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Full Length Research Paper

Trends of pearl millet (*Pennisetum glaucum*) yields under climate variability conditions in Oshana Region, Namibia

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ABSTRACT

The majority of small scale farmers especially in Southern Africa depend on rain-fed crop production for their livelihood. The rate of temperature increase is predicted to continue over the next two decades, with severe implications for physical and biological systems and human livelihoods. Climate change impacts have been felt in Namibia already over the past years. A field survey with questionnaire interviews was conducted in Oshana region to collect the primary data. The study found out that, in 2009 and 2011, pearl millet yields were significantly reduced in Oshana region attributed to severe floods that were experienced in which crop fields were inundated by flood water. The analysis of the historical rainfall data shows a change in rainfall intensity in the north central Namibia with shorter rainfall seasons and late arrival of the rainfall. This affected the production due to farmers still practicing cultural planting programmes. The planting date by farmers is 30th November and yield reduction is 31.7%, while the best planting date scenario simulated in CropWat analysis is 25th December and yield reduction is 20.9%. This shows the correlation of rainfall seasons shifting since the yield reduction seem to be low when crops are grown on the 25th December seasonally.

Keywords: Climate change, North Central Namibia, pearl millet, rainfall yields.

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INTRODUCTION

Climate change is one of the greatest challenges of mankind in the 21st century and its impacts may still be avoided if efforts are made to transform current energy systems. On the other hand climate variability has been always occurring in time and space but with climate change scientists shown that it is more variable now and predicted to be worse in the future Intergovernmental Panel on Climate Change (IPCC, 2012). Poor countries, particularly those in Africa, are amongst the most vulnerable to the negative effects of climate change (IPCC, 2007). They also have the least capacity to adapt to climate change due to their limited financial resources, skills and technology, and their dependence on climate-sensitive primary sectors (Boko et al., 2007).

Namibia is very vulnerable to the impacts of climate change due to its extreme aridity and dependence on primary industry combined with a limited adaptive capacity. The loss of agricultural productivity as a result of climate change could have severe economic impacts on farmers and on the Namibian economy (Brown, 2009). Considerable spatial heterogeneity in the trends has been observed, but it appears as if the northern and central regions of Namibia are experiencing a later onset and earlier cessation of rains, resulting in shorter seasons in most vicinity. As far as predictions for the future are concerned, it is not obvious whether Namibian rainfall will be reduced, although intensity is likely to be increased (Dirkx et al., 2009).

Namibia climate is favorable for pearl millet cultivation, since it falls in the arid tropics of the world. Pearl millet, commonly known as bulrush millet (*Pennisetum glaucum*), also classified as *P. typhoides*, *P. americanum*, or *P. spicatum*, is a cultivated, small-grain, tropical cereal grass. Vernacular names include: bajra (India), gero (Nigeria, Hausa language), hegni (Niger, Djerma language), sanyo (Mali), dukhon (Sudan, Arabic), and mahangu (Namibia) (Taylor, 2004). Pearl millet originated in western Africa, where the grain developed by natural selection and acquired considerable resistance to a large number of diseases and insects (Gomez and Gupta, 1993). It is cultivated mainly in the semiarid and arid tropics, almost exclusively by subsistence and small-scale commercial farmers (Taylor, 2004). Pearl millet is the most important cereal crop in south Asia and Africa where its grain constitutes the major source of cereals in human diet (Yadav, 2010).

Problem statement

Namibia's climate is highly variable and it is the driest country in sub-Sahara Africa (Dirkx et al., 2008; Brown, 2009; Yadav, 2010). Climate variability is expected to affect crop production hence, the need to investigate the relationship of climate variability and crop production is critical. This is helpful to know whether climate variability has a negative or positive effect to pearl millet production and whether the yield has been increasing or decreasing. Four important points can be drawn from what is known, which give us useful indications of current and potential yield vulnerabilities to climatic situation in Namibia for crop production. First, substantially more model agreement was reported on increases both in average temperatures and also in the intensity and frequency of hot days (Newsham and Thomas, 2009). Second the legitimacy of such concerns is bolstered by evidence from the Southern African region. The impacts of El Niño Southern Oscillation (ENSO) and the North Atlantic Oscillation on agricultural production in Africa, noting that climate models predict global climate change conditions which are more Niño-like in character (Newsham and Thomas, 2009).

Observing the strong association between ENSO trends and Southern Africa, they contend that productivity could be expected to drop by 20 to 50% (Newsham and Thomas, 2009). Third, observed trends in Namibian climate suggest, over the course of the second half of the twentieth century, a shorter growing season characterized by a later arrival of rainfall, an earlier cessation of rainfall, greater intervals between rainy days and, the combination of a shorter rainy season with higher temperatures might impact adversely on crop harvests. Later onset of the rains, the interruption of rains within the growing season and the adverse effects of drought upon soil conditions are all factors which could render crop failure a likely occurrence especially given that the majority of small-scale farmers in the north central Namibia and other regions rely largely on rainfall for their staple crops (Newsham and Thomas, 2009). Fourth, the devastating effects of sudden increases in rainfall intensity have demonstrated five years running, in 2008 to 2012 of severe flood.

It is not known how small-scale crop farmers incorporate their decisions in terms of climate and soil for pearl millet production especially with the increase in drought and flood situation. Much land used for agricultural purposes is already marginal, and seasonal rainfall variability (for example with rain coming in deluges and then long dry spells) as well as quantity obtained in such condition could mean pearl millet yield will no longer be viable. Undertaking such research gave us an insight with regards to how small-scale farmers incorporate their decision into crop production while taking into consideration of climate variability. Farmers do not have good contact with their respective Agricultural Extension Officers thus; farming activities are not well coordinated among them.

Objectives

1. To determine how climate variability conditions affect pearl millet yields over time.
2. To evaluate the traditional land use practices and determines the sustainable production options for pearl millet.

MATERIALS AND METHODS

Study area

Namibia is 824,292 square kilometers (km^2) situated along the southwest Africa coastline of the Atlantic Ocean. The study was conducted in Oshana region, located in the north central Namibia (Figure 1). The north central Namibia is located in the Cuvelai basin system, covering regions such as Oshana, Omusati, Ohangwena and Oshikoto. Oshana region is located in the heart or central area of the Cuvelai system with a complex ephemeral of shallow system and is dominated by flat plain land with a couple of vegetated water channels and that is why it was a target study site. Oshana region has a surface area of 5291 km^2 according to the second delimitation commission of 1998. It shares the border with Ohangwena region to the north, Oshikoto region to the east, Omusati region to the west and Kunene region to the south (ORC, 2011).

Data needs and sources

Fieldwork survey description

A random survey was carried out at Ongwediva and Uukwiyu Uushona constituencies, of which two villages were randomly sampled from each constituency. This was done with the help of constituency councilors, since they are well familiar with the areas. From each village, 15 farmers were interviewed. The survey focused on the small scale crop farmers and the local experts (Agricultural Extension Officers) to tape their knowledge on land use practices and traditional farming methods. This was done by a questionnaire method composed of both structured and semi-structured questions that were prepared for small scale crop farmers and Agricultural Extension Officers in the respective constituencies. The survey took a duration of two week in Omaalala village and Onamutai village (Ongwediva constituency), Onakamwandi village and Onandomba village (Ukwiyu Ushona constituency) to complete the interviews. The sample size of the study was 60 questionnaires in total of which 30 questionnaires

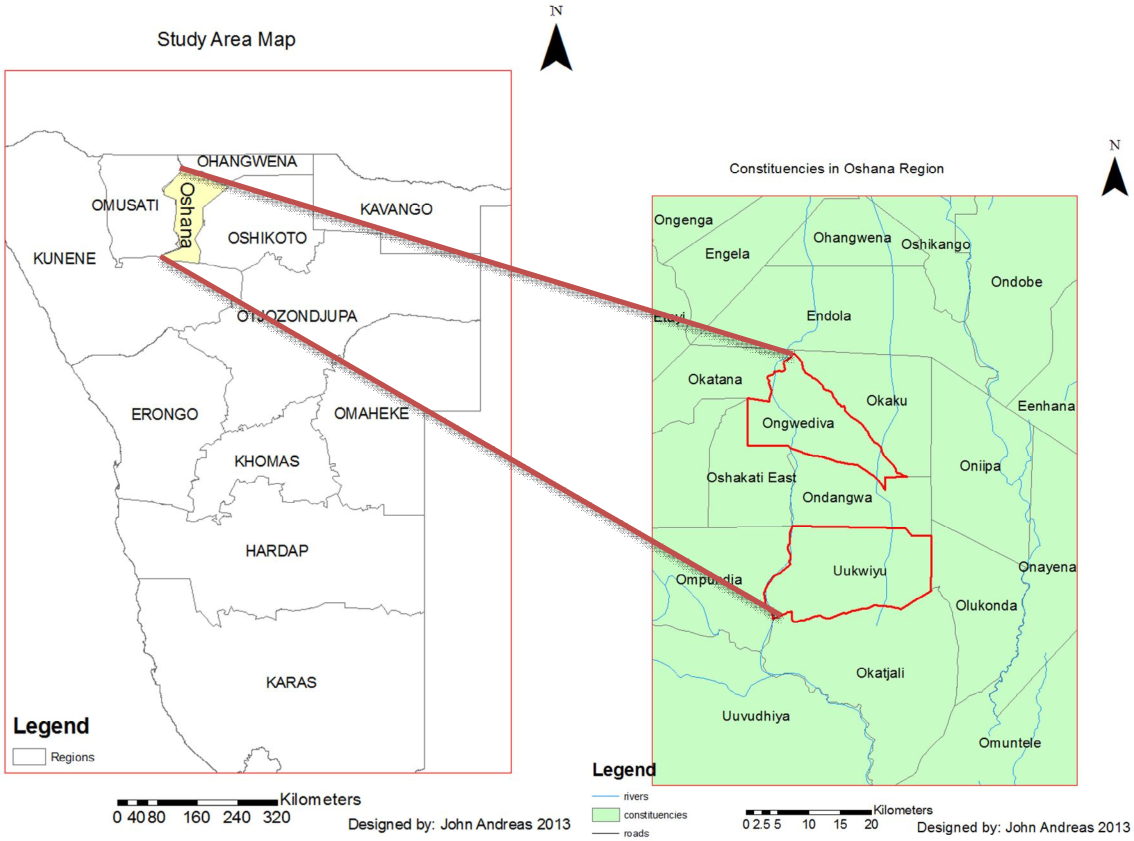


Figure 1. Map of Namibia with Oshana region in light yellow.

were used per constituency. Questions were translated into a vernacular language for better understanding and good communication, since most of the farmers do not speak English. Every individual farmer was interviewed with one questionnaire.

Collected data sources

Long term climate data (2003 to 2012) for Oshana region were obtained from the Namibian Meteorological Services (NMS). The key climate variables of interest were: daily rainfall in millimeter (mm), daily minimum and maximum temperature in degree Celsius (°C), daily relative wind speed in kilometer per day (km/day), daily relative humidity in percentages (%) and daily sunshine in hours per day (h/day). Some of these climate variables were not complete due to ineffective of records. For sunshine data, there was no record from the respective climate station (Ondangwa) therefore only the default data were used. Pearl millet annually yield production data were obtained from the Ministry of Agriculture, Water and Forestry (MAWF) under the division of early warning and disaster planning. There were no categories of millet types nor types of fertilizer applications being used by farmers. All the millet grown in Namibia are under rain-fed conditions. The data obtained were for ten years period as from 2003 to 2012 for Oshana region respectively. The data were used to compare with the precipitation data obtained from the NMS and determine the correlation of annual pearl millet yield with seasonal precipitation of the region. Pearl millet yield data from the field survey was only for a single season (2011/2012) due to lack of record keeping at small scale farming level. Annual yields were determined by using a 20 kilogram (kg) bucket by multiplying it with the total number the farmer filled up the bucket with millet harvests (e.g. 20 kg times 5 or 20).

CropWat for windows 8.0

CropWat for windows 8.0 (FAO 1998) was used for the simulation of effective rainfall, reference evapotranspiration, crop water requirement and yield reduction for pearl millet in Oshana region. The climate data used were that of Ondangwa climate station in Oshana region since this is the only current operational climate station in the region. CropWat was restricted for rain-fed schedule, based on annual practices of pearl millet and its planting dates. To calculate effective rainfall, reference evapotranspiration and crop water requirements in CropWat for windows 8.0, requires certain climatologically and physical parameter. Hence, the following climate data were utilized to feed the inlay form of the software: rainfall data millimetre (mm), minimum and maximum temperature degree Celsius (°C), relative humidity percentages (%), relative wind speed kilometre per day (km/day) and sunshine hours (h). Crop parameter required as input data in the model which include crop coefficient (Kc) were assumed to be default data in the CropWat model. The sole parameter entered into the model was only planting dates for pearl millet in the region according to the crop calendar of north central Namibia. Soil parameter that determine total available soil moisture and rainfall infiltration rate was also assumed to be default data for the CropWat model.

To calculate the total rain and effective rain, a method of USDA Soil Conservation services was used in CropWat for windows 8.0

(FAO, 1998). This method assumes that, the crop can use almost 60 to 80% of precipitation up to 250 mm per month. Over 250 mm per month, the crop benefit only about 10% of the total precipitation or in other words as precipitation increases, its efficiency decreases (Darshana Pandey et al., 2012). The Calculation of Crop Water Requirements (CWR) can be carried out by calling up successively the appropriate climate and rainfall data sets together with crop files and the corresponding planting dates. In this case CWR was only possible for the following years: 2007 and 2009 whereby the climate and rainfall data were successive. The Reference Evapotranspiration (ETo) represents the potential evaporation of a well-watered grass crop and the water needs of other crops are directly linked to this climatic parameter. The daily Reference Evapotranspiration (ETo) was calculated by using Penman Monteith method.

Irrigation scheduling is one of the very important elements of CropWat 8.0 with many several application possibilities (FAO, 1998). In this case, its application was based on the evaluation of pearl millet yield production under rain-fed conditions. The calculation of daily moisture balance is based on the soil water budget, where, on a daily basis, the soil moisture status is determined, accounting for incoming and outgoing water in the root zone of pearl millet. Pearl millet yield reduction was determined through the irrigation scheduling calculations. This calculation was done based on climate data/ETo, rainfall, crop and soil, but most of the data were not available especially for ETo, therefore only few where possible to get the results.

RESULTS

Monthly seasonal rainfall variation

Table 1 presents the monthly rainfall summary for each rainfall season. The rainfall season of 2003/2004 recorded the highest monthly rainfall of 179 mm that was in March and the lowest monthly rainfall recorded was 15.8 mm in October. Rainfall for this season was recorded in October until April with much rainfall recorded between December and March and this makes a total of 7 months rainfall period. In 2004/2005 rainfall season, the highest monthly rainfall of 154.7 mm was recorded in January and the lowest monthly rainfall was 1.7 mm in December. Rainfall for 2004/2005 seasons was recorded in October until February and this makes a total of 5 month rainfall period. A total of 240 mm of monthly rainfall was recorded in January as the highest in 2005/2006 rainfall season. The lowest monthly rainfall recorded for the season was in November with 1 mm. Rainfall for 2005/2006 season was recorded in October until April with much rainfall recorded in January to March, with a length of 7 month rainfall period. The 2006/2007 rainfall season recorded the highest monthly rainfall of 100.2 mm in January and the lowest monthly rainfall recorded was 6.3 mm in May. Rainfall was recorded in October until May and this makes a total of 8 month of rainfall period.

In 2007/2008 rainfall season, the highest monthly rainfall recorded in Oshana region was 195.5 mm in January and the lowest monthly rainfall was 1.5 mm in May. Rainfall was recorded in October until May with much rainfall recorded in January to March and this took a length of 8 month rainfall period. The rainfall season of 2008/2009, recorded the highest monthly rainfall of 378.4 mm that was in February while the lowest monthly rainfall recorded was 7.6 mm in April. The rainfall was recorded in November until April, takes a total of 6 month rainfall period. The rainfall season of 2009/2010, recorded the highest monthly rainfall of 165.4 mm in January and the lowest monthly rainfall was 0.4 mm in April. Rainfall for 2009/2010 season was recorded in September until April, with a length 8 month of rainfall period. In 2010/2011 rainfall season, the highest monthly rainfall recorded was 248.2 mm in March while the lowest monthly rainfall recorded was 0.4 mm in May. Rainfall was recorded in November until May with much rainfall recorded in January to March, takes a total of 7 month rainfall period. The rainfall season of 2011/2012, recorded a highest monthly rainfall of 170.8 mm in January while the lowest monthly rainfall was 0.6 mm in October. Rainfall was recorded in October until April with much rainfall recorded in December to March brings it to a total of 7 month rainfall period.

Annual reference evapotranspiration (ETo)

The altitude of Ondangwa station is 1081 m, latitude is 17.55 S and longitude 15.55 E. In 2003 there were no climate records for January, February and May. The average ETo for Oshana region in 2003 was 40.28 mm/day while average radiation was 21.4 MJ/m^2/day. The average monthly minimum temperature 15.8 °C, maximum temperature was 31.5 °C, relative humidity 37%, relative wind speed 110 km/day and sunshine 9.2 h (Figure 2). Monthly ETo increases towards the summer season and decreases towards winter season. Monthly temperatures were high during summer and low in winter while humidity was also high in summer and low in winter. Namibia receives more sunshine in summer time and less sunshine in winter.

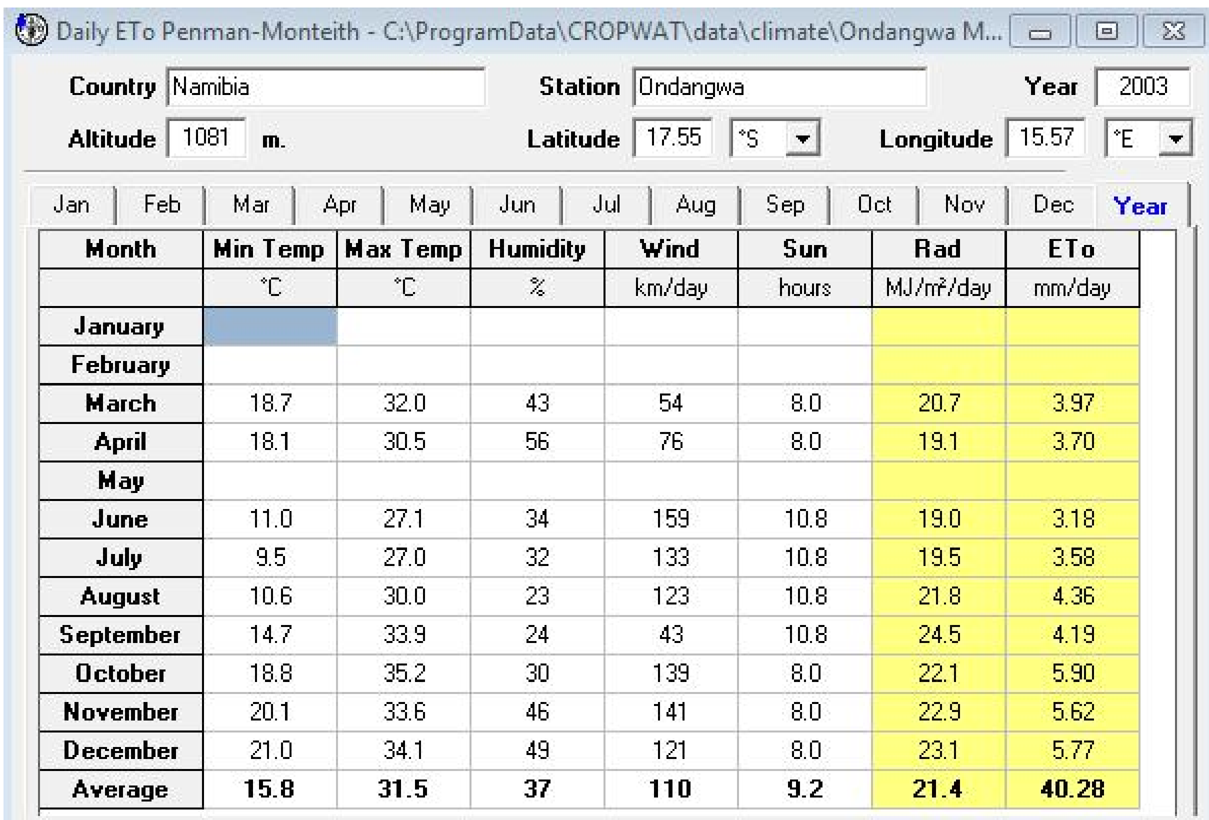
In 2004, there was no relative wind speed and sunshine data recorded as from September until December and the average monthly ETo was 34.32 mm/day and radiation 20.4 MJ/m^2/day. The average monthly minimum temperature 16.1°C, maximum temperature was 30.8°C, relative humidity 41%, relative wind speed 117 km/day and sunshine 9.1 h. Monthly ETo was high in summer and low in winter (Figure 3).

In 2005, certain climate data were missing and it was not possible to calculate the ETo for the region. It was only minimum and maximum temperature and relative humidity data that were inputted into CropWat makes it impossible to get the results for ETo. Minimum and maximum temperature for March, April and October were also not recorded as well as relative humidity for the same months. Without all these data, the average temperature were; minimum 16°C, maximum 31.9°C and relative humidity 17% (Figure 4).

The year 2006, all climate data were recorded for the

Table 1. Oshana region monthly seasonal rainfall summary.

Season \ Month	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
2003 - 2004	0	0	0	15.8	16.9	103.9	153.5	103.3	179	33	0	0
2004 - 2005	0	0	0	30.2	136.6	1.7	154.7	93	0	0	0	0
2005 - 2006	0	0	0	6.5	1	39.2	240.0	132	135	53.9	0	0
2006 - 2007	0	0	0	80.1	23.3	10.9	100.2	48.7	78.6	24.3	6.3	0
2007 - 2008	0	0	0	11.8	24.7	5	195.5	177.5	164.2	2.6	1.5	0
2008 - 2009	0	0	0	0	73.4	77.5	213.2	378.4	94.4	7.6	0	0
2009 - 2010	0	0	10.3	21.3	58	39	165.4	97.5	73.7	0.4	0	0
2010 - 2011	0	0	0	0	119.7	85.4	221.1	241.4	248.2	81.8	0.4	0
2011 - 2012	0	0	0	0.6	18.3	101.8	170.8	135	96.5	1	0	0



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Country Namibia Station Ondangwa Year 2003

Altitude 1081 m. Latitude 17.55 °S Longitude 15.57 °E

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Year

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January							
February							
March	18.7	32.0	43	54	8.0	20.7	3.97
April	18.1	30.5	56	76	8.0	19.1	3.70
May							
June	11.0	27.1	34	159	10.8	19.0	3.18
July	9.5	27.0	32	133	10.8	19.5	3.58
August	10.6	30.0	23	123	10.8	21.8	4.36
September	14.7	33.9	24	43	10.8	24.5	4.19
October	18.8	35.2	30	139	8.0	22.1	5.90
November	20.1	33.6	46	141	8.0	22.9	5.62
December	21.0	34.1	49	121	8.0	23.1	5.77
Average	**15.8**	**31.5**	**37**	**110**	**9.2**	**21.4**	**40.28**

Figure 2. Oshana region ETo 2003.

month of November and December and the rest of the months were without relative wind speed and sunshine data. The average monthly ETo for 2006 based on a two month data calculation was 11.89 mm/day, radiation 23 MJ/m^2/day, average relative wind speed 152 km/day and sunshine 8 h. The average monthly temperature was; minimum 15.2 °C, maximum 29.8 °C, and the average monthly relative humidity was 32% (Figure 5).

In 2007, the average monthly ETo recorded was 65.51 mm/day, radiation 21.3 MJ/m^2/day, minimum temperature 16.7°C, maximum temperature 33.1°C, relative humidity 40%, relative wind speed 157 km/day and sunshine 8.9 h. The monthly ETo has been increasing from the beginning of the summer season and decreases towards the end of the season. Monthly humidity was high in summer and lower in winter (Figure 6).

The year 2008 had some data also not recorded for some months and these were variables such as relative humidity and sunshine. Therefore the average monthly ETo and radiation calculated was based on a two month successive data available. The average monthly ETo was 10.54 mm/day, radiation 22.2 MJ/m^2/day, relative

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Country: Namibia Station: Ondangwa Year: 2004

Altitude: 1081 m. Latitude: 17.55 °S Longitude: 15.57 °E

Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	20.7	30.3	67	48	8.0	23.1	4.91
February	20.0	30.6	64	84	8.0	22.7	4.81
March	19.7	30.3	70	58	8.0	21.4	4.27
April	17.3	29.9	63	120	8.0	19.1	4.12
May	12.1	27.8	44	231	8.0	16.8	4.51
June	9.3	25.7	39	128	10.8	18.9	3.43
July	9.2	26.3	29	159	10.8	19.5	3.88
August	12.9	31.7	21	107	10.8	21.8	4.38
September	14.6	33.8	16				
October	18.3	34.6	34				
November	19.8	33.3	26				
December	19.0	35.4	16				
Average	**16.1**	**30.8**	**41**	**117**	**9.1**	**20.4**	**34.32**

Figure 3. Oshana region ETo 2004.

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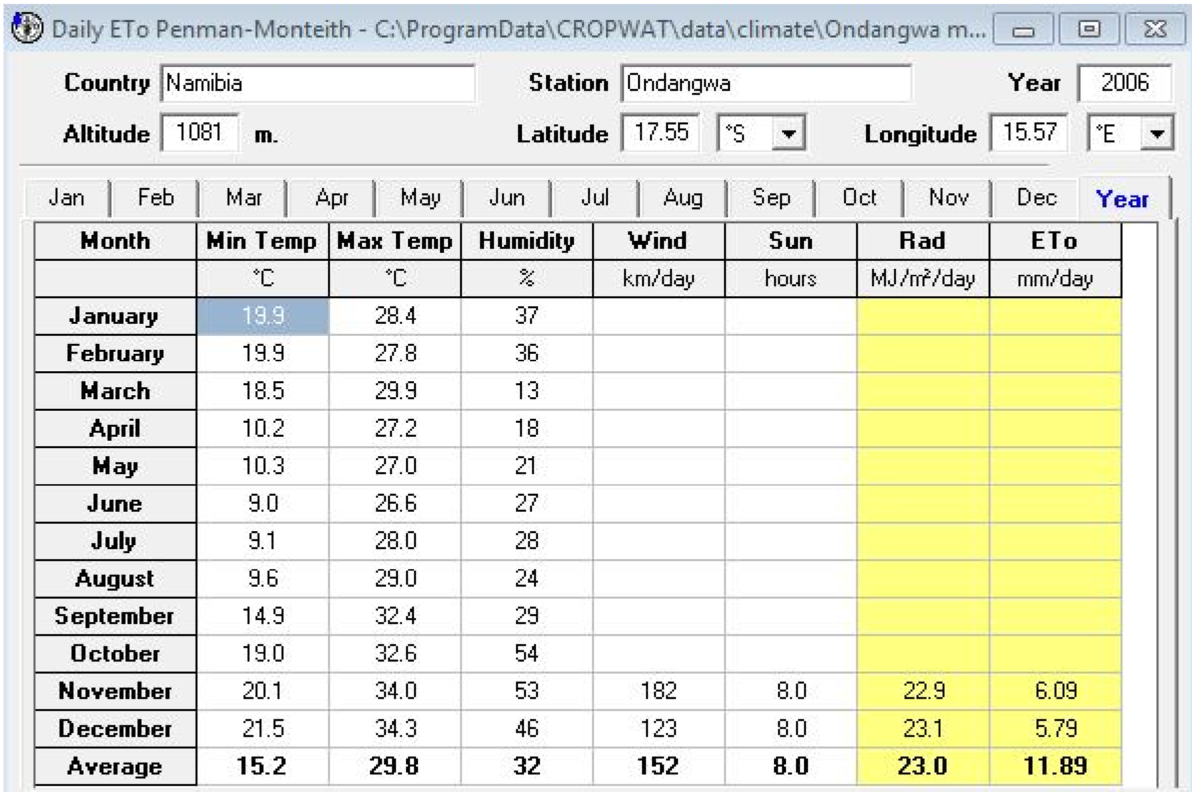
Country: Namibia Station: Ondangwa Year: 2005

Altitude: 1081 m. Latitude: 17.55 °S Longitude: 15.57 °E

Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	20.6	31.7	34				
February	20.4	31.1	45				
March							
April							
May	14.0	31.1	10				
June	10.9	28.8	9				
July	10.3	27.7	7				
August	11.5	30.2					
September	15.0	33.9	6				
October							
November	20.9	36.5	12				
December	20.6	35.8	14				
Average	**16.0**	**31.9**	**17**				

Figure 4. Oshana region ETo 2005.



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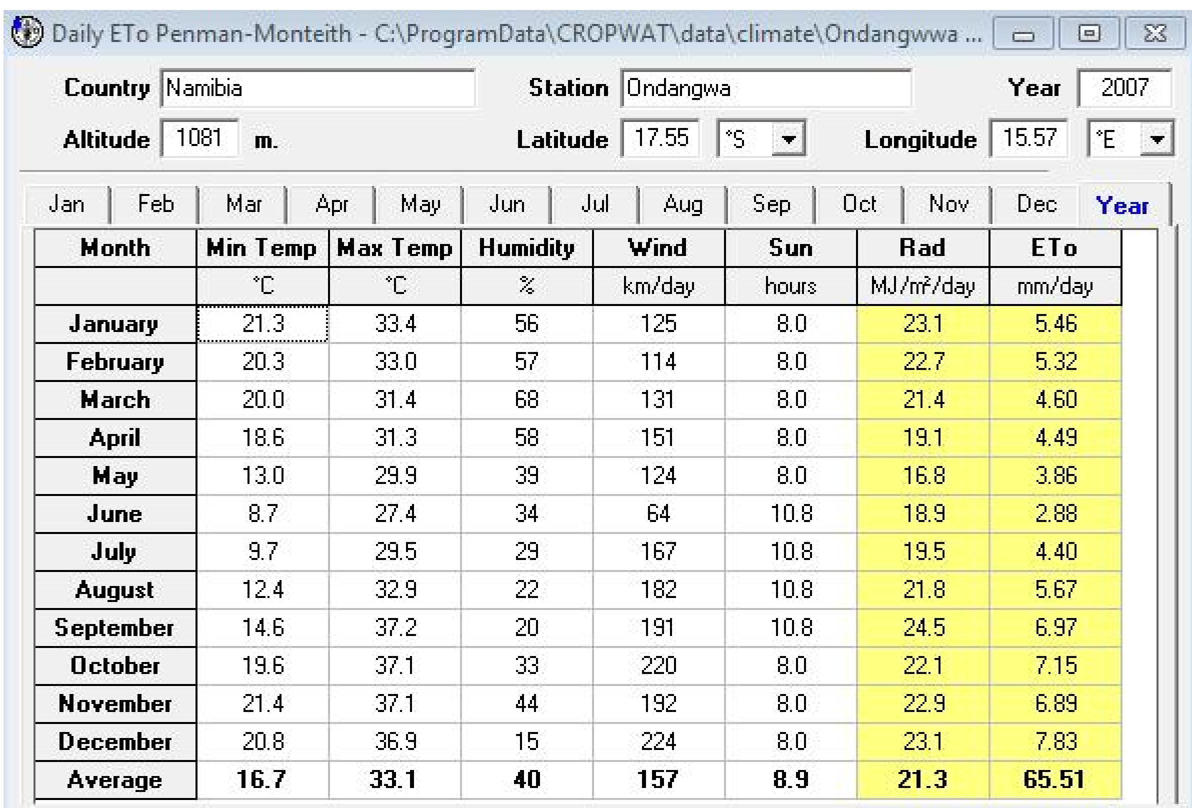
Country: Namibia | Station: Ondangwa | Year: 2006

Altitude: 1081 m. | Latitude: 17.55 °S | Longitude: 15.57 °E

Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	19.9	28.4	37				
February	19.9	27.8	36				
March	18.5	29.9	13				
April	10.2	27.2	18				
May	10.3	27.0	21				
June	9.0	26.6	27				
July	9.1	28.0	28				
August	9.6	29.0	24				
September	14.9	32.4	29				
October	19.0	32.6	54				
November	20.1	34.0	53	182	8.0	22.9	6.09
December	21.5	34.3	46	123	8.0	23.1	5.79
Average	**15.2**	**29.8**	**32**	**152**	**8.0**	**23.0**	**11.89**

Figure 5. Oshana region ETo 2006.



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Country: Namibia | Station: Ondangwa | Year: 2007

Altitude: 1081 m. | Latitude: 17.55 °S | Longitude: 15.57 °E

Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	21.3	33.4	56	125	8.0	23.1	5.46
February	20.3	33.0	57	114	8.0	22.7	5.32
March	20.0	31.4	68	131	8.0	21.4	4.60
April	18.6	31.3	58	151	8.0	19.1	4.49
May	13.0	29.9	39	124	8.0	16.8	3.86
June	8.7	27.4	34	64	10.8	18.9	2.88
July	9.7	29.5	29	167	10.8	19.5	4.40
August	12.4	32.9	22	182	10.8	21.8	5.67
September	14.6	37.2	20	191	10.8	24.5	6.97
October	19.6	37.1	33	220	8.0	22.1	7.15
November	21.4	37.1	44	192	8.0	22.9	6.89
December	20.8	36.9	15	224	8.0	23.1	7.83
Average	**16.7**	**33.1**	**40**	**157**	**8.9**	**21.3**	**65.51**

Figure 6. Oshana region ETo 2007.

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Country Namibia Station Ondangwa Year 2008

Altitude 1081 m. Latitude 17.55 °S Longitude 15.57 °E

Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	21.9	32.9		231	8.0		
February	20.7	29.7		185	8.0		
March	20.1	29.4	71	192	8.0	21.4	4.81
April	16.2	31.6		164	8.0		
May	13.3	31.1		121	8.0		
June	9.3	28.5		178	8.0		
July	9.3	28.6		175			
August	12.2	32.2		178			
September	14.6	37.2		182			
October	20.2	38.4		199			
November	20.9	34.7		186			
December	20.5	32.3	68	211	8.0	23.1	5.73
Average	**16.6**	**32.2**	**69**	**183**	**8.0**	**22.2**	**10.54**

Figure 7. Oshana region ETo 2008.

humidity 69%, and sunshine 8 h. The average monthly temperature was: minimum 16.6°C, maximum 32.2 °C and relative wind speed 183 km/day. Monthly temperatures were high during summer and low in winter season (Figure 7).

In 2009, the following data were not recorded for August; relative humidity, relative wind speed and sunshine. The monthly average ETo was 55.33 mm/day, radiation 21.3 MJ/m^2/day, minimum temperature 16.9°C, maximum temperature 32.6°C, relative humidity 65%, relative wind speed 170 km/day and sunshine 8.8 h (Figure 8). Monthly ETo increased at the beginning of the summer season and decreased towards the end of the season. Monthly humidity shows an uneven distribution while temperatures were high in summer and low in winter.

In 2010, relative humidity for October and maximum temperature for March were not recorded. The average monthly ETo was 50.22 mm/day, radiation 21.3 MJ/m^2/day, minimum temperature 16.4°C, maximum temperature 32.7°C, relative humidity 57%, relative wind speed 171 km/day and sunshine 8.9 h (Figure 9). Monthly ETo was very low in winter and high in summer. The monthly humidity decreases at the end of summer season and increases at the end of winter season.

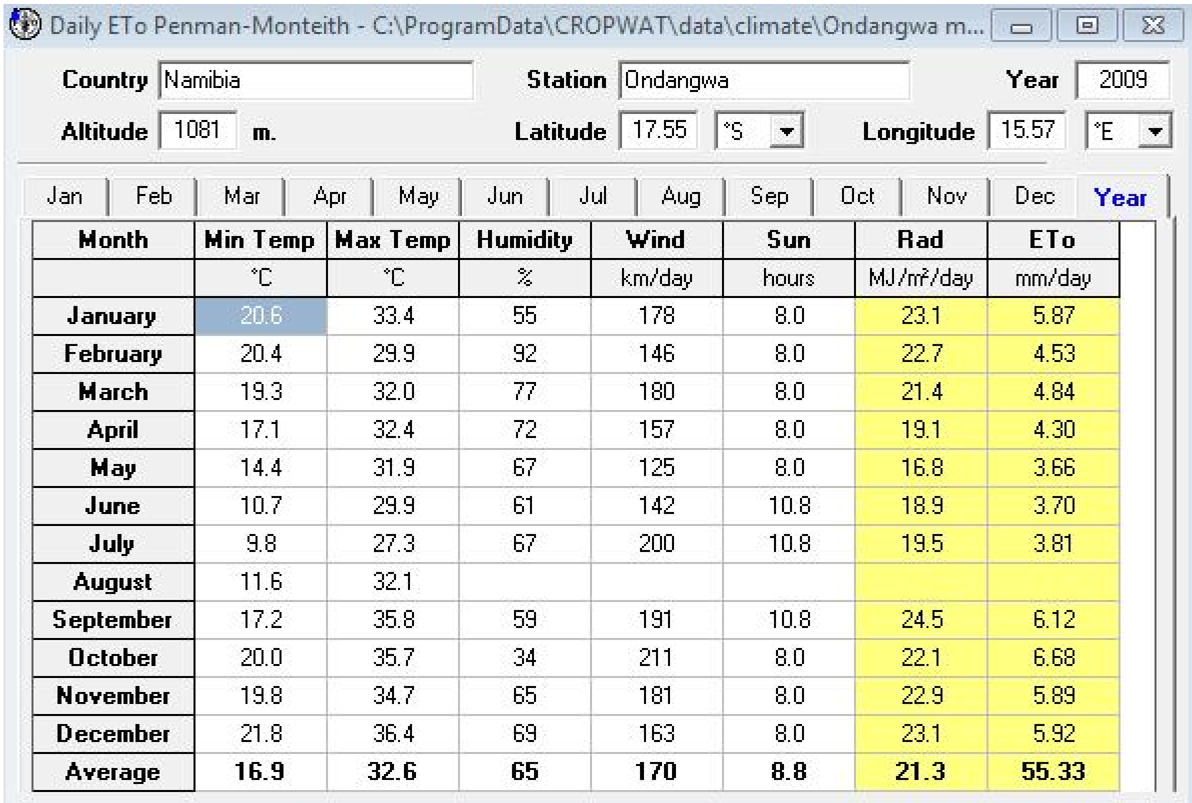
In 2011, the average monthly ETo was 66.50 mm/day, radiation 21.3 MJ/m^2/day, minimum temperature 15.6°C, maximum temperature 31.5°C, relative humidity 43%, relative wind speed 190 km/day and sunshine 8.9 h (Figure 10). Monthly ETo was very high at the beginning of the summer season and declined towards winter time. Monthly temperatures were high during summer months and low in winter time. Humidity declined from May to October while wind speed was high in winter time and low in summer.

In 2012, monthly minimum and maximum temperature for October, November and December were not recorded. The average monthly ETo for the year was 44.10 mm/day, radiation 20.9 MJ/m^2/day, minimum temperature 14.5°C, maximum temperature 31.6°C, relative humidity 38%, relative wind speed 157 km/day and sunshine 8.9 h (Figure 11). Monthly ETo increases in summer months and decreases in winter months and this is linked to monthly temperatures. Monthly humidity was low in winter and high in summer months while wind speed was low in winter and high in summer.

Pearl millet yields

Pearl millet yields from the fieldwork survey

The figure below shows pearl millet yields for Oshana region 2011/2012 rainfall season only, this is due to lack



Daily ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\Ondangwa m...

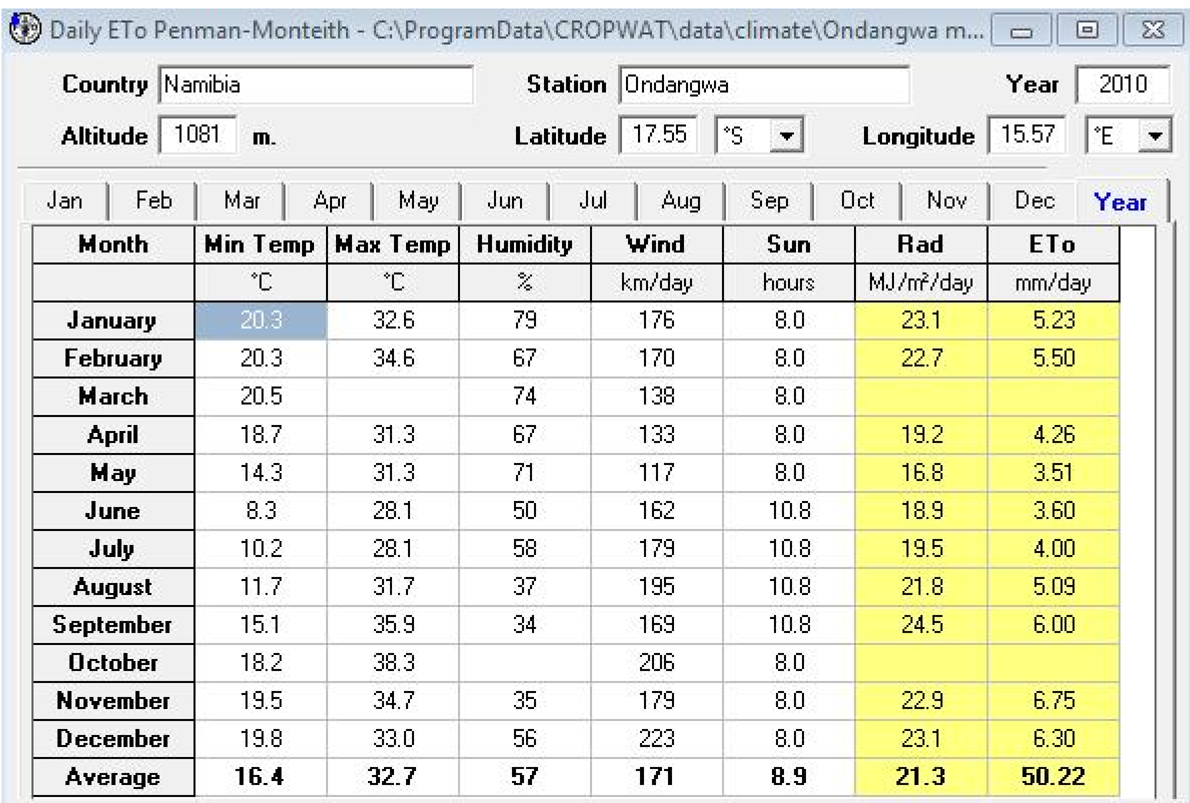
Country: Namibia | Station: Ondangwa | Year: 2009

Altitude: 1081 m. | Latitude: 17.55 °S | Longitude: 15.57 °E

Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	20.6	33.4	55	178	8.0	23.1	5.87
February	20.4	29.9	92	146	8.0	22.7	4.53
March	19.3	32.0	77	180	8.0	21.4	4.84
April	17.1	32.4	72	157	8.0	19.1	4.30
May	14.4	31.9	67	125	8.0	16.8	3.66
June	10.7	29.9	61	142	10.8	18.9	3.70
July	9.8	27.3	67	200	10.8	19.5	3.81
August	11.6	32.1					
September	17.2	35.8	59	191	10.8	24.5	6.12
October	20.0	35.7	34	211	8.0	22.1	6.68
November	19.8	34.7	65	181	8.0	22.9	5.89
December	21.8	36.4	69	163	8.0	23.1	5.92
Average	**16.9**	**32.6**	**65**	**170**	**8.8**	**21.3**	**55.33**

Figure 8. Oshana region ETo 2009.



Daily ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\Ondangwa m...

Country: Namibia | Station: Ondangwa | Year: 2010

Altitude: 1081 m. | Latitude: 17.55 °S | Longitude: 15.57 °E

Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	20.3	32.6	79	176	8.0	23.1	5.23
February	20.3	34.6	67	170	8.0	22.7	5.50
March	20.5		74	138	8.0		
April	18.7	31.3	67	133	8.0	19.2	4.26
May	14.3	31.3	71	117	8.0	16.8	3.51
June	8.3	28.1	50	162	10.8	18.9	3.60
July	10.2	28.1	58	179	10.8	19.5	4.00
August	11.7	31.7	37	195	10.8	21.8	5.09
September	15.1	35.9	34	169	10.8	24.5	6.00
October	18.2	38.3		206	8.0		
November	19.5	34.7	35	179	8.0	22.9	6.75
December	19.8	33.0	56	223	8.0	23.1	6.30
Average	**16.4**	**32.7**	**57**	**171**	**8.9**	**21.3**	**50.22**

Figure 9. Oshana region ETo 2010.

Daily ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\Ondangwa m...

Country: Namibia | Station: Ondangwa | Year: 2011

Altitude: 1081 m. | Latitude: 17.55 °S | Longitude: 15.57 °E

Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	19.5	29.4	64	130	7.5	23.1	5.11
February	19.1	30.7	65	162	8.0	22.7	5.18
March	19.4	29.9	64	193	8.0	21.4	5.05
April	18.3	31.1	65	208	8.0	19.1	4.61
May	13.1	30.3	51	203	8.0	16.8	4.40
June	8.0	27.9	30	194	10.8	18.9	4.55
July	7.7	27.5	36	182	10.8	19.5	4.35
August	10.0	31.4	27	192	10.8	21.8	5.58
September	15.0	36.2	18	204	10.8	24.5	7.12
October	17.4	35.8	22	220	8.0	22.1	7.43
November	20.1	35.7	30	206	8.0	22.9	7.11
December	19.7	32.0	48	183	8.0	23.1	6.02
Average	**15.6**	**31.5**	**43**	**190**	**8.9**	**21.3**	**66.50**

Figure 10. Oshana region ETo 2011.

Daily ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\Ondangwa m...

Country: Namibia | Station: Ondangwa | Year: 2012

Altitude: 1081 m. | Latitude: 17.55 °S | Longitude: 15.57 °E

Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	20.6	32.2	53	181	8.0	23.1	5.83
February	19.5	31.1	63	174	8.0	22.7	5.39
March	19.2	31.5	56	148	8.0	21.4	5.04
April	16.4	32.5	47	137	8.0	19.1	4.64
May	11.9	31.1	35	137	8.0	16.8	4.14
June	8.1	28.6	32	147	10.8	18.9	3.97
July	8.1	28.3	25	158	10.8	19.4	4.29
August	12.3	32.9	23	128	10.8	21.8	4.90
September	14.5	36.0	14	119	10.8	24.6	5.89
October			17	171	8.0		
November			39	210	8.0		
December			48	174	8.0		
Average	**14.5**	**31.6**	**38**	**157**	**8.9**	**20.9**	**44.10**

Figure 11. Oshana region ETo 2012.

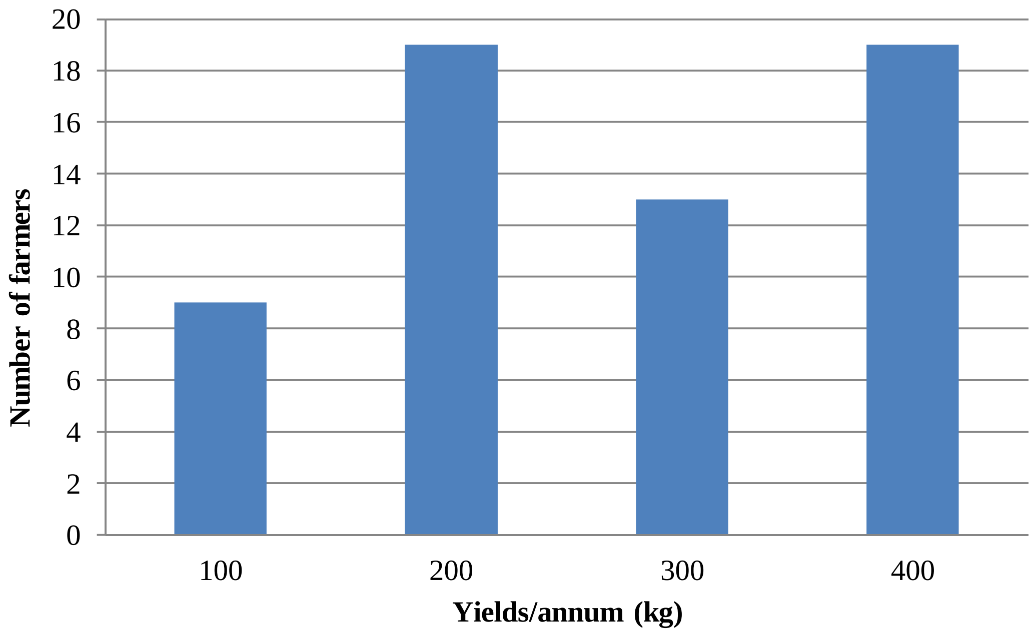


Figure 12. Pearl millet yields (2011/2012 season) for Oshana region.

of record keeping on small scale farming level and farmers could not provide yields for other past years. In Figure 12, 19 (32 %) of the farmers had a yield capacity of less than 200 kilogram per annum (kg/a), another 19 (32 %) of the farmers had a yield capacity of more than 300 kg/a. It also shows that, 13 (21 %) of the farmers had a yield less than 300 kg/a while 9 (15 %) of the farmers had a harvest less than 100 kg/a.

Long-term pearl millet yield data from the Ministry of Agriculture, Water and Forestry (MAWF)

The largest portion of crop fields cultivated in Oshana region was 35568 ha of land for 2009/2010 growing season, with a yield of 330 kg/ha. The highest recorded pearl millet yield for the region was 407 kg/ha with a total of 29788 ha cultivated land for 2005/2006 growing season. The lowest yield recorded was 119 kg/ha with a total of 34457 ha of land cultivated for 2010/2011 growing season (Table 2).

Table 2. Oshana region pearl millet seasonal production yield.

Crop seasons	hectares	Yield production (kg/ha)
2003/2004	24700	361
2004/2005	23218	336
2005/2006	29788	407
2006/2007	22230	245
2007/2008	32684	147
2008/2009	35250	145
2009/2010	35568	330
2010/2011	34457	119
2011/2012	33345	343

Trends of pearl millet yields under climate variability

The simulated yield reduction data were only possible for 2006/2007 and 2008/2009 crop seasons (Table 3). The actual pearl millet yield indicates a nonlinear trend from season to season and this has a correlation with the seasonal variability of average temperatures and precipitation in Oshana region. The yield reduction for pearl millet based on farmers' planting date (30th November) shows a high percentages of reduction compared to the yield reduction based on the simulated planting date CropWat scenario (that is, 25th December). The crop season of 2006/2007 has a yield reduction difference of 16.8% while 2008/2009 season has a yield reduction difference of 4.9% respectively.

DISCUSSION

Seasonal rainfall

Oshana region annual rainfall is very variable and unpredictable, with late arrival and early cessation in most cases. Farmers find it very difficult to start preparing for crop field cultivation. Monthly rainfall distributions vary from season to season with some season with a maximum length of 8 months rainfall period and some with 5 month rainfall period. The normal duration of

Table 3. Oshana region pearl millet yield trends under climate variability.

Seasons	Average rainfall (mm)	Average temperatures (°C)		Actual yields (kg/ha)	Yield reduction based on planting date by farmer 30th November (%)	Yield reduction based on planting date by CropWat scenario 25th December (%)	Difference of yield reduction (%)
		Min.	Max.				
2003/04	50.5	16.1	30.8	361	0	0	0
2004/05	34.7	16.0	31.9	336	0	0	0
2005/06	50.6	15.2	29.8	407	0	0	0
2006/07	31.0	16.7	33.1	245	44.8	28	16.8
2007/08	48.6	16.6	32.2	147	0	0	0
2008/09	70.4	16.9	32.6	145	18.6	13.7	4.9
2009/10	38.8	16.4	32.7	330	0	0	0
2010/11	83.2	15.6	31.5	119	0	0	0
2011/12	43.7	14.5	31.6	343	0	0	0

summer season in Namibia is approximately 7 month period (October to April). The highest monthly rainfall was recorded in 2008/2009 season with the lowest in 2006/2007 season. The duration of rainfall period in 2008/2009 season was 6 month from November to April and in 2006/2007 season was 8 month from October to May. The highest annual rainfall was also recorded in 2009 compared to all the years. 2009 had a rainfall length of 8 month from September to April with much rainfall received during the month of January to March. Meanwhile the highest seasonal rainfall was recorded in 2010/2011 with a rainfall length of 7 month with more rainfall received in January to March. 2008/2009 and 2010/2011 seasons recorded an average rainfall above normal in the second part of the seasons and this has contributed to waterlogging and totally submerging of most crop fields (NEWFIU, 2011).

Annual reference evapotranspiration (ETo)

In 2005, there was no ETo result due to lack of climate data and in some years, only certain months were fully recorded. This makes it impossible to calculate ETo for the whole period of 10 years. The highest Average ETo was recorded in 2011 and the lowest was in 2008. Average maximum temperature for 2011 was at 31.5°C and in 2008, the average maximum temperature was at 32.2°C. By looking at the average maximum temperature, 2008 had high temperature than 2011, the question now is, if the ETo for 2008 was calculated on a 12 month basis like in 2011 rather than 2 month, could it be high than that of 2011? The year 2007 recorded the highest average maximum temperature and the lowest was in 2006. 2007 was the hottest year on record compared to other years. According to NEWFIU (2009) report, drought condition was experienced in the region in 2007. The year 2011 was more humid than 2007 and it had high wind speed in comparison as well. Humidity and wind speed increases during summer time and decreases in winter time with more sunshine hours in winter and diminish in summer.

Pearl millet yields

It is very difficult to get the yield harvests for each year at small scale farming level because farmers do not keep records for their harvests. Therefore, only the last harvests (2011/2012) were possible of which farmers could only remember and estimate the yields objectively. Pearl millet reserves in the region are weakened by the drought in 2006/2007 and the flood for the past consecutive three years (NEWFIU, 2009). The majority of the farmers produced yields less than 15 bags of 20 kg per annum but normally they produce more or less 20 bags per season. Farmers claimed that what they had produced is not enough to feed their families up to the next season and what they had in storage can only last until July to August (NEWFIU, 2012). In most cases, farmers supplement their harvests with the market purchases to prolong the availability of their harvests to the next season. Oshana regional annual data from the MAWF indicated a decrease in pearl millet yields as from 2006/2007 to 2008/2009 and 2010/2011seasons, but the production rose up in 2009/2010 and 2011/2012 seasons.

The region has experienced frequent severe floods in 2007/2008 to 2008/2009 and 2010/2011. All 10 constituencies in Oshana region were affected by the flood in 2010/2011 rainfall season and mainly had very poor harvests. Flood situation in the region has affected the crop yields, because years without flood indicated better yields than those with flood. In 2010/2011 season, Oshana region pearl millet production prospect was reduced by 65% (NEWFIU, 2011). Poor harvests in the north central regions came as a result of floods and heavy rains received during 2007/2008, 2008/2009 and 2010/2011 seasons (NEWFIU, 2009). The highest seasonal pearl millet yield in Oshana region was recorded in 2005/2006 season while the lowest pearl millet yield recorded was in 2010/2011 rainfall season with more hectares of crop field cultivated than in 2005/2006 season. 2010/2011 season was heavily flooded and more people were located to high land in the region (ORC, 2011). Most of the crop fields were waterlogged and some were completely submerged by continuous heavy rainfall and flood in 2010/2011 season (NEWFIU, 2011). 2009/2010 season had more hectares of land cultivated than other seasons but its pearl millet yield was lower than that of 2003/2004, 2004/2005, 2005/2006 and 2011/2012 seasons.

The lowest land cultivated in hectares was recorded in the season of 2006/2007. The result shows that, pearl millet production yield does not depend on the amount of hectares of cultivated land, because in 2009/2010, pearl millet yield was lower than that of 2005/2006 season of which a big portion of land was cultivated. There are four different types of pearl millet cultivars in Namibia and they are: Kantana cultivar (traditional/Egypt mahangu) with a longer growing length to reach maturity, Kangala cultivar, Okashana1 and Okashana2 cultivars both has a shorter growing length compared to Kantana cultivar. Many farmers in Oshana region prefer planting Kantana cultivar instead of other cultivars and this is linked to various personal reasons. Some farmers narrated that Kantana cultivar has a good taste unlike other cultivars, it can be stored in basket storage for a longer period without deterioration and its stalk residue is thick, tall and good for house building. Few farmers intercrop Kantana cultivar with other cultivars especially Okashan1&2 but this create competition of nutrients among them and give poor yields. Some farmers claimed that, the other cultivars' seed available at the extension offices are for sale; hence they cannot afford the market price which is N$8.00 (0.8 euro) per seed bag of 2 kg.

CONCLUSION AND RECOMMENDATIONS

Climate variability contributed significantly to pearl millet yields in Oshana region for the past ten years. There has been a notification of increases in daily temperature and unevenly distribution of rainfall over the region during summer time with an average maximum temperature of 33.1°C. Increases in annual average temperature could also lead to high rate of evapotranspiration and this has been predicted already that, in Namibia, even if rainfall changes little from present levels, the water balance is expected to become drier because of an increase in evaporation rates due to temperature increases. An increase in evaporation of about 5 per cent is expected per degree of warming (Reid et al., 2007). Pearl millet yield production is fluctuating anomaly or to say inconsistently and this has a correlation with climate variation of every single rainfall season. Both rainfall and temperature in Namibia are sensitive to the El Niño-Southern Oscillation (ENSO) effect, and rainfall is below average during El Niño conditions. Rainfall in the future is projected to become even more variable than at present (Reid et al., 2007). From the field observations, more crop fields are located in flood prone areas and this makes it easy for water to flood the crop fields when too much rain is received.

Pearl millet is a rain-fed, dry crop type and it does not grow well in waterlogged soils, contributing to low yields under flood conditions. The projected CropWat planting date scenario indicated low yield reduction; hence it is advisable for farmers in Oshana region to start sowing on the 25th December every season. Farmers should at least make use of both pearl millet available cultivars through intercropping, one with long duration to reach maturity and the other one with short duration to reach maturity depending on the climate situation. Alternative crop varieties e.g. cassava and rice will also be a possible solution to climate change adaptation. This alternative will enhance diversification of pearl millet cultivars within a crop field to adapt with climate scenarios. Diversified cultivar systems, enhancing precision of seasonal climate predictions and strengthening seed availability of diverse varieties would aid farmers in their tactical choices of crops and cultivars to maximize production in each cropping season (Haussmann et al., 2012). The Namibian government should increase the cultivation tractor subsidy services in the regions. A method of developing variety types of pearl millet cultivars with high degrees of heterozygosity and genetic heterogeneity for adaptation traits will help achieving better individual and population buffering capacity in pearl millet. Traits that potentially enhance adaptive phenotypic plasticity or yield stability in variable climates include photoperiod-sensitive flowering, plastic tillering, flooding tolerance, seedling heat tolerance and phosphorus efficiency. The development of heterozygous and/or heterogeneous cultivars is, therefore, one option to enhance the cultivar's capacity for buffering against climate variability (Haussmann et al., 2012).

Crop improvement alone cannot produce miracles; therefore the development of new improved and climate-proof cultivars must go hand in hand with sustainable soil fertility management and water conservation and drainage techniques if possible (Haussmann et al., 2012). More researches and development on pearl millet seed varieties and cultivar adaptability to climate variability in Namibia should be conducted to improve farmer's pearl millet yield production. Farmers training and awareness on climate scenarios should be conducted in communal areas all over the country. Key elements for enhancing farmers' capacity to contribute to and benefit from research and development undertakings include the following:

1. Enhanced access to new improved varieties and ability to maintain them; this may require strengthening of

community-based quality seed production of the range of crops and cultivars that show specific adaptation to a community's environment.

2. Effective communication methods for linking farmers and development actors, facilitating two-way information flows in ways that are mutually comprehensible.

3. Enhanced capacity to test new varieties and crop management practices under their conditions.

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