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Monitoring and Forecasting of Pearl Millet (*Pennisetum glaucum* L.) Yield in Two Areas of Traditional Rain-fed Agriculture in Western Sudan*

Mukhtar Ahmed Mustafa and Yasir Mohamed Hashim[1]

Desertification and Desert Cultivation Studies Institute, University of Khartoum, Shambat, Sudan

Abstract: A study was conducted to test the validity of an FAO method for monitoring and forecasting pearl millet yield in two traditional rain-fed areas in western Sudan; namely, Al-Obeid and Al-Fashir. The periods of crop development were delineated from the graphs of mean normal (30 years) rainfall (Pn) and potential evapotranspiration (PET) versus 10-day interval (dekad) during the growing season. Annual water satisfaction indices (SI) were estimated for 10 years from annual water balance for the period 1987-1996. This index indicates the extent to which the water requirement of the crop was satisfied in a cumulative way. Highly significant cubic relationships between Pn or PET and seasonal dekads were obtained for both areas. For Al-Obeid, Pn for three dekads were equal to 0.5 PET and for the remaining dekads they were below 0.5 PET, while for Al-Fashir Pn was below 0.5 PET for all dekads. Thus, according to the FAO classification system, the two areas have no growing seasons. Since this conclusion contradicts with acctual practice, a modification of the system is proposed. According to the modified system, there is a growing season but it is still very dry in both areas. Trendline equations for the distribution of Pn and PET were developed for the two areas. An example for the calculation of SI for millet (dukhn) grown in 1987 in the two areas was presented and analyzed. The corelation between millet yield and seasonal rainfall was not significant in Al-Obeid area, but it was highly significant (r^2=0.947) and cubic in Al-Fashir area. The correlations between yield and SI were significant and cubic in Al-Obeid (r^2=0.447)

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[1] Present address: Humanitarian Aid Commission, Ministry of Huminatarian Affairs. Khartoum, Sudan

and Al-Fashir (r^2=0.845). The pooled data gave a significant correlation (r^2 = 0.401) between yield and SI index.

INTRODUCTION

Traditional rain-fed agriculture is prevalent in western, central, eastern and some parts of southern Sudan. This system is practiced in a wide range of soils with mean annual rainfall ranging from less than 400 mm in western Sudan to more than 800 mm in southern Sudan. In western Sudan, the cultivated soils are mainly loamy sands, 'gradud' sandy clay loams and alluvial loam soils on the valleys (wadies). The main crops include sorghum, millet, groundnut, sesame, water mellons, and roselle (karkadi). Millet is a favoured stable grain in western Sudan.

Al-Obeid is the capital of North Kordofan State which lies between latitudes 13°N -45°N and longitudes 3°E-11°E with an altitude of 546 m above mean sea level (m.s.l.). The mean annual rainfall is 318 mm. Al-Fashir is the capital of North Darfur State which lies between latitudes 12°N-34°N and longitudes 25°E-35°E with an altidude of 845 m above m.s.l.. The mean annual rainfall is 213 mm. The mean annual rainfall for both areas is always much less than the potential evapotranspiration throughout the growing season. Furthermore, they are both characterized by recurrent drought periods during the short growing season (70 days), thus rendering the crops vulnerable to water stress.

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The great Sahelian drought (1968-1973) and its consequent dramatic socio-economic impact raised international concern and attention to, *inter alia*, food security. FAO was among the first to take action in this regard. It established a global information and early warning system on food and agriculture in response to a recommendation of the UN World Food Conference held in November 1974. Frére and Popov (1976) developed a method for monitoring and forecasting the productivity of sorghum as an input to the global information and early warning system on food and agriculture. This method is based on cumulative soil water balance for successive 10 days period (dekad) during the growing season of the crop. A water satisfaction index (SI) is calculated and used as an indicator for monitoring the crop performance and forecasting its yield. This index indicates the extent to which the water requirement of the crop was satisfied in a cumulative way. At the end of the season, the index reflects the cumulative water stress endured by the crop, dekad after dekad, and the higher the final index, the smaller is the water stress and the higher is the forecasted yield. Frére and Popov (1979) elaborated the method and presented some results obtained in some African and Asian countries. In western Sudan, like many developing countries, the yield of crops under rain-fed farming systems is subjected to wide temporal and spatial variation due to variations in rainfall intensity, quantity and distribution, soil fertility, recurrent droughts, flooding, inadequate services, limited support to research and extension, shortage of inputs and limitations of formal credit (Anonymous 1990). Thus, it became increasingly important to forecast the production of cereal crops, particularly sorghum and millet to predict the size of harvest and the quantity required to be imported or available for export.

A previous paper addressed the production of sorghum yield in the mechanised rain-fed sector (Hashim and Mustafa 2007). This paper addresses millet yield in two traditional rain-fed areas. The specific objectives were to (i) monitor the yield of millet and relevant meteorological data for two main traditional rain-fed areas in western Sudan, (ii) determine the growth periods of millet in these two areas using the long-term rainfall and estimated potential evapotranspiration data, and (iii) test the validity of the FAO method for monitoring and predicting millet yield using SI as an indicator in the two areas.

MATERIALS AND METHODS

This study was undertaken at Al-Obeid in North Kordofan State and Al-Fashir, in North Darfur State. They were selected because of their importance as traditional rain-fed millet production areas, difference in their seasonal rainfall and availability of the required yield and meteorological data.

Three sets of data were used: soils, crops, and meteorological data. The values of the available water of the prevalent soil orders in the different areas were estimated from different soil survey reports. The crop yield data during the period of the study (1987-1996) were taken from the records of the Ministry of Agriculture and Forestry. The meteorological data included normal rainfall (30-years averages) per dekad, starting from the 10th (April) to the 30th (October) dekad. The actual data per dekad included rainfall, maximum and minimum temperatures and wind speed for the period of the study. These meteorological data were obtained frrom the National Meteorological Authority, Ministry of Science and Technology.

Determination of the periods of millet development

Periods of millet development were determined by the method of Cocheme and Francquine (1967) as outlined by Popov (1984) using 30-years data of mean normal rainfall (Pn) and potential evapotranspiration (PET), which was estimated according to the following modified Penman equation:

$$PET = c\,[W.Rn + (1-W)\,.\,f(u).\,(e_a-e_d)] \qquad [1]$$

where

c = adjustment factor for the day and night effects on PET;

W= temperature – related weighting factor;

Rn = net radiation (mm/d);

f(u) = wind-related function;

e_a = saturation vapour pressure at mean air temperature (mb);

e_d = mean actual vapor pressure of the air (mb);

$(e_a - e_d)$ is the vapour pressure deficit.

The details of the calculation method are given in Doorenbos and Pruitt (1977). According to Cocheme and Franquine (1967) method, the growing season commences when the rainfall exceeds half PET and ends when the quantity of water stored in the soil is depleted. The following four growth periods were distinguished from the plot of Pn, PET, PET/2 and PET/10: Land preparation period: $0.1\ PET < Pn < 0.5\ PET$; intermediate period(s): $0.5\ PET < Pn < PET$; wet period: $Pn > PET$. Crops are seeded at the first intermediate period, and at the second intermediate period (if any), the crop reaches the maturity stage. Four types of growing seasons were distinguished: normal, when the graph shows a wet period and depicts two intermediate periods; intermediate, when the rainfall is below PET but greater than PET/2; humid, when the rainfall is greater than PET all the season and dry when rainfall is below 0.5 PET (Frére and Popov 1979).

Computation of the water satisfaction index (FAO index)
The data were prepared dekad-wise during the growing season, i.e., from 1 to 10, 11 to 20 and from 21 to the end of the month. Crop coefficients for millet were calculated by the procedure outlined by Doorenbos and Pruitt (1977). The crop water requirement (WR) per dekad was calculated by the following relation: WR = k PET, where k is the crop coefficient. The amount of rainfall in excess of crop water requirement (Pa–WR) replenishes the amount of depleted available water and the remainder, if any, is assumed to be lost by deep percolation in the case of the permeable soils of Al-Obeid (loamy sand) or Al-Fashir sandy loam. The available water (AW) of the loamy sand and the sandy loam were estimated from available data as 77 and 84 mm, respectively. The soil water reserve (SWR) is estimated as the SWR in the previous dekad plus (Pa–WR) of the current dekad. The difference (SWR–AW) gives the excess or deficit (D) of soil water. SI, expressed in percentage, is given by the following relation:

$$SI = 100 - (D/ WR_t) \times 100 \qquad [2]$$

where WR_t is the total crop water requirement of the whole season.

The index of the last dekad in the growing season reflects the cumulative water stress endured by the crop and is used as an indicator for forecasting crop yield. When there is no deficit, SI is equal to 100.

Simple statistical parameters were computed using Microsoft Office Excel.

RESULTS AND DISCUSSION

Millet growth periods
Fig. 1 shows a highly significant cubic bell-shaped relationship between Pn and the seasonal dekads, which accounted for 82 and 71 per cent of the variation of Pn in Al-Obeid and Al-Fashir, respectively. The trendlines also show a highly significant cubic bell – followed by trough-shaped relationships between PET and the seasonal dekads, which accounted for 93 and 75 per cent of the variation of PET in Al-Obeid and Al-Fashir,

respectively. In general, PET decreased with increase in rainfall due mainly to increase in relative humidity which sometimes coincided with decrease in temperature. This was reflected in the trendlines which are shown on Fig.1. It was interesting to note that the convex portion of the rainfall trendlines coincided with the concave portion of the PET trendlines and *vice versa*. In view of the very high coefficient of determinations, the use of these trendline equations for predicting Pn and PET in the two traditional rain-fed agricultural areas is recommended. They may prove useful for monitoring and forecasting growth and yield of other crops grown in these areas.

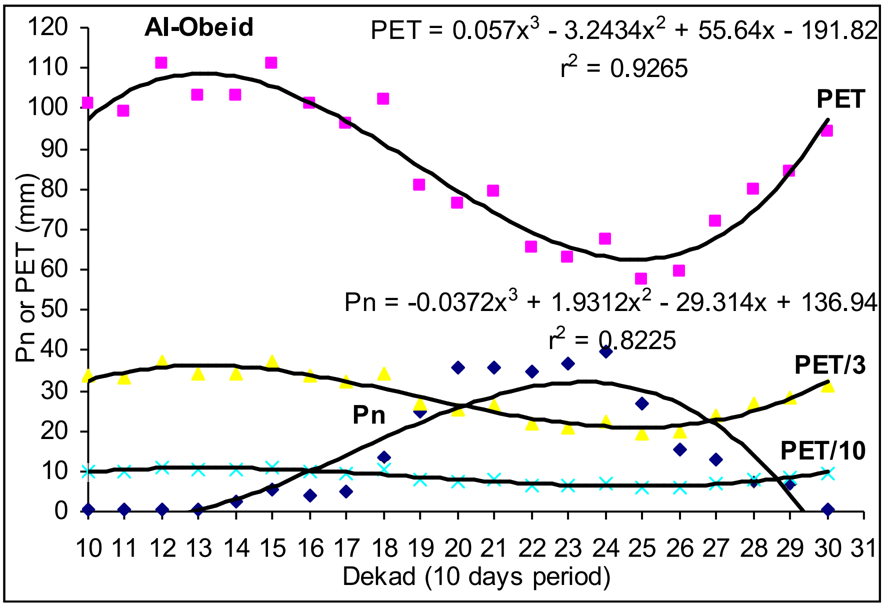
The data showed that in Al-Obeid area, Pn for dekads 23, 24 and 25 was equal to PET/2 but it was below PET/2 for other dekads. In Al-Fashir area, Pn was below PET/2 throughout the season. The data of PET/2 were not plotted in Fig. 1 to evade crowding when PET/3 were plotted in the same graph. According to the definition of Frére and Popov (1979), the growing season of Al-Obeid may be considered dry, while that of Al-Fashir area is of type 4, i.e., typical dry all year round. According to this classification system, there is essentially no growing season in these two areas. Nevertheless, the local community still grows some food crops for subsistence livlihood. Traditionally, they grow their crops with the first rains and hope for a relatively good rainy season. If a good season is realized, they will get their needed staple food and may also harvest an additional cash crop, e.g., 'karkade'. However, if they are hit with prolonged drought, no harvest may be obtained and a famine may set in and force them to immigrate to big cities. Thus, under subsistence farming systems in the drylands, Frére and Popov's classification system may not be suitable. In contrast, a previous study showed that the growing seasons of the mechanized rain-fed subsector fitted this system. The growing seasons of Al-Gedarif, Al-Damazin and Kosti were found to be semi-normal, normal and intermediate, respectively (Hashim and Mustafa 2007).

The contradiction that resulted by applying Frére and Popov's classification system to the traditional rain-fed subsector prompted its modification to fit the actual practice under subsistence farming system in these drylands. Since the long-term data showed that the areas are very dry, it may be more realistic if PET/3 is used instead of PET/2 for delineating the growth periods. Adoption of this new criteria resulted in a new land prepartion period (0.1 PET < Pn < 0.3 PET), an intermediate period (0.3 PET < Pn < PET) and no wet period (Pn > PET) for the growing seasons of the two studied areas. The growing season for both areas was still dry, but a growing season existed when this modified system was adopted.

Table 1 presents the growing periods of the two study areas. The preparation period (initial) of Al-Obeid begins in the second dekad of June and continues until the third dekad of July (41 days). The normal rainfall increases gradually from 4.2 mm to 35.5 mm, with a total amount of 82.6 mm. Thus, there was ample time and wide soil moisture variation to select the opportune time for land preparation and even seeding of crops. In view of the low and erratic rainfall and short season, it is possible to seed in the first dekad of July, by which time the area will receive about 47 mm of rainfall. The modified system defines the growing period as the one when Pn is greater than one third PET but less than PET. It consists of one extended intermediate period, which in Al-Obeid starts from the third dekad of July to about the third dekad of September (66 days).

Table 1. The modified periods of millet development in the two studied areas using PET/3 instead of PET/2 as a delineating index.

Period	0.1 < Pn < 0.3 PET	0.3 PET < Pn < PET	Pn =PET/10
		Al-Obeid	
Starting date	12 June – 23 July	24 July – 27 Sept.	17 Oct.
Length (days)	41	66	20
		Al-Fashir	
Starting date	12 June –10August	11August–15 Sept.	3 Oct.
Length (days)	59	36	18



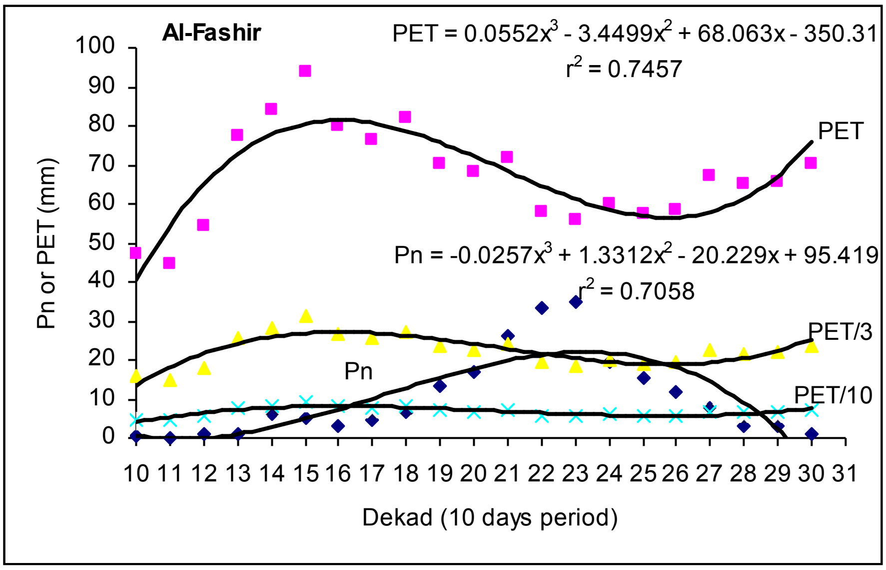


Fig. 1. Distrbution of mean annual rainfall (pn) and potential evapotranspiration (PET) and the grwoth periods in Al- Obeid and Al-Faashir areas during the rain seasons, using PET/3 instead of PET/2 as a delineating index

For Al-Fashir, the preparation period (initial) begins in the second dekad of June and continues until the first dekad of August (59 days). The normal rainfall increases gradually from 3 to 33 mm with a total amount of 105 mm. In view of the low and erratic rainfall and short season, it is possible to seed in the second dekad of July, by which time the area receives about 45 mm of rainfall. The growing period continues from the first dekad of August to the second dekad of September (36 days).

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Variation of rainfall and PET

The comprehensive rainfall and PET data for the study period (1987-1996) are presented elsewhere (Hashim 2000). However, summary statistics for these data are presented in this section.

Al-Obeid: The total seasonal rainfall during the study period ranged from 102 mm (1990) to 374 mm (1992) with a mean of 231 mm and a C.V. of 32.7% (Table 2). The maximum 'dekadal' rainfall within each season ranged from 41 mm (1989) to 133 mm (1992) with a mean of 86 mm and a C.V. of 38.2%. The minimum 'dekadal' rainfall in the various seasons was zero. The mean 'dekadal' rainfall ranged from 11 mm (1990) to 42 mm (1992) with a mean of 26 mm and a C.V. of 33.2%.The variation within each season was high to very high ranging from 67% (1989) to 153% (1995) with a mean of 121%. Thus, the seasonal rainfall was low and erratic.

Table 2. Seasonal and within season (21-29 dekads) variation of rainfall and potential evapotranspiration in Al-Obeid and Al-Fashir areas during the period 1987-1996

Year	Total rainfall (mm)	Within season variation				
		Maximum (mm)	Minimum (mm)	Mean (mm)	STD (mm)	C.V. (%)
Al-Obeid						
1987	231	83	0	26	35.9	140
1988	236	118	0	26	38.0	145
1989	213	41	0	24	15.9	67
1990	102	44	0	11	14.7	129
1991	142	53	0	16	17.2	109
1992	374	133	0	42	50.7	122
1993	201	72	0	22	21.9	98
1994	278	93	0	31	36.0	116
1995	249	111	0	28	42.5	153
1996	281	113	0	31	40.2	129
Mean	231	86		26		121
STD	75.5	32.9		8.5		
C.V.(%)	32.7	38.2		33.2		
Al-Fashir						
1987	162	81	0	18	30.0	167
1988	204	107	0	22	36.0	159
1989	102	37	0	11	13.5	119
1990	86	38	0	10	13.7	143
1991	192	92	0	21	32.5	152
1992	190	52	0	21	21.5	102
1993	57	34	0	6	11.0	174
1994	208	41	0	23	17.6	76
1995	127	60	0	14	21.0	149
1996	100	31	0	11	12.9	116
Mean	143	57		16		135.7
STD	55.1	27		6.0		
C.V.(%)	38.6	47.0		38.5		

In contrast, the seasonal PET was high and uniform (Table 3) and ranged from 712 mm (1988) to798 mm (1989) with a mean of 762 mm and a very low C.V. of 3.9%. The maximum 'dekadal' PET ranged from 86 mm (1988) to 111 mm (1987) with a mean of 95 mm and a C.V. of 7.9%. The minimum 'dekadal' PET ranged from 62 mm (1988) to 84 mm (1989) with a mean of 76 mm and a C.V. of 8.3%. The mean seasonal PET ranged 79 mm (1988) to 89 mm (1989) with a mean of 85 mm and a C.V. of 3.9%. The temporal variation of PET was also low ranging from 6% to11% with a mean of 7 %.

Al-Fashir: The total seasonal rainfall during the study period ranged from 57 mm (1993) to 208 mm (1994) with a mean of 143 mm and a C.V. of 38.6% (Table 2). The maximum 'dekadal' rainfall within seasons ranged from 31 mm (1996) to 107 mm (1988) with a mean of 57 mm and a C.V. of 47%. The minimum 'dekadal' rainfall in the various seasons was zero. The mean 'dekadal' rainfall ranged from 6 mm (1993) to 23 mm (1994) with a mean of 16 mm and a C.V. of 38.5%. Thus, the temporal variation within each season was high to very high ranging from 76% (1994) to 152% (1991) with a mean of 136%. Thus, the seasonal rainfall was low and erratic.

In contrast, the seasonal PET was high and uniform (Table 3). The seasonal PET ranged from 560 mm (1989) to 627 mm (1993) with a mean of 602 mm and a very low C.V. of 3.9%. The maximum 'dekadal' PET ranged from 72 mm (1989 and 1990) to 78 mm (1993) with a mean of 75 mm and a C.V. of 3.1%. The minimum 'dekadal' PET ranged from 56 mm (1989/90/94) to 63 mm (1993) with a mean of 59 mm (1992) and a C.V. of 4.7%. The mean seasonal PET ranged from 62 mm (1989 and 1990) to 70 mm (1993 and 1996) with a mean of 67 mm and a C.V. of 4.3. The temporal variation of PET was also low ranging from 9% to 6% with a mean of 7.9%.

The results of both locations showed that, as expected, the variation of Pa or PET between seasons is lower than that within one season. Al-Fashir was drier than Al-Obeid. The mean seasonal rainfall of the latter was 1.6-fold that of the former, and the mean PET of Al-Obeid was 1.3-fold that of Al-Fashir.

Table 3. Seasonal and within season (21-29 dekads) variation of potential evapotranspiration (PET) in Al-Obeid and Al-Fashir areas during the period 1987-1996

Year	Total PET (mm)	Within season variation				
		Maximum (mm)	Minimum (mm)	Mean (mm)	STD (mm)	C.V. (%)
Al-Obeid						
1987	795	111	77	88	9.4	11
1988	712	86	62	79	7.5	9
1989	798	101	84	89	5.9	7
1990	792	101	82	88	5.7	6
1991	786	94	80	87	4.9	6
1992	741	90	74	82	5.7	7
1993	765	94	79	85	5.1	6
1994	727	87	71	80	6.2	8
1995	758	93	74	84	6.0	7
1996	752	94	78	83	5.4	6
Mean	762	95	76	85		7.3
STD	30.1	7.5	6.3	3.3		
C.V.(%)	3.9	7.9	8.3	3.9		
Al-Fashir						
1987	615	76	61	68	4.8	7
1988	598	73	57	66	5.9	9
1989	560	72	56	62	5.5	9
1990	560	72	56	62	5.5	9
1991	609	75	57	68	6.2	9
1992	607	77	59	67	5.7	8
1993	627	78	63	70	4.5	6
1994	594	73	56	66	5.3	8
1995	620	74	62	69	4.8	7
1996	626	78	61	70	5.1	7
Mean	602	75	59	67		7.9
STD	30.1	2.3	2.7	2.9		
C.V.(%)	3.9	3.1	4.7	4.3		

Water statisfaction index (SI)
Table 4 shows an example for the calculation of SI of millet for Al-Obeid and Al-Fashir areas in 1987 season.

For Al-Obeid area, the normal rainfall (Pn) during the growing period amounted to 203 mm, and was relatively high and well distribute'd during July and August. However, the total actual rainfall (Pa) for this season was 173 mm and 92% of it fell in two dekads; namely, 23 and 24. In dekads no. 23, 24 and 28, Pa was much higher than Pn, and the reverse was true in the remaining dekads. Actually, 94% of the seasonal rainfall occurred during these three dekads. The extremely low Pa in dekads 21 and 22, amounting to only 3.5% of the seasonal rainfall, coupled with the relatively high WR, resulted in high water deficits. There was no soil water reserve to compensate for the water deficit. SI was reduced successively to 93% and 83%. In dekad 23, Pa was relatively very high-enough to compensate the WR leaving only an insignificant water deficit which did not reduce SI. In dekad 24, Pa was relatively very high but it was not enough to satisfy WR leaving a deficit of 19 mm which reduced SI to 80%. In the three dekads of September, there was essentially no rainfall but higher WR and in the absence of SWR, SI was reduced markedly reaching 37 by dekad 27. In dekad 28, the rainfall was higher than WR resulting in SWR equal to 13, which is lost by deep percolation. The water deficit was equal to zero, and SI remained equal to 37. In dekad 29, Pa was less than WR by 4, which was too small to affect SI. This final index is used as an indicator of yield.

During the growing period, for Al-Fashir area, the rainfall decreased from 35 mm to 12 mm with a total amount of 81 mm. The cumulative actual rainfall (Pa) during this period was 139 mm, received in two dekads only. In comparison to Al-Obeid area, the growing season is shorter and the actual cumulative rainfall was greater than the normal, but it was badly distributed. In dekad 21, WR was relatively low, although it was 6-fold Pa, resulting in a relatively low water deficit, which reduced SI by 5%. In dekad 22, WR, which was more than 7-fold Pa, resulted in moderate water deficits that reduced SI by 10%. In dekad 23, Pa was greater than WR by 14 mm which was lost by deep percolation, and SI remained at 85%. In dekad 24, the deficit was 15 mm reducing SI to 82%. Like in Al-Obeid, there was no significant rainfall in dekads 25, 26 and 27, and WR in these dekads was relatively high resulting in high deficits that reduced SI successively to 41%. The lack of rainfall coupled with WR reduced SI to 30% by the end of season.

Table 4. Calculation of water satisfaction index (SI) of millet for Al-Obeid and Al- Fashir areas (1987 season)

Variable/	July	August			September			October	
dekad*	21	22	23	24	25	26	27	28	29
					Al-Obeid				
Pn, mm	36	35	37	40	27	15	13	7	7
Pa, mm	2	6	83	77	5	0	0	58	0
PET, mm	111	87	77	87	85	86	93	84	85
Kc	0.39	0.81	1.1	1.1	1.1	1.1	0.87	0.53	0.2
WR, mm	43	70	85	96	94	95	81	45	17
Pa – WR	-41	-64	-2	-19	-89	-95	-81	13	-17
SWR,mm	0	0	0	0	0	0	0	13	0
D, mm	-41	-64	-2	-19	-89	-95	-81	0	-4
SI**	93	83	83	80	66	50	37	37	37
					Al-Fashir				
Pn, mm	26	33	35	19	15	12	8	3	3
Pa, mm	5	7	81	58	0	0	11	0	0
PET, mm	76	65	61	66	67	68	74	72	66
Kc	0.39	0.81	1.1	1.1	1.1	1.1	0.87	0.53	0.2
WR, mm	30	53	67	73	74	75	64	38	13
Pa – WR	-25	-46	14	-15	-74	-75	-53	-38	-13
SWR,mm	0	14	0	14	0	0	0	0	0
S / D, mm	-25	-46	0	-15	-74	-75	-53	-38	-13
SI**	95	85	85	82	67	52	41	33	30

* Dekad = 9,10 or 11 days period according to the month; Pn = mean normal rainfall; Pa = mean actual rainfall; PET = potential evapotranspiration; SWR = soil water reserve; D = soil water deficit

** SI = the water satisfaction index; the seasonal water requirement used for the calculatiing SI was 625 mm for Al-Obeid and 592 mm for Al-Fashir.

Relationships between yield, seasonal rainfall and SI

The millet yield for Al-Obeid area ranged from 12 kg / fed (one feddan = 0.42 ha) in 1995 to 77 kg / fed in 1994 with a mean 42.2 kg/ fed and a C.V. of 53%, while that for Al-Fashir ranged from from 15 kg/ fed (1995) to 100 kg / fed (1994) with a mean of 47.9 kg / fed. and a C.V. of 62%. This high variation in yield may be attributed to variations in amount and distribution of rainfall, agricultural inputs, sowing dates and pests. Furthermore, the yield data were field estimates collected by the Administration of Statistics of the Ministry of Agriculture and Forestry, thus introducing human error.

Fig. 2 shows a non-significant cubic correlation ($r = 0.614$) between millet yield and seasonal rainfall in Al-Obeid area. In view of its low coefficient of determination (38%), the cubic relationship implies that the seasonal rainfall alone is not a good indicator of yield. The final drop in yield with increase in rainfall may be attributed to late sowing, pests, diseases and inprecision of yield assessment. However, the data of Al-Fashir area gave a highly significant ($P < 0.001$) cubic correlation ($r = 0.973$) between crop yield and seasonal rainfall. Fig. 3 shows a significant ($P = 0.05$) cubic correlation ($r = 0.669$) between yield and SI in Al-Obeid area. However SI accounted for only 44.7% of the variation of yield. The yield versus SI relationship in Al-Fashir yielded a highly significant ($P < 0.001$) cubic correlation ($r = 0.919$), and SI accounted for 85% of the variation of yield. The initial and final drops in yield with increase in SI in Al- Fashir and Al-Obeid, respectively, may also be attributed to factors other than those inherent in SI, including imprecise assessment of yield.

Fig.4 shows a non-significant cubic correlation between yield and seasonal rainfall ($r = 0.526$) and a significant ($P = 0.05$) correlation between yield and SI ($r = 0.633$) for the pooled data of the two areas. However, the seasonal rainfall and SI accounted for 28% and 40% of the variation in yield, respectively. This may be attributed to the multitude of factors, other than seasonal rainfall or SI, that affect yield. However, SI is a better indicator for monitoring and forecasting yield than the seasonal rainfall, because it is a systematic procedure based on the water balance equation. The use of actual field measured data is suggested for future research.

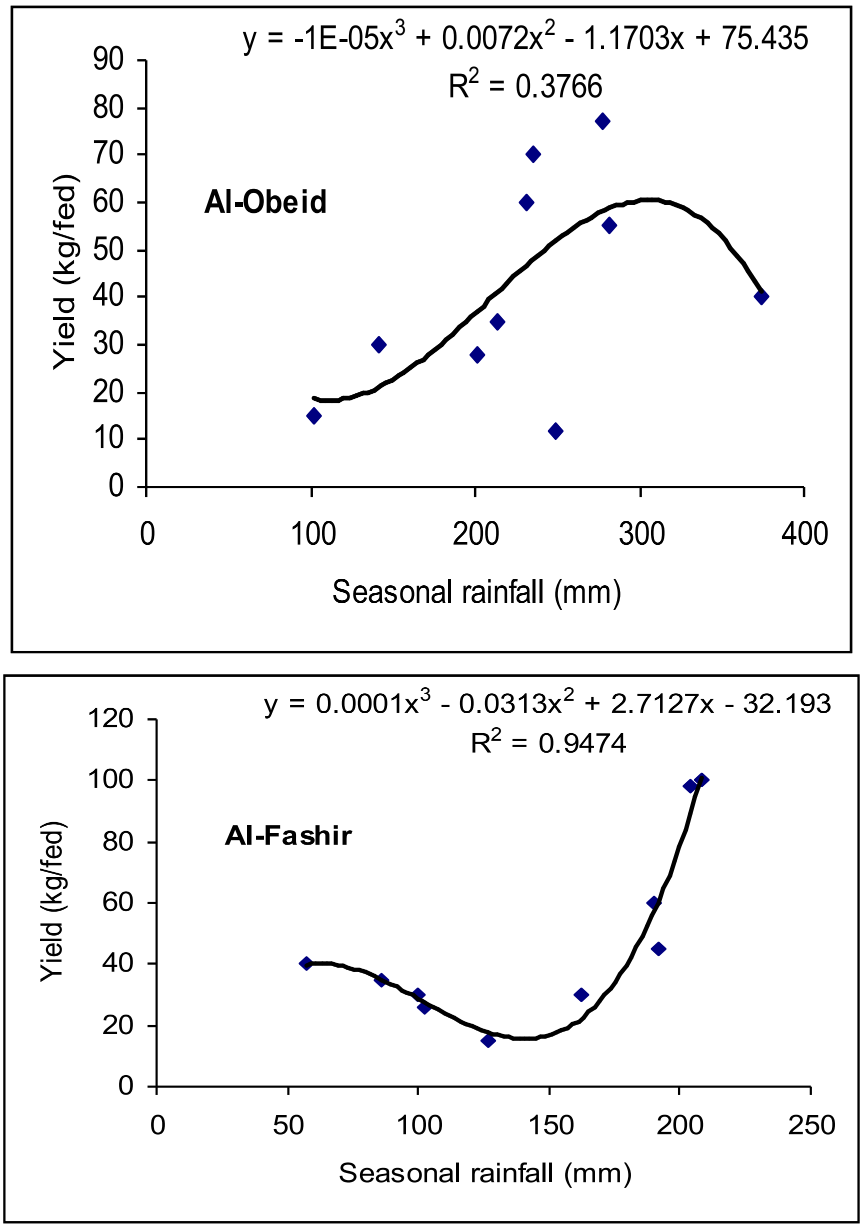

Fig. 2. Millet yield as a function of seasonal rainfall for Al- Obeid and Al-Fashir during the rainy season

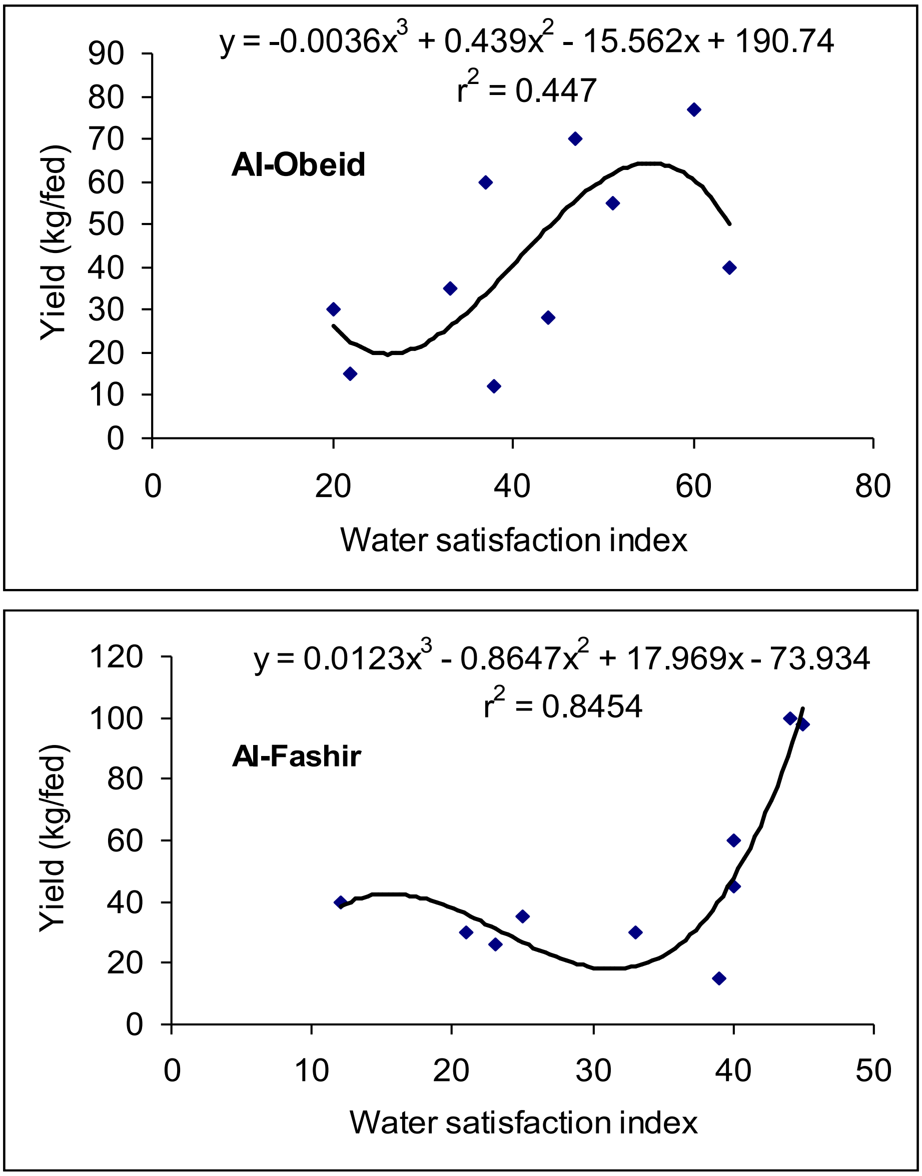

Fig. 3. Millet yield as a function of the water satisfaction index for Al-Obeid and Al-Fashir

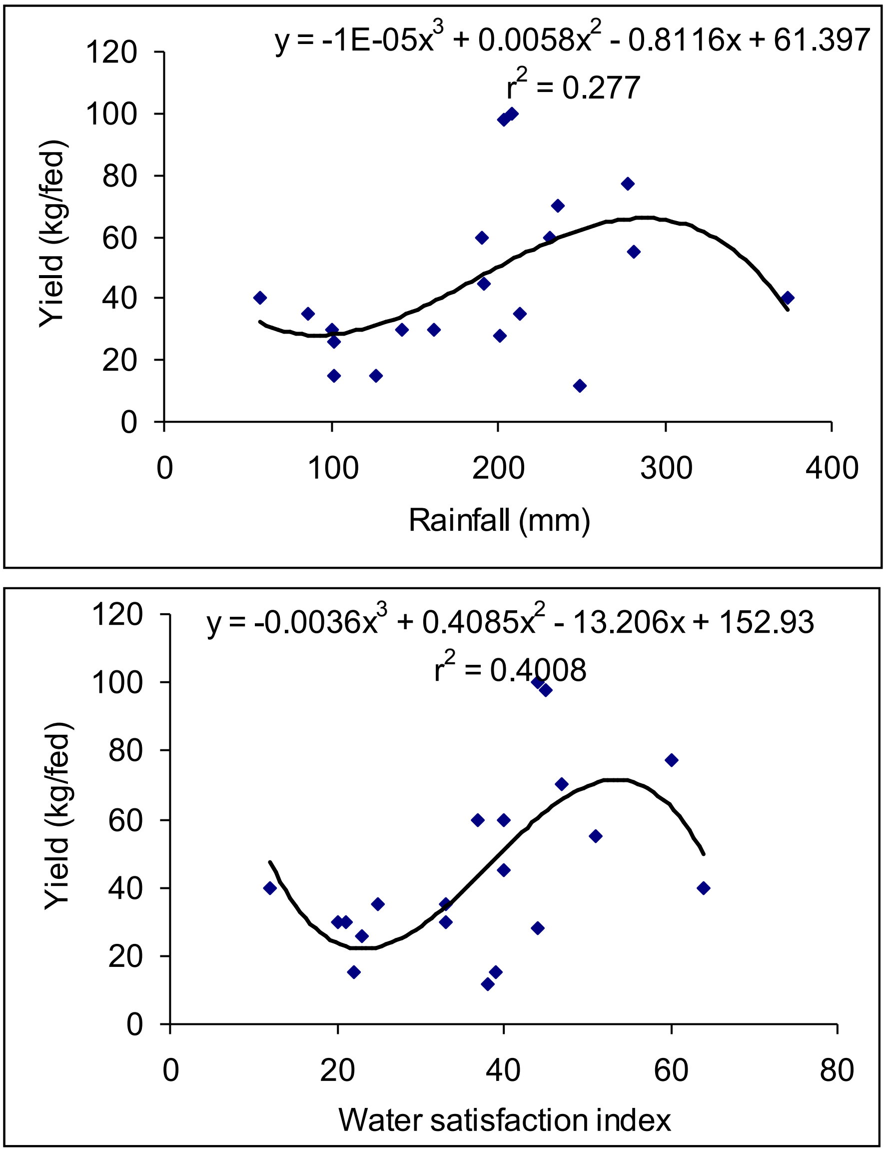

Fig. 4. Millet yield as a function of (A) seasonal rainfall and (B) the water satisfaction index for Al-Obeid and Al-Fashir

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مراقبة وتنبؤ انتاجية الدخن في منطقتين للزراعة المطرية التقليدية بغرب السودان*

مختار أحمد مصطفى و ياسر محمد هاشم[1]

معهد دراسات التصحر واستزراع الصحراء
جامعة الخرطوم ، شمبات ، السودان

موجز البحث: أجريت هذه الدراسة لاختبار صحة طريقة منظمة الأغذية والزراعة التابعة للأمم المتحدة للمراقبة والتنبؤ بإنتاجية الدخن في منطقتين للزراعة المطرية التقليدية فى غرب السودان ، هما الأبيض والفاشر . تم تقدير فترات نمو المحصول من الرسم البياني لمعدلات الامطار (Pn) والبخرنتح (PET) طويلة المدى (30 عاماً) كدالة لفترة العشرة أيام المتتالية (فترة) خلال موسم نمو المحصول . كما حسب دليل استيفاء الرطوبة السنوى لمدة عشر سنوات من ميزان ماء التربة السنوى خلال فترة الدراسة (1987– 1996) . يعبر الدليل على مدي استيفاء الاحتياجات المائية للمحصول بطريقة تراكمية. توصلت الدراسة لعلاقات تكعيبية معنوية بين معدلات الأمطار أو البخرنتح طويلة المدي وفترة العشرة أيام المتتالية . فى منطقة الابيض كانت معدلات الامطار مساوية لمعدلات البخرنتح فى ثلاث فترات ، وأقل منها فى بقية الفترات خلال الموسم الزراعي ، بينما كانت معدلات الامطار في الفاشر أقل من معدلات البخرنتح فى كل الفترات . تدل هذه النتائج وفق طريقة منظمة الأغذية والزراعة التابعة للأمم المتحدة على عدم وجود موسم زراعي فى المنطقتين . وبما أن هذا الإستنتاج يتناقض مع الممارسة العملية ، فقد تم اقتراح تعديل هذه الطريقة لتستوعب الزراعة المطرية التقليدية . ودلت الطريقة المعدلة على وجود موسم زراعي جاف فى المنطقتين . اشتملت

* جزء من أطروحة قدمها المؤلف الثاني لجامعة أمدرمان الإسلامية كجزء من مطلوبات درجة الماجستير في الزراعة

[1] العنوان الحالي: مفوضية العون الانساني ، وزارة الشئؤن الإنسانية ، الخرطوم ، السودان

الدراسة على أمثلة لحساب دليل استيفاء الرطوبة لمحصول الدخن الذى زرع فى موسم 1987 بمنطقتي الدراسة . كانت علاقة الترابط بين انتاجية الدخن وكمية الامطار الكلية للموسم فى الابيض غير معنوية ، ولكنها كانت معنوية ($ر^2$ = 0.947) وتكعيبية فى الفاشر . كما وجدت علاقة ترابط تكعيبية ومعنوية بين إنتاجية الدخن ودليل استيفاء الرطوبة في الابيض ($ر^2$ = 0.447) والفاشر ($ر^2$ = 0.845) . ودل التحليل الاحصائي لمجموعة بيانات المنطقتين على علاقة معنوية ($ر^2$ = 0.401) بين الإنتاجية ودليل استيفاء الرطوبة .