Rainfall Probability Analysis for Crops Scheduling in Kwaebibirem District, Eastern Region of Ghana

ERIC COBBINA[1] and CATHERINE DR. PUEYO *[2]

[2] College of Engineering and Technology, Tarlac Agricultural University, Camiling, Tarlac, Philippines

Abstract

Ghana is a country where most farmers practice traditional farming system in which crops are grown depending on the type of climate per cropping season. This study aimed to conduct a rainfall probability analysis in Kwaebibirem District, Eastern Region of Ghana in order to predict the probable rainfall occurrence in the next five (5) years and to develop a recommended cropping schedule in the area based on the said prediction. An equation was derived for the rainfall probability occurrence for the next five (5) years using Seasonal Autoregressive Integrated Moving Average (SARIMA). Thirteen years worth of data (January 2006- December 2018) of the UG Gagasa Meteorological Station were used as references for the prediction of the rainfall occurrences for 2020-2024.Results revealed that there will be rainfall occurrences throughout every year from 2020-2024. The rainfall occurrences will be low from the first week of every year, to the 14th week and will increase in volume from the 15th-26th weeks, which is the period for the major growth season. Based on the predicted rainfall probability occurrence, maize was recommended to be planted twice a year over the five-year period. Tomato may also be planted twice in 2021, 2022, and 2024 while chili pepper may be grown twice in 2022, 2023, and 2024. But rice may be grown only once year from 2020- 2024.

Keywords: rainfall probability, SARIMA, cropping schedule

Introduction

Ghana is a country where most farmers practice traditional farming system in growing crops. With this type of farming, agricultural productivity depends mainly on the climatic conditions. Favorable climatic conditions are indicators of good crop production.

Kwaebibirem District is located in the South-western corner of the Eastern Region of Ghana, between latitudes 1 degree 0W and 0 degree 35.E, and longitudes 6 degrees 22N and 5 degrees 75S. On the north, it is bounded by the Birim North District, Atiwa District and East Akim Municipal in the east, and on the south, by Denkyembour District. The Kwaebibirem District is one of the 26 Districts in the Eastern Region of Ghana, with Kade as its capital. The Kwaebibirem District has a land area of about 12.30 square kilometers and farming is the main source of income of the locals.

Water is a limiting resource for intensive crop production especially during dry season. The annual rainfall in Ghana varies from 1,400- 1,000 mm covering more than 50% of the entire country. Higher annual rainfall occurrence which exceeds 1,900 mm occurs in some parts of Asante and Western Regions of Ghana. The variation of the annual rainfall (14001000 mm) is more than enough to support the annual water requirement of most crops. However, this rainfall is not uniform throughout the whole year in some parts of the country. Because of this, crops to be grown are dependent on the amount of rainfall occurrence in the area.

In Kwaebibirem District, farmers obtain most of the water supply for their crops from rain. The crops to be grown and the time to start planting are dependent on the occurrence of rainfall. A cropping schedule that is suited for Kwaebibirem Districts condition with the projected rainfall occurrence in the next five (5) years will be of great help for the farmers to schedule their cropping activities.

The general objective of the study was to predict the rainfall probability for crop scheduling in Kwaebibirem District. Specifically, it aimed to derive an equation and/or model for rainfall probability occurrence in the next five (5) years (2020-2024), predict the rainfall probability occurrence and project the volume of rainfall from 2020- 2024, and lastly to develop a recommended cropping schedule for 2020- 2024 in Kwaebibirem District.

Methodology

Conceptualization of the Study

The predicted rainfall probability occurrence in the next five (5) years as a tool to develop a recommended cropping schedule in Kwaebibirem District was conceptualized and proposed to be able to help the local farmers in scheduling their crops in the next five (5) years for a better crop production.

Selection of the Location of the Study

Kwaebibirem District was selected as the area for the development of a cropping schedule mainly because farming is the predominant economic activity employing about 47.8% of the economically active population. Thus, this serves as the main source of livelihood in the area. The people of Kwaebibirem District are peasant farmers who depend on rain-fed irrigation, labour intensive, and relatively cheap subsistence agriculture.

The District has a meteorological station which is located at Denkyembour (thus, UG-GAGASA). The District lies within

* **Correspondence**: Catherine Pueyo; *Address*: College of Engineering and Technology, Tarlac Agricultural University, Camiling, Tarlac, Philippines *Email:* cathypueyo030585@gmail.com;

the semi-equatorial climate zone with a double maximal rainfall regime. Farmers depend mainly on rainfall as a major source of water for their crops. Because of this, cropping schedule depended on rainfall occurrence. Hence, a cropping schedule for the District was conceptualized to help the farmers schedule their crop production ahead of time to attain optimum yield and higher income (Figure 1).

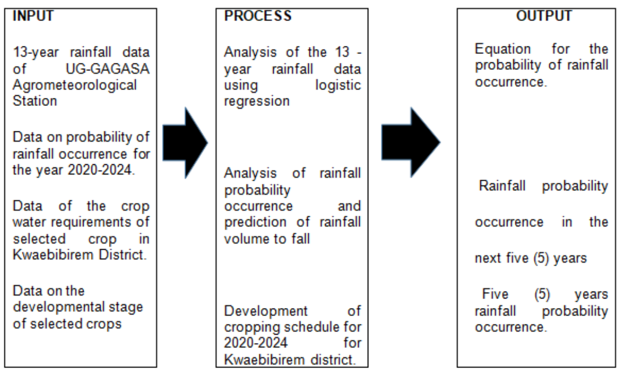

Figure 1. Conceptual Framework of the Study.

Gathering of Rainfall Data

The data from UG-GAGASA Agrometeorological Station, located at Kwaebibirem District, Ghana, were requested by the researcher through the assistant meteorologist officer at UG-GAGASA Agrometeorological Station, with the assurance that the data will be used solely for research purposes.

Daily rainfall data from January 2006 to December 2018 were sent through electronic mail. The data were then processed and used in the projection of the rainfall probability occurrence from 2020-2024.

Processing of the Data

The daily rainfall data in millimeters gathered at the UG-GAGASA Agrometeorological Station were processed by first, adding the daily reading to a weekly basis, with a total of 52 weeks. Next was putting the weekly data from 2006-2018 in a tabular form. The sum per week and sum per month were also computed and represented in line graphs for visual inspection of the series and to observe the behavior of extremely high and extremely low rainfall occurrences.

Autoregressive Integrated Moving Average was used to make a forecast of the weekly rainfall for the next five (5) years. Autoregressive Integrated Moving Average, or ARIMA, is one of the most widely used forecasting methods for univariate time series data forecasting. Although the method can handle data with a trend, it does not support time series with a seasonal component. An extension to ARIMA that supports the direct modeling of the seasonal component of the series is called SARIMA.

Using the Seasonal ARIMA Model

The Seasonal Autoregressive Integrated Moving Average was used to predict the weekly rainfall from 2020- 2024. Autoregressive Integrated Moving Average, ARIMA (4, 0, 2) (0, 1, 1) [52] was the model derived. Rainfall probability occurrence was modeled using Seasonal Autoregressive Integrated Moving Average (SARIMA). In this model, seasonal differencing of appropriate order was used to remove non-stationarity from the series.

A seasonal ARIMA model was formed by including additional seasonal terms. It was capable of modelling a wide range of seasonal data which were written as follows:

ARIMA (p,d,q) (P,D,Q)m   Model 1

where:

(p,d,q) - refers to the non-seasonal part of the model, p=number of autoregressive terms, d= number of non-seasonal difference and q= moving average terms

(P,D,Q) - refers to the seasonal part of the model, P= seasonal autoregressive terms, D= number of seasonal differences, Q= number of seasonal moving average

m - number of observations per year

The auto ARIMA function using non seasonal differences were used to determine the p,d,q and the P,D,Q values of the thirteen-years rainfall data in Kwaebibirem District. Model 2 shows the derived ARIMA model.

Determining Rainfall Probability Occurrence and Volume

The rainfall probability occurrence for 2020-2024 was determined using Seasonal Autoregressive Integrated Model Analysis. The data used for the prediction were the thirteen-years worth of rainfall data (January 2006- December 2018) of the UG Gagasa Meteorological Station. The daily recorded rainfall data were added and the mean was computed on a weekly basis since the cropping schedule was developed on a weekly basis. The generated data were then ran using Seasonal ARIMA and the rainfall volume was projected.

Determining the Peak Rainfall Occurrence

The peak rainfall occurrence was then identified as the highest volume of rainfall predicted in a given year. One peak rainfall for every year from 2020-2024 was identified as the peak rainfall. An annual graph of the projected rainfall was presented to be able to clearly identify the behavior of rainfall occurrence and the peak rainfall.

Developing a Cropping Schedule

A cropping schedule was developed by plotting the projected rainfall for a given year and matching it to the crop water requirements of the selected crop. The schedule was then based on the period where the crop would be best grown in order to attain an optimum yield and a good crop production.

A cropping schedule for rice, maize, pepper, and tomato was developed considering the water requirement of the different stages of growth development of these identified crops and the rainfall probability occurrence for 2020-2024.

Statistical Analysis

Seasonal Autoregressive Integrated Moving Average (ARIMA) was used in predicting the rainfall probability occurrence for 2020-2024. To check whether the weekly rainfall series was stationary, Dickey-Fuller test was performed.

Results and Discussion

Probability of Rainfall Occurrence in Kwaebibirem District for 2020-2024

The probability of rainfall occurrence was modeled using Seasonal Autoregressive Integrated Moving Average (SARIMA). An ARIMA model is a class of statistical models for analyzing and forecasting time series data. In this model, seasonal differencing of appropriate order is used to remove non-stationarity from the series. Appendix 1 shows the codes used to be able to run and generate the predicted values.

A seasonal ARIMA model is formed by including additional seasonal terms and is capable of modeling a wide range of seasonal data and is written as follows:

ARIMA (p,d,q) (P,D,Q)m (Model 1)

where:

(p,d,q)	-	refers to the non-seasonal part of the model, p=number of autoregressive terms, d= number of non-seasonal difference and q= moving average terms
(P,D,Q)	-	refers to the seasonal part of the model, P= seasonal autoregressive terms, D= number of seasonal differences, Q= number of seasonal moving average
m	-	number of observations per year

The auto.ARIMA () function using nsdiffs() was used to determine the p,d,q and the P,D,Q values of the thirteen-years worth of rainfall data (January 2006- December 2018) in Kwaebibirem District. Model 2 shows the derived ARIMA model.

ARIMA (4,0,2) (0,1,1) 52 Model 2

where:

(p,d,q)	-	(4,0,2),
(P,D,Q)	-	(0,1,1)
m	-	52 weeks

Using ARIMA (4, 0, 2) (0, 1, 1) 52, it was revealed that the number of non-seasonal autoregressive terms (p) was equal to four which means that four differencing was used to stationarize the series. This means that by using the rainfall data, it was likely to rain if it has been raining in the past four days. The number of non-seasonal differences (d) = 0 means that there were no non-seasonal differences needed for stationarity. The number of moving average terms (q) = 2 means that there were two allowed set of errors at previous points in the past.

The seasonal auto regressive terms (P) = 0 means that there were no seasonal autoregressive terms identified in the given data. This means that the data showed variation of rainfall occurrences in general. A total of 52 observations per year were identified. The ARIMA model was presented using the following functions:

$$\hat{y}_t = \textit{Autoregressive terms and or filter} + \textit{integrated filter} + \textit{Moving average filter} + \textit{error} \quad \text{(Model 3)}$$

Autoregressive functions were derived from the analysis based on fourth order difference to make the function stationary. The following equation was derived:

$$-1.29y_{t-1} - 0.520.29y_{t-3} + 0.15y_{t-4} + y_{t-52} + \varepsilon_t \quad \text{(Equation 2)}$$

where:

$1.29, 0.52, 0.29, 0.15$	= the model parameters computed by the software
$y_{t-1}, y_{t-2}, y_{t-4}, y_{t-3}$	= the past series values generated, past lags,
y_{t-52}	= uncorrelated random values of the given data
ε_t	= past lag errors

There was no integrated filter or stochastic trend developed from the rainfall data given hence, it was 0. The moving average term was extracted from the model and the following equation was derived:

$$+1.29y_{t-53} - 0.52y_{t-54} - 0.29y_{t-55} - 0.15y_{t-56} \quad \text{(Equation 3)}$$

Predicted Rainfall Probability Occurrence for 2020

Figure 2 shows the predicted rainfall probability occurrence for the year 2020. It was predicted that rainfall would be distributed all throughout the year with 71.24 mm on week 21 as the highest, while 4.47mm of rainfall for week 52. Results also showed that most of the rainfall predictions ranged from 20-40 mm. It was also noted that 40 to 70 mm of rainfall would most probably occur during weeks 16- 27 and weeks 35- 42. During these periods, crops with higher water requirements are recommended to be grown. Also, activities requiring more water are suggested to be undertaken during this period.

Predicted Rainfall Probability Occurrence for 2021

Figure 3 shows the projected rainfall value for 2021. It is shown that there will be a maximum of 70.83 mm of rainfall on week 21 and the lowest predicted rainfall would occur on week 52 with a value of 3.65 mm. Weeks 17-27 and week 36 would have a greater than 40 mm rainfall. It is recommended that the crops with higher water requirements should be planted during this period. Weeks 1-16, 27- 32, and 42-52 would have a lower than 40 mm rainfall, which means that crops with lower water requirement should be grown in this period. The predicted values are shown in Appendix Table 14.

Predicted Rainfall Probability Occurrence for 2022

Figure 4 reveals that the highest rainfall volume would probably occur on week 21 at 70.14 mm and the lowest would be where:

$1.29, 0.52, 0.29, 0.15$ = the model parameters computed by the software

$y_{t-53}, y_{t-54}, y_{t-55}, y_{t-56}$ = the future series values generated

The white noise error or the error generated from the software was extracted. The following equation was derived for the lagged errors: (Equation 4)

$$+1.45\varepsilon_{t-1} + 0.82\varepsilon_{t-2} - 0.91\varepsilon_{t-52} - 1.33\varepsilon_{t-53} - 0.76\varepsilon_{t-54}$$

Where:

ε_{t-52} = error generated from uncorrelated random variables

$\varepsilon_{t-1}, \varepsilon_{t-2}$ = error generated from past lagged variables at second order

$\varepsilon_{t-53}, \varepsilon_{t-54}$ = error generated from the future lagged variables at second order

The three (3) equations generated from the autoregressive variables, integration filter, moving average filter, and the total errors were added and combined to come up with the model in forecasting the equation of the probability of rainfall in Kwaebibirem District for 2020- 2024 using seasonal Autoregressive Moving Average (ARIMA). Equation 5 shows the forecasting equation using seasonal ARIMA:

$$\hat{y_t} = -1.29y_{t-1} - 0.52y_{t-2} + 0.29y_{t-3} + 0.15y_{t-4} + y_{t-52} + 1.29y_{t-53} - 0.52y_{t-54} - 0.29y_{t-55} - 0.15y_{t-56} + \varepsilon_t + 1.45\varepsilon_{t-1} + 0.82\varepsilon_{t-2} - 0.91\varepsilon_{t-52} - 1.33\varepsilon_{t-53} - 0.76\varepsilon_{t-54}$$

(Model 4)

where :

$-1.29y_{t-1} - 0.520.29y_{t-3} + 0.15y_{t-4} + y_{t-52} + \varepsilon_t$ = the autoregressive function

$+1.29y_{t-53} - 0.52y_{t-54} - 0.29y_{t-55} - 0.15y_{t-56}$ = the moving average terms

$+1.45\varepsilon_{t-1} + 0.82\varepsilon_{t-2} - 0.91\varepsilon_{t-52} - 1.33\varepsilon_{t-53} - 0.76\varepsilon_{t-54}$ = error

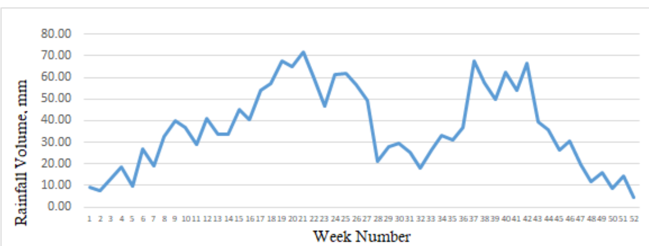

Figure 2. Rainfall probability occurrence for 2020

on week 52 with a value of 3.09 mm. Predicted rainfall data revealed that week 16-23 and 36-43 will have more than 40 mm rainfall while weeks 1-15, 24-35, and 44-52 will have a volume of less than 40 mm. Based on the projected values, it is suggested that crops with higher water requirement should be planted on weeks 16-23 and 36-43. Crops with low water requirement may be planted on weeks 1-15, 24-35, and 44-52.

Predicted Rainfall Probability Occurrence for 2023

Figure 5 shows that the highest projected rainfall volume would be 69.66 mm and the lowest projected rainfall volume would be 2.71 mm. However, the highest predicted rainfall volume would be on the 21st week and the lowest would be on the 52nd week. There would be a limited rainfall in 2023. Data also revealed that weeks 17-26 and 36-42 would have a predicted rainfall volume of more than 40 mm, while weeks 1-16, 27-35 and 43-52 showed a rainfall volume lower than 40 mm. It is then recommended that crops with lower water requirement be planted during this period. Planting crops with higher water

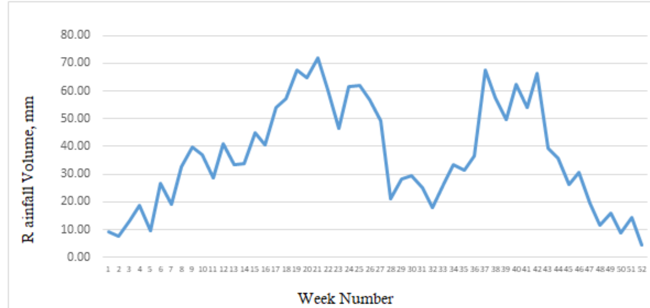

Figure 3. Rainfall probability occurrence for 2021

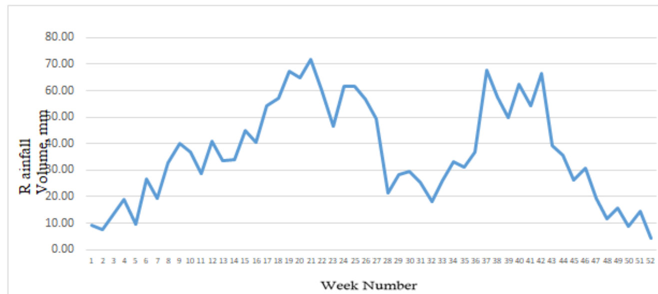

Figure 4. Rainfall probability occurrence for 2022

requirement should be less.

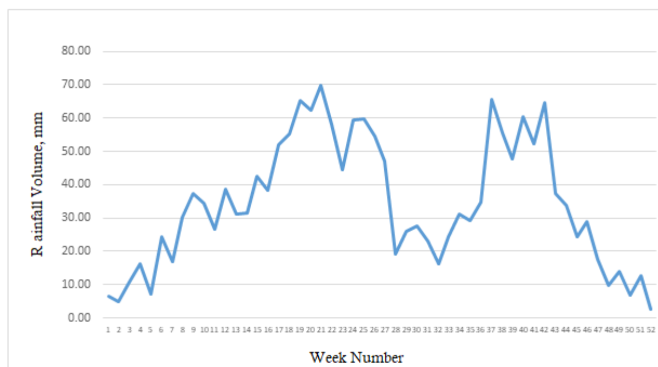

Figure 5. Predicted rainfall probability occurrence for 2023

Predicted Rainfall Probability Occurrence for 2024

Figure 6 shows the predicted rainfall probability occurrence for 2024. It is shown that there would be a limited predicted volume for the year. The maximum rainfall volume would be 69.32 mm on week 21 and as low as 2.44 mm on week 52. Rainfall volume greater than 40 mm was predicted on weeks 15-27 and 35-42, while rainfall volume less than 40 mm was predicted on weeks 1-14, 28-34, and 52-43. Crops with less water requirements may be planted on weeks 1-14, 28-34 and 43-52.

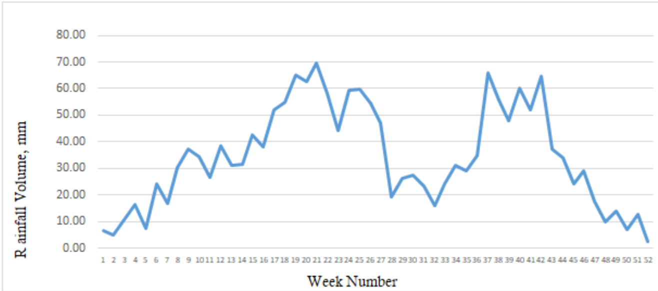

Figure 6. Rainfall probability occurrence for 2024

Predicted Peak Rainfall

Based on the predicted values, the peak rainfall for a certain year was determined by getting the highest predicted rainfall volume at a given week. For 2020-2024, the predicted peak rainfall volume would be on week 21, around the month of May with predicted values of 71.84 mm for 2020, 70.83 mm for 2021, 70.14 mm for 2022, 69.66 mm for 2023, and 69.33 mm for 2024. It means that based on the thirteen-years worth of data (January 2006- December 2018), at the fourth level differencing using ARIMA; week 21 was most likely to have the highest rainfall volume. Also, based on the predicted values, the highest rainfall volume was more likely to occur during weeks 19- 22 and weeks 40- 42, during the months of May and October. It is recommended to schedule crops that require more water during these periods.

Recommended Cropping Schedule for Kwaebibirem District

To be able to help the farmers plant crops suitable to the conditions of Kwaebibirem District and thus would improve productivity, a cropping schedule was developed based on the projected rainfall probability occurrence and the volume of rainfall that was most likely to occur at a given period.

Crop	Growth Stage	Duration days	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Maize	Emergence													
	4-leaf (V4)	0-7												
	8-leaf (V8)	8-20												
	12-leaf (V12)	20-30												
	Early Tassel (R1)	30 - 45												
	Silking (R2)	45-60												
	Blister Kernel (R3)	60-70												
	Beginning Dent (R4)	70-109												
	Full Maturity (R5)	109 -130												
Rice														
	land preparation	1-15												
	panting	1-15												
	Panicle initiation	15 - 67												
	Flowering to Maturity	67 - 104												
	Ripening	104 - 160												
Tomato														
	Planting	1												
	Vegetative	01 15												
	First Flowering	15 - 30												
	First Fruitset	30 - 40												
	Fruit Growth	40 - 60												
Pepper														
	planting	1												
	Vegetative	01 25												
	flowering	25 - 35												
	fruit set	35 - 45												
	first harvest	45 - 70												
	harvest to last harvest	70 - 240												

Legend:
Maize – (yellow) Tomato- (red)
Rice- (green) Pepper- (dark blue)

Table 1. Recommended cropping schedule for 2020

Table 1 shows the developed cropping schedule for 2020. Based on the predicted data, maize would have two growing seasons which would be during the major and minor seasons. The minor season starts from February and ends in May, while the major season would start from July and ends in November. However, there may be a reduction in days during silking, beginning dent, and full maturity. This may occur based on high water level during the period. Meanwhile, blister kernel would have an increment in days for both minor and the major seasons. Table 2 presents the output from the 2021 predicted data for the selected crops. The weekly distribution of rainfall in the study area is valuable with maximum rainfall for the stages of the crops. It was observed that only maize and tomatoes would have two growing seasons during the year 2021. Two growing seasons are recommended for maize based on the predicted value. Hence, only one growing season for rice and chili pepper is recommended.

Crop	Growth Stage	Duration days	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Maize	Emergence													
	4-leaf (V4)	0-7												
	8-leaf (V8)	8-20												
	12-leaf (V12)	20-30												
	Early Tassel (R1)	30 - 45												
	Silking (R2)	45-60												
	Blister Kernel (R3)	60-70												
	Beginning Dent (R4)	70-109												
	Full Maturity (R5)	109 -130												
Rice														
	land preparation	1- 15												
	panting	1- 15												
	Panicle initiation	15 - 67												
	Flowering to Maturity	67 - 104												
	Ripening	104 - 160												
Tomato														
	Planting	1												
	Vegetative	01 15												
	First Flowering	15 - 30												
	First Fruitset	30 - 40												
	Fruit Growth	40 - 60												
Pepper														
	planting	1												
	Vegetative	01 25												
	flowering	25 - 35												
	fruitset	35 - 45												
	first harvest	45 - 70												
	harvest to last harvest	70 - 240												

Table 2. Recommended cropping schedule for 2021

The predicted data revealed that only rice would have one growing season, while maize, tomatoes, and pepper would have two seasons. However, there would be a reduction and late increment in days and weeks during the growth stages of the crops. During the growth stage in maize, the minor season would be from the third week of February and would be completed on the last week of May. The major season would be on the second week of July and would end in November as shown in Table 3.

Table 4 presents the weekly rainfall distribution data for 2023 based on the five (5) years predicted data for crop scheduling. It shows that there would be an adequate determination for the production of maize, rice, tomato, and chili pepper in 2023. Again, it is proven that there will be both late and early stages of growth among the crops during the growth stages. Based on the projected rainfall volume, two growing seasons may be recommended for maize and pepper production and one growing season for tomato and rice.

Table 5 indicates the weekly rainfall distribution data for 2024 based on the five (5) years predicted data for crop scheduling. Two growing seasons would be recommended for maize, tomato, and chili pepper based on the predicted value. There would only be one growing season for rice. This shows that

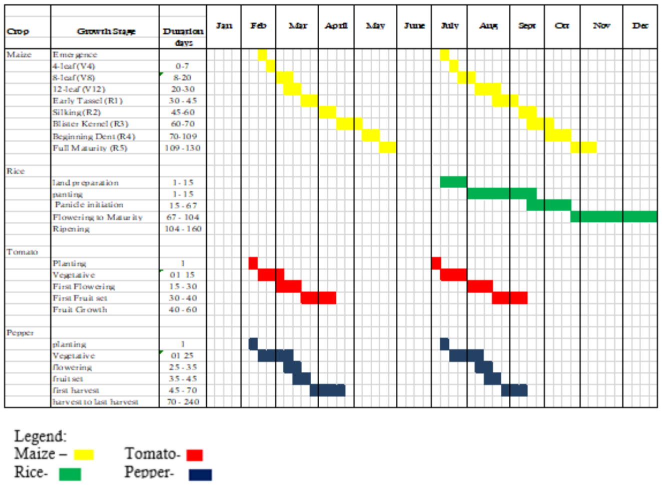

Table 3. Recommended cropping schedule for 2022

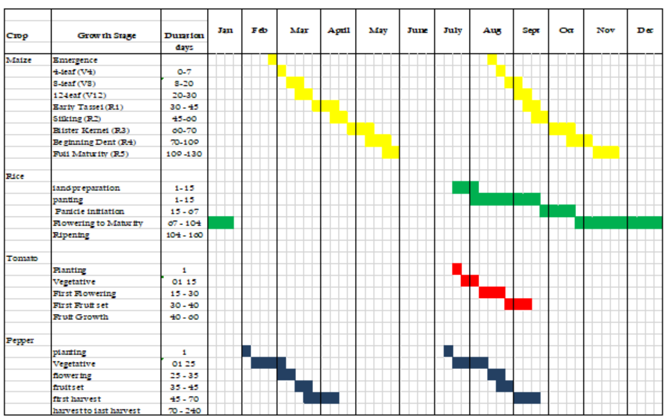

Table 4. Recommended cropping schedule for 2023

there would be an effective growth of the crops. However, the planting date for tomato at the minor growing season would be on the month of February. During this period, there would be an increment in days and weeks during the first fruit set due to the limited rainfall distribution. But there would be no reduction in days or weeks during that period for that year.

Conclusions

Based on the predicted data of the crop scheduling, the following conclusions were drawn:

1. Time series modeling using the Seasonal Autoregressive Moving Average (SARIMA) predicted the rainfall probability occurrence using the thirteen-years worth of previous data. An equation to predict rainfall data was also derived based on the given data. The equation below was derived:

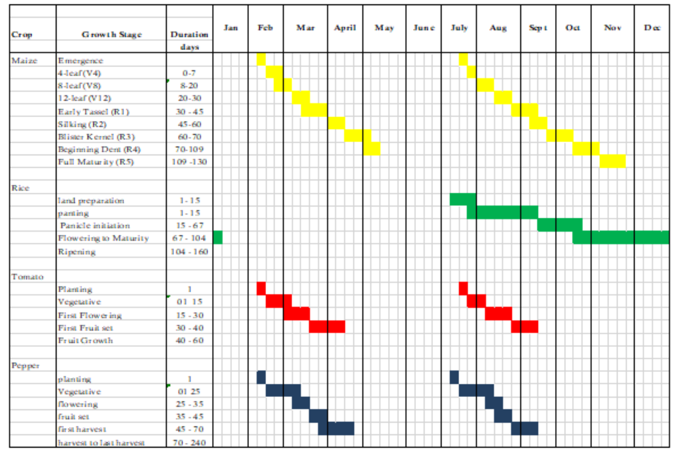

Table 5. Recommended cropping schedule for 2024

$$\hat{y}_t = -1.29y_{t-1} - 0.52y_{t-2} + 0.29y_{t-3} + 0.15y_{t-4} + y_{t-52} + 1.29y_{t-53} - 0.52y_{t-54} - 0.29y_{t-55} - 0.15y_{t-56} + \varepsilon_t + 1.45\varepsilon_{t-1} + 0.82\varepsilon_{t-2} - 0.91\varepsilon_{t-52} - 1.33\varepsilon_{t-53} - 0.76\varepsilon_{t-54}$$

2. A five-year (2020-2024) rainfall probability occurrence and volume was predicted based on the thirteen-years worth of rainfall data using Seasonal ARIMA. The total projected rainfall volume for 2020 was 1,902.71 mm, 1,851.42 mm for 2021, 1,816.2 mm for 2022, 1,792.22 mm for 2023, and 1,775.73 mm for 2024.

3. Using ARIMA for the data collected, the peak rainfall occurrence would be on every 21st week of the year. The peak rainfall was expected to occur from May-June of every year.

4. A five-year (2020-2024) cropping schedule was developed using the predicted rainfall occurrence and crop water requirements for maize, corn, tomato, and pepper, for the farmers of Kwaebibirem District.