is simultaneously delicate and susceptible to erosion, as indicated by the FAO[10]. Historical data from 1950 to 2016 exposes the challenges faced by Comoros, including deforestation and accelerated biodiversity degradation [11]. Additionally, issues such as a deficiency in agricultural knowledge, insufficient advancements in control systems throughout maize cultivation, inadequate irrigation system development, and the use of low-yield fertilizers further contribute to the consistent decline in yield witnessed in recent years.

It is obvious that crop yield depends on many factors. Indeed the cereal yield, in particular the maize yield, is depend on environmental or other factors. In this case, it is important to mention the technological factors, which is the time used as a technological variable (denoted as 't'). In this context, time is the technological variable thus the following model is established;

$$\text{Yield\_t} = \partial t + C \quad (1)$$

Yield_t------ tendency yield

t------ time variable /using time as technology progress

∂ ------parameter for technological yield coefficient

C-----Constant, yield based on initial value in 1987

Figure 7 bellow shows the trend and actual maize yields. It can be seen that the trend yield declines with the actual yield over the years from 1987 to 2021. And figure 8 shows the meteorological yield after subtracting the trend and actual maize yields.

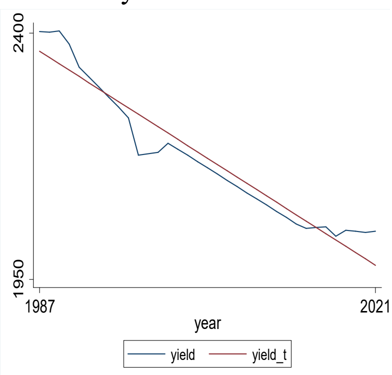

Figure 7. Maize Tendency Yield and Real Yield

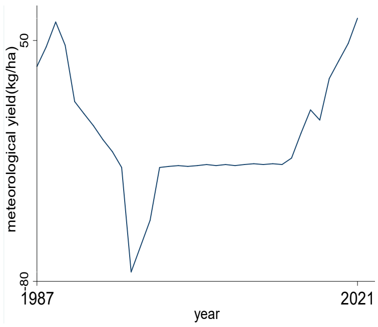

Figure 8. Meteorological Yield

To follow up on our work, we therefore established a regression of the trend yield model(eq.1) from which the results are as follows:

Table 1. Reg Yield_t

yield	Coef.	Std. Err	t	P>│t│
t _cons	-11.5 2367	0.5 10.5	-21.9 225.6	0 0
	R-squared = 0.93		Adj R-squared = 0.9352	

R2 explained 93% of the variation in maize yield, taking into account the results of the regression in the above table (Table 1). It can therefore be concluded that the variation in yield could be caused by the technological variable "t". There are also meteorological factors that influence yield even more than the technological factor. Therefore, by subtracting the real maize yield and the tendency yield, we have defined the meteorological yield (Figure. 8):

$$ym = \text{yield} - \text{yield\_t} \quad (2)$$

Considering Figure 8, the results showed a change in maize yield that varies regularly. This is considered to be due to climatic factors that influence yield. In this context, we have defined a model of meteorological efficiency concepts that includes environmental factors such as temperature, rainfall, sunshine and wind.

2.4. Analysis of the Weather Impact on Yield

In this study we will opt for the trend analysis model. Indeed trend analysis is a useful framework for forecasting crop yields. long-term crop yield trends reflect technology improvements (for example, new seed with high yield) as well as improvement in production practices such as pest integrated management and precision planting. Though trend analysis could examine the crop yield, weather-related yield would make the expectation yield deviate from actual yield. Following this process, model spreading is followed by Fisher's integral regression which is established as follow:

$$\sum_i \int_0^\tau a_i(t) x_i(t) dt \quad (3)$$

My = α_0 +My – meteorological yield,

α_0 – constant,

Meteorological Effects on Comoros expected crop Yield

xi(t) – meteorological factors (i is number from 1 to 4, 1,2,3 and 4 represent rainfall, sunshine, temperature and wind, respectively),

ai(t) – regression coefficient,

t – the time of year
τ – The period of production growth depends on the season (j – independent period),

$$a_i(t) = \sum_j \alpha_{ij}\varphi_{ji} \quad (4)$$

φji is j times polynomial, is the constant, we institute (3) into (4),

$$M_y = \alpha_0 + \sum_i \int_0^t \left(\sum_j \alpha_{ij}\varphi_{ji}\right) X(t)dt \quad (5)$$

$$M_y = \alpha_0 + \sum_i \sum_j \alpha_{ij}\varphi_{ji} \quad (6)$$

Here, we had:

$$\rho_{ji} = \int_0^\tau X_i(t)\varphi_j dt \quad (7)$$

φj could be derived from the Chebyshev-orthogonal polynomial in the following
(φ0 ¼ 1).

$$\varphi_{K+1}(X) = \varphi_1(X)\varphi_k(X) - \frac{k^2(n^2-k^2)}{4(4k^2-1)}\varphi_{k-1}(X) \quad (8)$$

$$\text{C\_my} = \sum_{\alpha_{ij}} * \varphi_j \quad (9)$$

In the function (9), "c_my" is the coefficient for meteorological yield; "αij" is estimated from function (8).
According to the maize yield growth stages, Based on the growth stages of maize yield, a classification of six periods was established corresponding number of days.
Model construction
Meteorological yield was estimate from the difference between real yield and tendency yield, the amount of precipitation, the temperature, sunshine and wind. As shown in equation below.

$$my = a * ss + \beta * \text{rf} + \gamma * \text{tr} + \delta * \text{wd} + \mu \quad (10)$$

Among them: my- maize meteorological yield; ss-average daily sunshine vector; rf- vector of amount of precipitation; tr- daily average temperature vector; wd- average daily of wind speed vector; a , β, γ, δ are the vectors of yield coefficient to be obtained for sunshine, precipitation, temperature and wind.
Fisher Integral Regression model

$$\text{my} = \alpha_0 + \int_0^t a_{1j} * (t)x_1(t)dt + \int_0^t a_{2j} * (t)x_2(t)dt + \int_0^t a_{3j} * (t)x_3(t)dt + \int_0^t a_{4j} * (t)x_4(t)d, \quad (11)$$

Where as my = maize meteorological yield , α_0=Constant, T= Time of year, a_{ij}=Regression Coefficient of weather factor xi on yield Y, x1------xn are the weather variables here referred as x1=sunshine, x2=temperature, x3=rainfall, and x4=wind) $x_1(t)$ = Weather factor as a function of time t, τ = harvesting stages in growth periods.
Therefore, the α_i (t) is a function which is determined by the Chebyshev polynomial approximate and is given as shown by the orthogonal polynomials linear function of time t in equation (12).

$$\alpha_i(t) = \sum_j \alpha_{ij}\,\varphi_{ji} \quad (12)$$

α_{ij} means parameter of meteorological factors and φ_{ji} is Chebyshev orthogonal polynomial matrix.
Where φij is j = 1, 2, 3…5 is a functional form of maize growth stage and time, which is approximated by Chebyshev polynomial obtained by substituting the value of $\alpha_i(t)$ in equaion(13)

$$\hat{y} = \alpha_0 + \sum_i \sum_j \alpha_{ij}\,\varphi_{ji}\; x_{ij} \quad (13)$$

The φ_j is value normally derived from the orthogonal polynomial function-Chebyshev as shown in equation below.

$$\varphi_2(x)\varphi_k - \frac{k^2(n^2-k^2)}{4(k^2-1)}\varphi_{k-2}(x) \quad (14)$$

From the designed data we have determined the maize growth cycle from October to February of the corresponding year, according to the formula (14) we can obtain the Chebyshev orthogonal table (Table 2).

Table 2. The Chebyshev Orthogonal Polynomial Matrix

stage	date	group	φ0	φ1	φ2	φ3	φ4	φ5
Emergence	20-Oct---13-Nov	1	1	-5	3	6	-19	-35
jointing	14-Nov---28-Nov	2	1	-3	-1	5	-8	-18
tasseling	29-Nov---13-Dec	3	1	-1	-3	2	0	-12
flowering	14-Dec---2-Jan	4	1	1	-3	-2	0	12
filling	3-Jan---6-Feb	5	1	3	-1	-5	-8	18
Harvesting	7-Feb---26-Feb	6	1	5	3	-6	-19	35

The orthogonal Chebyshev polynomial function (Equation 14) was used to obtain the orthogonal Chebyshev matrix in Table 2. Table 3 shows the results of the coefficient test values and the equation test values after stepwise regression of the orthogonal polynomials. First of all we can represent the function in the following way:

$$p_{ij} = \sum_{i=1}^{6}\sum_{j=1}^{4} \varphi_{ij}\, x_j \quad (15)$$

Where "i" represents the number of growth stages of maize that has 6 stages and "j" values 1 to 4, representing the respective meteorological factors; temperature, precipitation, sunshine and Wind, respectively. From function (15) we can rewrite the "my" meteorological yield function as follows:

$$my = a_0 + \sum_{i=1}^{6}\sum_{j=1}^{4} a_{ij} p_{ij} \quad (16)$$

3. Results and Analysis

Derived from function (16), stepwise regression was performed estimate the coefficients for meteorological determinants as illustrated in the subsequent table (Table 3). The results showed that, the amount of precipitation, temperature, sunshine and wind had significant effects on the meteorological yield.

Then, the Fisher integral regression model was established. After multiple linear regression; by applying stepwise regression equation, the following equation was generated:

ym=-0.79*p_r1-0.21*p_r3-0.02*p_r4+0.07*p_r5-32.70*p_s1-4.49*p_s2-22.44*p_s3-2.64*p_s4-113.17*p_t1+8.88*p_t2+17.18*p_t5-357.62*p_w0-107.55*p_w2+12.25*p_w3-33.85*p_w4+2.71*p_w5. (17)

The model showed that the characteristics of the meteorological elements have a significant effect on the maize of the Comoros, as shown in Table.3. Where α_{ij} is the parameter of the meteorological factors and φ_{ji} is the Chebyshev orthogonal polynomial matrix. Function (18) can be obtained from functions (15) and (16) as follows:

$$my = a_0 + \sum_{i=1}^{6}\sum_{j=1}^{4} a_{ji}\varphi_{ij}x_j \quad (18)$$

And then, from (18) we can get (19)

$$my = a_0 + \sum_{i=1}^{6}\sum_{j=1}^{4} \alpha_j x_j \quad (19)$$

Where a_{ij} is the meteorological-yield variation coefficient of meteorological elements in the j growth stages. "α_j" defines the multiplication of meteorological coefficient of variation of yields and the Orthogonal Polynomial Matrix of Chebychev "φ_{ij}". x_j represents the meteorological factors. The regression method was applied to the 1987 to 2022 data to find the variation coefficient in yield and meteorological elements of crops in the different growing season according to the groups established. With the regression, the meteorological-yield coefficients of maize can be derived according to their respective different growing stages. This is presented in Table 4.

Table 3. Test Value of Orthogonal Polynomial Stepwise Regression

Variable	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]		note
p_r1	-0.79	0.24	-3.25	0.005	-1.31	-0.28	***
p_r3	-0.21	0.06	-3.83	0.001	-0.33	-0.10	***
p_r4	-0.02	0.01	-2.41	0.028	-0.04	0.00	**
p_r5	0.07	0.03	2.4	0.028	0.01	0.13	**
p_s1	-32.70	12.66	-2.58	0.019	-59.41	-6.00	**
p_s2	-4.49	2.19	-2.05	0.056	-9.10	0.13	*
p_s3	-22.44	8.94	-2.51	0.022	-41.30	-3.58	**
p_s4	-2.64	0.92	-2.87	0.011	-4.58	-0.70	**
p_t1	-113.17	51.49	-2.2	0.042	-221.79	-4.54	**
p_t2	8.88	5.53	1.61	0.127	-2.79	20.55	-
p_t5	17.18	7.78	2.21	0.041	0.75	33.60	**
p_w0	-357.62	149.01	-2.4	0.028	-672.00	-43.24	**
p_w2	-107.55	45.68	-2.35	0.031	-203.94	-11.16	**
p_w3	12.25	6.33	1.94	0.070	-1.10	25.60	**
p_w4	-33.85	14.35	-2.36	0.030	-64.12	-3.59	**
p_w5	2.71	1.35	2.01	0.061	-0.14	5.56	**
_cons	-642.49	383.98	-1.67	0.113	-1452.62	167.63	-

		R-squared = 0.6021			Prob>F=0.1705	Adj R-squared =0.6021	

Table 4. Meteorological-yield Coefficients of Maize According to Their Respective Different Growing Stages

No.	stage	Duration	Period(d)	Temperature(°C)		Rainfall(mm)		Sunshine(h)		Wind(km/h)	
				mean	a(t)	sum	a(r)	mean	a(s)	mean	a(w)
1	Emergence	Oct20-Nov13	25	22.7	-31	1757.2	0.77	8.6	-263	2.9	-96
2	jointing	Nov14-Nov28	15	23.3	27	1744.6	0.25	8.8	-189	2.9	-3
3	tasseling	Nov29-Dec13	15	23.6	-86	2830	-0.41	8.5	-64	2.6	-76
4	flowering	Dec-14--Jan-2	20	23.7	86	6907.9	0.41	7.7	89	2.8	-60
5	filling	Jan-3--Feb-6	35	23.7	-27	17061.5	0.12	7	237	3.3	-29
6	Harvesting	Feb-7--Feb-26	20	23.8	31	8103.6	0.10	6.9	333	3.1	-54

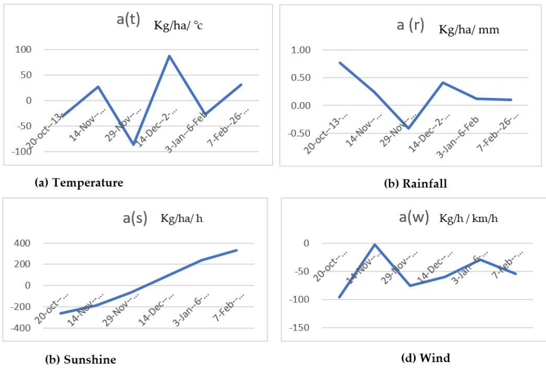

Figure 9. Meteorological Yield Coefficients (Graphic representation)

Figure 9 displays graphical representations of the meteorological yields coefficients, including temperature, rainfall, sunshine, and wind, as depicted in figures a, b, c, and d.

3.1. Analysis of the Meteorological Factors on the Maize Growth Stages

(1) Temperature

At the emergence stage (between October 20 and November 13), the average temperature recorded is 22.7°C and this degree appear be insufficient to support the optimal growth of maize. A decline in temperature has the potential to impede growth, with a decrease of 1°C resulting in a yield reduction of 31 kg/ha.During the jointing stage (November 14--November 20), the average temperature is 23.3°C. During this period, the observed temperature appears to positively impact maize yield, with an estimated increase of 27 kg/ha for every 1°C rise. At the tasseling stage (November 29 to December 13), the average is 23.3°C. Studies show that a decrease in temperature can be caused by a decrease in solar radiation [12]. Following this logic, an increase in solar radiation can also cause an increase in temperature. This can be explained by the decrease in yield during this period, if we note that during the same period the hours of sunshine have increased by 8.5 hours. A decrease of 1°C, the yield will be reduced by 86 kg/ha. During the flowering stage (December 14 to January 2), the average temperature is 23.71°C. The observed temperature at this stage is optimal for yield growth. A rise of 1°C, the yield will increase by 86 kg/ha). During the filling stage, the average temperature is 23.7°C. A similar temperature observed during the flowering stage. However, at this point, this average temperature does not positively impact maize yield. A drop in temperature by 1°C, yield growth will decrease by 27 kg/ha. At the Harvest stage (February 7–February 26), the average is 23.8°C. This shows to be an optimal temperature for the harvest. An increase of 1°C, the maize yield will increase by 31 kg/ha.

(2) Rainfall

At the emergence stage, the sum of rainfall is 1,757.2mm. Considering this provides enough moisture to the ground. A 1mm increase in rainfall, the yield will increase by 0.77kg/ha. During the jointing stage, the amount of rainfall is 1,744.6mm. At this stage, agronomists emphasize a heightened sensitivity to water scarcity. A 1mm increase in rainfall, the yield is expected increase by 0.25kg/ha). During tasseling stage the rainfall is 2,830mm. A rise in rainfall by 1mm, the yield is expected to reduce by 0.41 kg/ha. The flowering stage just as the jointing stage, is highly sensitivity to water deficit, the sum of rainfall during this stage is 6,907.9mm. A 1mm increase in rainfall, the yield will increase by 0.12kg/ha. At the Harvest stage the sum of precipitation is 8,103.6mm. A 1mm increase of rainfall, the yield could increase by 0.10 kg/ha.

(3) Sunshine

The duration of sunshine from the emergence stage to the tasseling stage is almost identical, at 8.6 hours and 8.5 hours respectively. During the emergence stage, the yield decreases by 263 kg/ha, followed by a decrease of 189 kg/ha during the second stage, and a further decrease of 64 kg/ha during the tasseling stage. However, during the flowering stage, the number of hours of sunshine increases to 7.7 hours, and for every additional hour of sunshine, the yield increases by 89 kg/ha. During the harvest stage, the average duration of sunshine is 6.9 hours, and for every additional hour of sunshine, the yield increases by 333 kg/ha.

(4) Wind

The influence of the wind is not good for maize yield. From the emergence stage to the harvest stage, the influence of wind does not show positive results for maize yield.

4. Discussion

To ensure an improvement in maximum yield and profitability in any maize cultivation practice, we need to have a good understanding of all facets of maize plant development. Understanding the different growth stages of the maize plant and improving our knowledge of the needs of each stage will allow us to better understand the care required at each stage to ensure effective protection. Of course, it is necessary to directly link the effects of the environmental factors that generate maize production in order to better understand, adapt and prevent future yields. Mansoor Maitah, et al.2021 [13], in their studies conducted in the Czech Republic, explain to us that water deficit with the combination of precipitation and temperature is more important and critical in maize production. It is obvious to know that at each stage of growth there are the effects of meteorological factors that affect the yield, either negatively or positively. Often, temperature and precipitation have a greater impact on maize production, but the lack of sunshine hours is also an obstacle to the growth of maize production [14]. Many studies show that the effects of water stress during the growth period are the main causes of potential yield reduction. In fact, meteorological factors are one of the important factors that determine the pounds of maize grain and the nutritional quality of the grain [15].

As noticed in this study, maize production in Comoros very sensitive to meteorological factors. Temperature and precipitation was found to have a positive influence in maize yield. As for sunshine hours, the influence is negative during the first growth stages to the beginning of the reproductive phase. On the contrary, the influence of wind was negative during all the six stages of the maize production cycle. It is recommended to emphasize concurrent enhancements in crop management and pest control. Explore the possibility of altering the planting period by considering different sowing dates, analyzing alternative seasons that may significantly boost maize yield. A study has indicated the importance of distinguishing between the impact of climate trends and the temporal trends associated with planting and crop development [16]. Therefore, achieving optimal planting dates and aligning them with growth phases is key to enhancing crop yield. Over the years, maize production in Comoros has been declining. For instance, in 2021 Comoros attained a 6.29 million tons, however, compared to the previous year, there was a 0.17% reduction [17]. Contribution to this among other is the declining yield as traced by the yield trend. In this study, it was observed that more than normal precipitation during harvest stage distorts maize growth causing reduction in yield. More so, wind has negative effect on yield throughout stage of maize production. This research has successfully identified a noteworthy issues – the potential cause of continuous decline in yield associated with the impact of meteorological factors. This discovery opens the door to proposing alternative models or cultural strategies that can enhance future yield potential.

5. Conclusions

We have come to the following conclusions:

First, there is an effect of meteorological factors on maize yield throughout the growing season.

Second, the degree of impact of each meteorological factor is not the same during the maize growing season.

Thirdly, understanding that maize cultivation needs more temperature, especially during the emergence period, is the first measure we can take in the face of the situation. More precipitation is key at the initial stages maize growth compared to the later stages especially close to the harvesting stage. Our results also show that the wind is too strong to continue throughout the growing season, which may explain why the crop is unable to adapt. However, in order to hope for a good yield potential in the coming years, our results suggest that it is necessary to develop an adaptation system by covering the plants, for example, to maintain the maximum temperature. In the case of water, which can remain in the growing areas and cause stunted growth, we can use the drainage system, especially at the tasseling stage. Our results also suggest that it is useful to consider using seed varieties that produce short stems that can withstand and avoid strong winds. More importantly, all these measures should be synched with good farm management practices and by efficient utilization of sensitive inputs such as fertilizer. And let's not forget the importance of irrigation to maintain productivity in unfavourable climate change scenarios.

Author Contributions

Conceptualization, Yu Wen, He Ping and Soule Bacar Islam ; methodology Yu Wen and Soule Bacar Islam,Wang Yu, Li Ganqiong; software, Chen Wei.; validation, Yu Wen, Soule Bacar Islam, Li Ganqiong and Wasng Yu.; formal analysis, Soule Bacar Islam ;investigation, Soule Bacar Islam, Thakfiyou Achirafi .; resources, Zhao Longhua, Thakfiyou Achirafi, Zhou Han ; data curation, Soule Bacar Islam; writing—original draft preparation, Soule Bacar Islam.; writing—review and editing, Yu Wen.; Nyamaa Nyamsuren, Lyankhua Bayasgalankhuu, Ahmed, Abdul-Gafar, Liu Baohua; visualization, Li Jianzhen; supervision, Li Ganqion, He Ping; project administration, Ding Wencheng ; All authors have read and agreed to the published version of the manuscript." Please turn to the CRediT taxonomy for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

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Data Availability Statement

The yield data come from the official statistics website of the Food and Agriculture Organization of the United Nations (FAO) which contains various yields of crops of different varieties and over several years. Yield data were collected from 1970 to 2021, covering all the arable areas of the Comoros, and the daily meteorological data come from the private website www.meteoblue.com Overall, the data are very detailed and cover all months of each selected year.

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