ISSN 2330-6440 Vol 3, No 2, May 2016

Determination of crop water requirements of maize in Nigeria by using FAO CROPWAT 8.0

Jazuli Abdullahi,[a] Gozen Elkiran[b]

[a] NEU—Near East University, Engineering Faculty, Near East Boulevard, 99138, Nicosia, North Cyprus
jazulibinabdallah@gmail.com

[b] NEU—Near East University, Engineering Faculty, Near East Boulevard, 99138, Nicosia, North Cyprus
gozenelkiran@gmail.com

Abstract. Water demand is increasing day by day in the entire world, which is why water scarcity is among the most disturbed issues in current time. Crop water requirements estimation is a reliable way of managing water used by agriculture. This research was conducted to determine the crop water requirements of the major crop (Maize) grow in Nigeria, at four aridity zones which are, Semi-Arid, Moist Sub-Humid, Dry Sub-Humid and Humid zones and to compare the difference in water demands of the maize in the four zones in order to come out with best region to grow maize in Nigeria with more efficiency and less water demands. CROPWAT 8.0 was used in carrying out the research using Penman-Monteith method which was regarded as the best method by FAO. The result showed that effective rainfall was sufficient to provide the crop (Maize) with the required water it needed to grow in both Moist Sub-Humid, Dry Sub-Humid, and Humid zone while irrigation water was needed to be added to rainfall water in order to achieve the crop water requirements of the maize in Semi-Arid zone. Thus, the three (3) zones were more efficient in Maize production.

Keywords: crop water requirement, water demand, aridity zones, Nigeria, maize, irrigation water.

1 INTRODUCTION

Water is regarded as an undisputed common liquid in the world, it is of immense benefits to all forms of life, water is also essential for crops. Water demand is increasing day by day in the entire planet (this world) which is why water scarcity is among the most disturbed issues in current time. Due to rashness in the use of surface water, global changes in climate, improper use of ground water and quick ascendance in industrial pollution led to scarcity or decrease in fresh water resources. Rapid population increase causes more demand for crop and food and more water demand. (Bastiaanssen et al., 2000).

As agriculture constitute the major water use in the world, management of water use by agriculture is important. Crop water requirements estimation is a reliable way of managing water use by agriculture. Evapotranspiration rate (ET mm/day) is used in expressing the crop water requirements (Banik et al., 2014).

Crop water requirement according to Hess (2005) referred to the aggregate sum of water needed for evapotranspiration between the period of planting and harvesting of a given crop at a definite climate regime while sufficient soil water upholds irrigation and rainfall so that crop yield, as well as plant growth, are not limited. Each and every crop has its individual water requirements. NIWR (Net Irrigation Water Requirements) in a definite scheme during a

particular year are hence the summation of individual water requirements of crops (CWRi) determine for every irrigated crop i. Crop water requirements are computed independently for every cropping period when dealing with multiple cropping (period of planting many crops per year). (Adeniran et al., 2010).

However, Smith (1992), Smith et al.,(1991) and FAO (1992) unveiled that CROPWAT is aimed as a sophisticated tool to assist irrigation engineers, agronomists, and agro-meteorologists in order to have evapotranspiration by using standard calculations and studies of water use by crops, and most especially the management and design of irrigation schemes. Crop water requirements rely largely on the conditions of an environment (Broner and Schneekloth, 2003). Water is use by plants for cooling reasons and the leading/pushing force for the process is influential weather conditions.

The 10th largest maize producer in the world is Nigeria and it is the largest maize production country in the whole of Africa, with South Africa as second (IITA, 2003). Both white and yellow varieties of maize are grown in the entire country with North Central Nigeria as the largest producing area. Smallholders farmers constitute 70%, with 5 ha average area of cultivated production land representing 90% of the aggregate sum of farm input (Cadoni et al., 2013). Maize is a predominant food crop that impacts positively to the socio-economic developments of the Sub-Saharan Africa, with Nigeria inclusive having per capital of 40kg/year (FAOSTAT, 2003).

The aims of this study were to determine the crop water requirements of maize in the four (4) aridity zones of Nigeria, compare the difference in water consumptions/requirements of the crop (maize) in the four different aridity zones in order to see how the difference in climate affects the water requirements of each zone and to determine the best region to grow maize in Nigeria.

2.0 MATERIALS AND METHOD

2.1 Study Location

Nigeria is situated in West African region of the tropical zone, it has latitudes between 4^0N to 14^0N and longitudes of $2^0$2'E to $14^0$30'E with an area of 923,770 km^2. The distance from North to South of Nigeria is 1,050 km while the optimum distance from East to West is 1,150 km. Nigeria is surrounded by Benin to the west, Niger to the North and Northwest, Chad to the Northeast and Cameroon to the East, while the Southern Nigeria is surrounded by Atlantic Ocean. Land in Nigeria comprises of dense rain forests and thick mangrove forests at South, and the close-to-desert situation at the Northeastern part of the country (FAO AQUASTAT, 2005). Nigeria consists of 36 states and federal capital territory Abuja (as in Fig. 1)

Fig. 1. Map of Nigeria.

[Source: Country Pasture/Forage Resource Profiles Nigeria, FAO AQUASTAT, 2005. Accessed 20-1-2016]

A semi-arid climate is present in the northern part (as shown in Fig. 2) while the south climate is humid. With the exclusion of ultra-humid strip around the cost having averages rainfall of over 2,000mm/yr, is present in this region close to a year round. The pattern of rainfall in Nigeria are demarcated in to dry and wet seasons. June – September is the period of higher rainfall concentration. 61million hectare is the maximum cultivatable area in Nigeria.

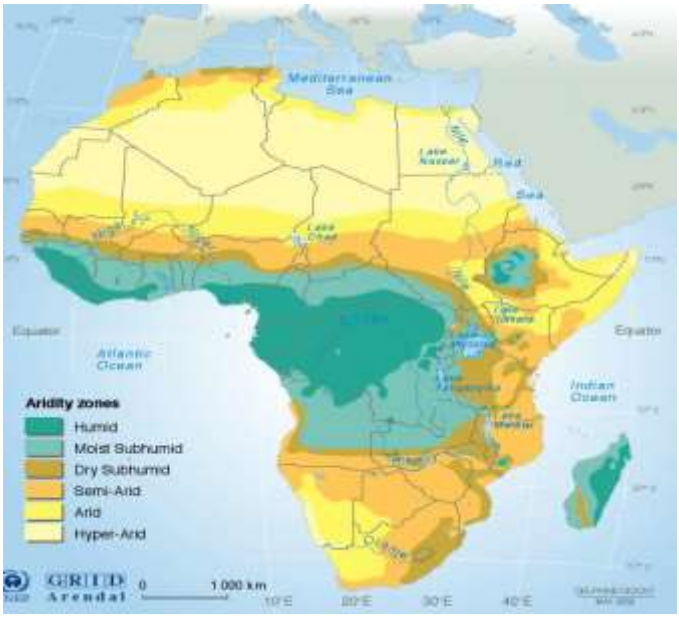

Fig. 2. Map of Africa showing aridity zones.

[Source: World Meteorological Organization (WMO), United Nation Environment Programme (UNEP), climate change 2001. Accessed 23-02-2016)]

This research was conducted in four (4) aridity zones in Nigeria. One region was taken from each aridity zone. The aridity zones and regions selected were Katsina in Katsina state from semi-arid zone, Samaru in Kaduna state from Dry sub-humid zone, Minna in Niger state from Moist sub-humid zone and Port-Harcourt in Rivers state from Humid zone. The regions were written in red (black) in Fig. 3 below which represents the chosen locations/regions of the research.

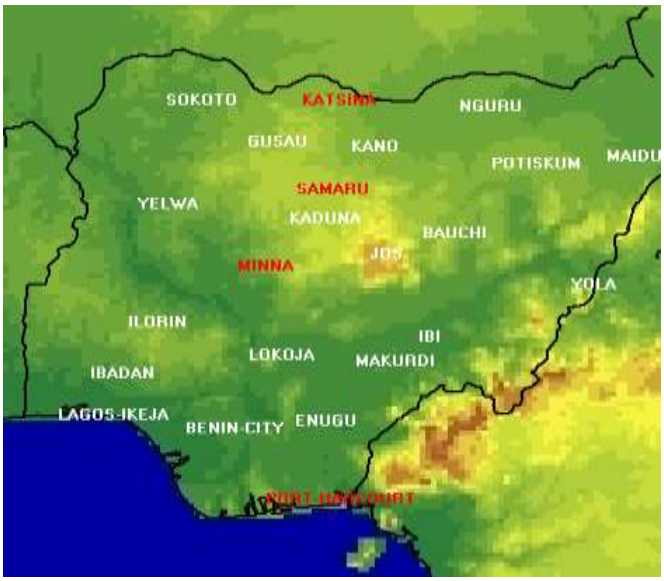

Figure 3: Map of Nigeria showing the study locations.
[Source: FAO, 1993. CLIMWAT for CROPWAT. Accessed 23-02-2016]

2.2 CROPWAT Model

This research was based on CROPWAT 8.0, which was the latest computer program developed by land and water division of FAO, used in calculating the crop water requirements and irrigation requirements of crops with respect to crop data, soil, and climate (FAO, 1998). However, CROPWAT 8.0 also help in providing irrigation schedules and water supply calculations schemes of different cropping pattern.

2.3 Reference Evapotranspiration (ET_O)

The reference crop evapotranspiration described as the potential evapotranspiration by well wetted grass crop (Laghari et-al, 2014). There are four methods to determine reference evapotranspiration which are; Penman-Monteith, Blaney-criddle, Radiation and Pan Evaporation methods (FAO 56, 1998). Penman-Monteith method which required meteorological data was regarded by FAO as the best method to determine reference evapotranspiration.

This research was, therefore, carried out using Penman-Monteith method. The reference evapotranspiration was obtained by using

$$ETo = \frac{0.408\,\Delta(Rn-G) + \gamma\frac{900}{T+273}U2\,(es-ea)}{\Delta + \gamma\,(1+0.34U2)}, \quad (1)$$

Where by

ETo = Reference evapotranspiration [mm day-1],

Rn = net radiation at the crop surface [MJ m-2 day-1],

G = soil heat flux density [MJ m-2 day-1],

T = mean daily air temperature at 2 m height [°C],

$\mathcal{U}_2$ = wind speed at 2 m height [m s-1],

$\mathrm{e}s$ = saturation vapour pressure [kPa],

$\mathrm{e}a$ = actual vapour pressure [kPa],

$\mathrm{e}s - \mathrm{e}a$ = saturation vapour pressure deficit [kPa],

γ = slope vapour pressure curve [kPa °C-1],

Δ = psychrometric constant [kPa °C-1].

2.4 Crop Water Requirement

According to FAO (1998), even though crop water requirement and crop evapotranspiration ET_C have similar values, crop water requirement implied to water supplied for evapotranspiration while the crop evapotranspiration is the amount of water escape/evaporates through evapotranspiration. Crop water requirement was defined by FAO as

$$CWRi = \sum_{t=0}^{T} (Kci \,.\, ETo - P_{eff}), \qquad (2)$$

Where, *Kci* = coefficient of crop *i* at growth stage t and T referred to final growth stage.

ETo = reference evapotranspiration.

P_{eff} = effective rainfall.

2.5 Data Used

The meteorological data for the study location which was maximum and minimum temperatures, humidity, wind speed, sunshine hours, and radiation as well as rainfall data were adopted from CLIMWAT for CROPWAT by FAO. The crop parameters for which includes crop coefficient in the initial stage, middle stage, and late stage, and root depth were taken from crop water information of FAO database. The planting period was taken from crop calendar of FAO crop calendar (2013).

3.0 RESULT

The results obtained were presented in Tables 3.1 to 3.6. The months of the year, minimum temperature, maximum temperature, humidity, wind speed, sunshine hours, radiations, and Reference Crop Evapotranspiration (ETo) were given for each of the four zones in tables 3.1.1, 3.2.1, 3.3.1, and 3.4.1, respectively. Months of plantation to harvest, decade (10 days), development stages, crop coefficient, Crop Evapotranspiration per day and per decades, effective rainfall, and irrigation requirements of the Maize were given in Tables 3.1.2, 3.2.2, 3.3.2, and 3.4.2 respectively. Regions, area harvested, and Crop Water Requirements were placed in Table 3.5. Total water needed, irrigation water requirement, crop quantity produced, and total income were shown in Table 3.6, while Fig.4 showed Reference Crop Evapotranspiration of the zones for each month and their average.

3.1 Semi-Arid Zone (Katsina Region)

Table 3.1.1. Reference crop evapotranspiration for Maize using Penman-Monteith method

MONTHLY ETO PENMAN-MONTEITH DATA

COUNTTRY : NIGERIA	STATION: KATSINA	LONGITUDE: 7.68°E
ALTITUDE: 517 M	LATITUDE: 13.01°N	ZONE: SEMI-ARID

Month	Min. Temp. (°C)	Max. Temp. (°C)	Humidity (%)	wind (km/day)	Sunshine hours	Rad. (MJ/m2/day)	ETo (mm/day)
January	12	30.1	24	138	8.3	18.8	4.66
February	14.5	32.8	18	156	8.2	20.2	5.52
March	19.6	37	17	130	7.1	19.9	5.71
April	23	38.6	26	156	6.9	20.2	6.48
May	24.1	37.3	44	190	7.6	21.1	6.63
June	23	34.7	56	199	8.1	21.5	6.1
July	21	30.7	71	173	7.3	20.4	4.81
August	20.5	28.8	80	147	5.6	18	3.89
September	20.6	30.7	75	112	7.8	21.1	4.44
October	19.5	34	53	95	8.7	21.2	4.8
November	15.3	33.5	31	104	8.8	19.8	4.67
December	12.2	30.1	28	121	9.3	19.6	4.44
Average	18.8	33.2	44	143	7.8	20.1	5.18

Table 3.1.2: Crop water requirement of Maize in Katsina region of Semi-Arid Zone.

CROP WATER REQUIREMENT

ETo STATION: KATSINA | CROP: MAIZE (GRAIN)

RAIN STATION: KATSINA | PLANTING DATE: 06-01

Month	Decade	Stage	Kc coeff.	ETc (mm/day)	ETc (mm/decade)	Effective Rain (mm/decade)	Irrigat. Req. (mm/decade)
Jun	1	Init	0.3	1.88	18.8	15.8	3
Jun	2	Init	0.3	1.83	18.3	18.9	0
Jun	3	Deve	0.43	2.45	24.5	26.2	0
Jul	1	Deve	0.67	3.52	35.2	35.3	0
Jul	2	Deve	0.91	4.38	43.8	42.9	0.9
Jul	3	Mid	1.12	5.03	55.3	44.1	11.2
Aug	1	Mid	1.14	4.7	47	47.2	0
Aug	2	Mid	1.14	4.31	43.1	50.4	0
Aug	3	Mid	1.14	4.56	50.2	42.4	7.7
Sep	1	Late	1.06	4.53	45.3	33.5	11.8
Sep	2	Late	0.81	3.59	35.9	26.9	9.1
Sep	3	Late	0.55	2.49	24.9	18.9	6
oct	1	Late	0.38	1.76	5.3	2.7	0.8
					447.6	405.3	50.5

3.2 Moist Sub-Humid Zone (Minna Region).

Table 3.2.1: Reference crop evapotranspiration for Maize using Penman-Monteith method

MONTHLY ETO PENMAN-MONTEITH DATA

COUNTTRY : NIGERIA | STATION: MINNA | LONGITUDE: 6.53°E

ALTITUDE: 260 m | LATITUDE: 9.61°N | ZONE: MOIST SUB-HUMID

Month	Min. Temp. (°C)	Max. Temp. (°C)	Humidity (%)	wind (km/day)	sun.hours	Rad. (MJ/m2/day)	ETo (mm/day)
January	20.4	34.7	35	199	7.9	19.1	6.04
February	22.8	36.8	30	199	8.2	20.7	6.77
March	24.5	37.1	36	181	8.1	21.7	6.75
April	24.8	35.7	59	190	7.5	21	5.98
May	23.7	32.8	72	173	7.5	20.6	5.06
June	22.3	30.7	79	156	6.6	18.9	4.25
July	22.1	29.1	82	138	4.5	15.9	3.52
August	21.8	28.8	85	130	4.2	15.7	3.36
September	21.6	30	82	130	5.6	17.9	3.82
October	21.5	32	77	121	8	20.7	4.43
November	19.4	34.4	55	173	8.6	20.3	5.31
December	19.3	34.7	40	173	8.4	19.2	5.51
Average	22	33.1	61	163	7.1	19.3	5.07

Table 3.2.2: Crop water requirement of Maize in Minna region of Moist Sub-Humid Zone.

CROP WATER REQUIREMENT

ETo STATION: MINNA | CROP: MAIZE (GRAIN)

RAIN STATION: MINNA | PLANTING DATE: 06-01

Month	Decade	Stage	Kc coeff.	ETc (mm/day)	ETc (mm/decade)	Effective Rain (mm/decade)	Irrigat. Req. (mm/decade)
Jun	1	Init	0.3	1.36	13.6	40	0
Jun	2	Init	0.3	1.27	12.7	42.2	0
Jun	3	Deve	0.43	1.71	17.1	43.5	0
Jul	1	Deve	0.66	2.48	24.8	44.7	0
Jul	2	Deve	0.89	3.14	31.4	46.1	0
Jul	3	Mid	1.09	3.78	41.5	47.6	0
Aug	1	Mid	1.11	3.79	37.9	49.8	0
Aug	2	Mid	1.11	3.73	37.3	51.6	0
Aug	3	Mid	1.11	3.9	42.9	50.8	0
Sep	1	Late	1.04	3.81	38.1	51.6	0
Sep	2	Late	0.79	3.03	30.3	52.1	0
Sep	3	Late	0.54	2.17	21.7	44	0
oct	1	Late	0.38	1.59	4.8	10.7	0
					354	574.6	0

3.3 Humid Zone (Port-Harcourt Region).

Table 3.3.1: Reference crop evapotranspiration for Maize using Penman-Monteith method

MONTHLY ETO PENMAN-MONTEITH DATA

COUNTTRY : NIGERIA | STATION: PORT-HARCOURT | LONGITUDE: 7.01°E

ALTITUDE: 18 m | LATITUDE: 4.85°N | ZONE: HUMID

Month	Min. Temp. (°C)	Max. Temp. (°C)	Humidity (%)	wind (km/day)	Sunshine hours	Rad. (MJ/m2/day)	ETo (mm/day)
January	21.2	32.4	77	164	5.3	16.4	3.91
February	22.6	33.4	78	190	6	18.2	4.42
March	23.2	32.7	78	190	4.9	17	4.25
April	23.3	32.1	79	199	5	17.2	4.22
May	23	31.3	83	199	5.1	16.6	3.88
June	22.6	30	84	181	3.8	14.2	3.3
July	22.3	28.7	87	181	3	13.3	2.96
August	22.4	28.7	86	190	3	13.7	3.07
September	22.3	29.3	86	181	2.7	13.5	3.05
October	22.3	30.2	85	164	3.9	15	3.36
November	22.3	31.2	83	138	4.8	15.7	3.51
December	21.3	31.8	81	147	5.5	16.3	3.69
Average	22.4	31	82	177	4.4	15.6	3.64

Table 3.3.2: Crop Water Requirement of Maize in Port-Harcourt region of Humid Zone

ETo STATION: PORT-HARCOURT | CROP: MAIZE (GRAIN)

RAIN STATION: PORT-HARCOURT | PLANTING DATE: 06-01

Month	Decade	Stage	Kc coeff.	ETc (mm/day)	ETc (mm/decade)	Effective Rain (mm/decade)	Irrigat. Req. (mm/decade)
Jun	1	Init	0.3	1.05	10.5	40	0
Jun	2	Init	0.3	0.99	9.9	42.2	0
Jun	3	Deve	0.43	1.37	13.7	43.5	0
Jul	1	Deve	0.66	2.04	20.4	44.7	0
Jul	2	Deve	0.9	2.66	26.6	46.1	0
Jul	3	Mid	1.1	3.3	36.3	47.6	0
Aug	1	Mid	1.12	3.41	34.1	49.8	0
Aug	2	Mid	1.12	3.45	34.5	51.6	0
Aug	3	Mid	1.12	3.44	37.9	50.8	0
Sep	1	Late	1.05	3.21	32.1	51.6	0
Sep	2	Late	0.8	2.45	24.5	52.1	0
Sep	3	Late	0.54	1.71	17.1	44	0
oct	1	Late	0.38	1.22	3.7	10.7	0
					301.3	574.6	0

3.4 Dry Sub-Humid Zone (Samaru Region).

Table 3.4.1: Reference crop evapotranspiration for Maize using Penman-Monteith method.

MONTHLY ETO PENMAN-MONTEITH DATA

COUNTTRY : NIGERIA | STATION: SAMARU | LONGITUDE: 7.58°E

ALTITUDE: 685 m | LATITUDE: 11.18°N | ZONE: DRY SUB-HUMID

Month	Min. Temp. (°C)	Max. Temp. (°C)	Humidity (%)	wind (km/day)	Sunshine hours	Rad. (MJ/m2/day)	ETo (mm/day)
January	14	30.7	28	225	7.9	18.8	5.85
February	15.8	32.6	25	225	8.5	20.9	6.52
March	19.3	35.2	28	173	8.1	21.6	6.34
April	21.6	35.7	48	173	7.2	20.6	5.93
May	26.6	33.1	53	164	7.3	20.5	5.72
June	19.8	30.6	76	156	7	19.7	4.53
July	19.3	28.3	82	164	5.5	17.6	3.76
August	19.2	27.5	84	147	4.5	16.2	3.4
September	19	29.1	81	112	6.1	18.6	3.84
October	17.3	31.3	70	104	8.1	20.6	4.35

November	15.6	31.8	43	138	8.8	20.2	4.88
December	14	30.7	34	199	8.3	18.8	5.38
Average	18.5	31.4	54	165	7.3	19.5	5.04

Table 3.4.2: Crop Water Requirement of Maize in Samaru region of Humid Zone

ETo STATION: SAMARU CROP: MAIZE (GRAIN)

RAIN STATION: SAMARU PLANTING DATE: 06-01

Month	Decade	Stage	Kc coeff.	ETc (mm/day)	ETc (mm/decade)	Effective Rain (mm/decade)	Irrigat. Req. (mm/decade)
Jun	1	Init	0.3	1.48	14.8	38.3	0
Jun	2	Init	0.3	1.36	13.6	41.1	0
Jun	3	Deve	0.43	1.84	18.4	43.3	0
Jul	1	Deve	0.67	2.7	27	45.6	0
Jul	2	Deve	0.91	3.43	34.3	47.9	0
Jul	3	Mid	1.12	4.06	44.7	49	0
Aug	1	Mid	1.14	4.01	40.1	50.5	0
Aug	2	Mid	1.14	3.87	38.7	52	0
Aug	3	Mid	1.14	4.03	44.4	51	0
Sep	1	Late	1.06	3.93	39.3	53	0
Sep	2	Late	0.81	3.1	31	54	0
Sep	3	Late	0.55	2.19	21.9	39.8	0
oct	1	Late	0.38	1.57	4.7	6.5	0
					372.8	572	0

Table 3.5: Regions, area harvested and crop water Requirements of the four (4) Aridity zones

Aridity zones	Regions	Area harvested (ha)	CWR (m^3/ha)
Semi-Arid	Katsina	59,383	4,458
Moist Sub-Humid	Minna	41,297	3,524
Humid	Port-Harcourt	54,287	3,001
Dry Sub-Humid	Samaru	62,575	3,713

Table 3.6: Total Water Needed, Irrigation Water Needed, Quantity Produced and Total Income of each region for the year 2013.

Aridity zones	Regions	Total Water Needed (m^3)	Irrigation Water Requirement (m^3)	Q. Produced (ton)	Total Income ($)
Semi-Arid	Katsina	264,727,631	17,102,189	347,171	41,660,470
Moist Sub-Humid	Minna	145,530,276	0	241,436	28,972,275
Humid	Port-Harcourt	162,915,287	0	317,380	38,085,600
Dry Sub-Humid	Samaru	232,342,089	0	365,836	43,900,327

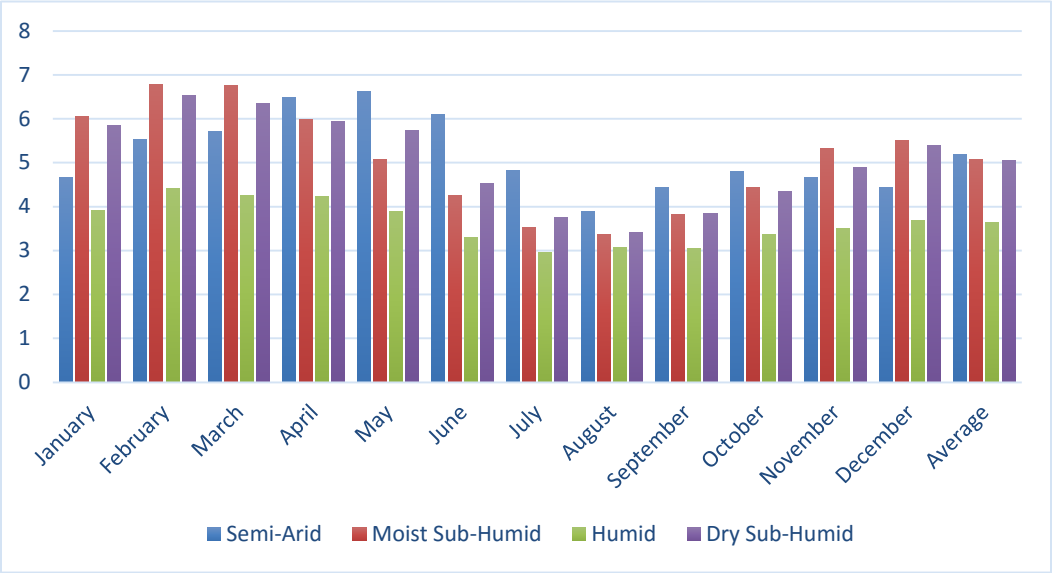

Fig. 4. Monthly ETo distribution for the four aridity zones

As obtained from the results, Semi-Arid zone has the highest average for Maize reference evapotranspiration (ETo) (as seen in fig.4.) compared to other three aridity zones, this may be largely due to a higher temperature the zone experienced than the other regions. Moist Sub-Humid zone was second in terms of average reference evapotranspiration of the Maize, followed by Dry Sub-Humid and Humid had the least average Maize reference evapotranspiration.

However, as seen in Table 3.5, Maize grown in Katsina region of Semi-arid zone had the highest crop water requirements than the others, followed by Samaru of Dry Sub-humid, Minna of Moist Sub-humid, and Lastly Port-Harcourt of Humid. Despite being the second water requiring region, Samaru had the largest cultivated area with 62.6 thousand hectares, followed by Katsina, Port-Harcourt, and Minna was the least with 41.3 thousand hectares (Table 3.5)

Moreover, as the largest crop water requirements region (as seen in table 3.5), Katsina had the highest total water needed which was 264.7 million cubic meter. The second was Samaru, then Port-Harcourt, and lastly Minna which had 145.5 million cubic meter of water. In all the four zones, only Semi-arid needed an addition of irrigation water to grow the Maize which amount to 17 million cubic meter of water, whereas rainfall water was sufficient for Maize production for others (Table 3.6).

With both highest rainfall and irrigation water utilized, Katsina failed to be the largest Maize production region, having managed to produce 347.2 thousand tons, which was second to Samaru's 365.8 thousand tons. However, Minna produced less which was 241.4 thousand tons (Table 3.6). As expected, due to its greater production value, Samaru was the first region to choose when it comes to total income with $43.9 million. The next was Katsian, Port-Harcourt, and Minna, with $29 million (Table 3.6). The overall income can be summed up to be $152.6 million (Table 3.6).

Conclusion

It was gathered that Maize reference crop evapotranspiration is higher in Semi-Arid than the other aridity zones. Meanwhile, Semi-Arid zone possessed higher demand for crop water requirements, than other zones and a difference of over 700 m^3/ha can be calculated from the closest Port-Harcourt region of Humid zone (as seen in table 3.5). Moist Sub-Humid, Dry Sub-Humid, and Humid zones required no irrigation water for maize to grow owing to sufficient rainfall in the zones while Semi-Arid zone required irrigation water due to scarcity and insufficiency of rainfall.

As the world continue to experience an increase in global warming which leads to increase of water scarcity due to drying surface water (Lakes, Rivers, Streams), it would be better to grow Maize where there is sufficient rainfall to grow the crop (Maize) and where less crop water requirement is needed. Therefore, Moist Sub-Humid, Dry Sub-Humid, and Humid zones are the efficient and suitable regions to grow Maize in Nigeria. In general, Port-Harcourt region of Humid zone is the best region in Nigeria for Maize production because of its least crop water requirements and high rainfall availability.

Acknowledgement

My special gratitude to my parent, brothers, and sisters who always encourage me and make necessary sacrifice in all my life endeavors. My appreciation and words of acknowledgement can never be over emphasized to my lecturer, and mentor Assoc.Prof.Dr. Gozen Elkiran, for his guidance throughout this research.

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