Optimum Water Requirements for the Commercial Production of Fodder Sorghum and Fodder Maize in Khartoum State

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Introduction

Khartoum state is an important area for fodder production to satisfy the requirements of increasing animal numbers for meat and dairy products, the demand for which is continuously increasing due the normal population growth and mass immigration of rural communities to the capital towns and other settlements. In addition to this, a remarkable activity for cattle and sheep for export has resulted in increasing the area of fodder crops. Irrigation cost and management, no doubt, plays an important role for the production of fodder crops. Efficient utilization of the land and water resources will therefore be reflected directly to the interest of the farmer, the consumer, and also to the interest of export trade. The objective of this work is to maximize returns from irrigation water at the farm level for the production of fodder sorghum and fodder maize in Khartoum state. The final goal is establish an all-year round irrigation schedule in which the varying amounts and intervals of irrigation are identified and to extend the use of the F.A.O model (1984) by including the variations in the available water holding capacity of different soils, so that the irrigation interval can be added to the original Penman Montieth Model which was recommended by F.A.O 1984

A series of experiments started since 1975 and continued to 2005, to give complementary information relating crop productivity to irrigation level and variation in climate.

Materials and Methods

Experimental Site

The experiments were conducted in the Demonstration Farm of the Faculty of Agriculture, University of Khartoum. The soil of which alkaline (pH is between 8 and 8.5) has high clay content of 40 to 50%, poor structure, low organic matter content , low permeability but with high water holding capacity . The gravimetric soil moisture contents at 0.3 bar (Field capacity) and 15 bar (assumed to be permanent wilting point) is 54.3 and 16.1% respectively (Dover 1966). Bulk density varies with depth and ranges between 1.25 in the top 15 cm and increases to 1.58 to the depth between 75 and 90 cm.

Irrigation system

irrigation water was pumped from a reservoir, at the rate of 35.2 liters per minute through a pipe system to serve 48 experimental plots, each of 4 × 4 m. The plots were separated to a depth of 90 cm by corrugated iron sheets to avoid lateral movement of

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water between the experimental plots. This system was designed by El Nadi [1969], Figure (A).

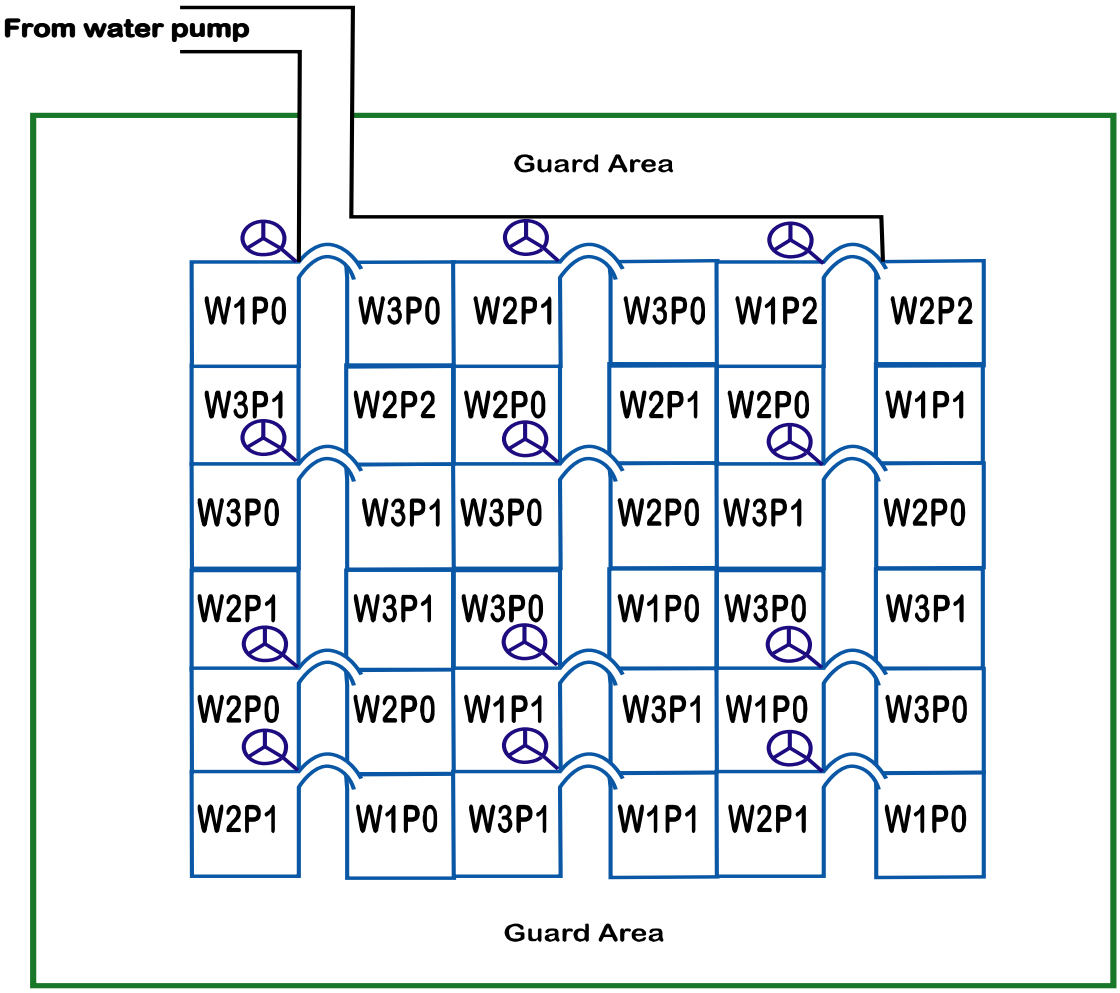
Soil moisture determination

For the experiments carried out between 1972 and 1976 soil moisture was determined by the use of the soil moisture neutron probe.

Three aluminum access tubes were installed at different sites in each plot and the average soil moisture content was determined at the depths of 30, 45, 60, 75, and 90 cm. For the experiments carried out after 1976 three average reading of soil moisture were determined gravimetrically at the depths of 30, 60 and 90 cm.

Some of the experiments presented in this paper were conducted in the mentioned plots in Figure (A) and the others were conducted in a field layout in the Demonstration Farm of the Faculty of Agriculture, U of K.

Figure (A)



Five experiments were carried on Fodder Sorghum and three others for Fodder Maize to study the productivity of these fodder crops in response to different levels of irrigation and different climatic conditions.

Experiment No (1) & (2)

The Response of Growth and Yield of Fodder Sorghum to Irrigation Level

Objective:

Two experiments were conducted for two seasons to study the response of fodder sorghum to three irrigation treatments of equal daily application of 8mm, but delivered at different intervals of 7, 10 and 13 days. The treatments were as shown in Table (1).

Results

The results are summarized in Tables No.1 to No.3 and figures No.1 to No.4.

Table (1) .Number of irrigations and amounts of water received by different treatments.

Treatment	Pre-experimental period		Experimental period		Total amount of water (mm)
	Number of irrigations	Amount per irrigation (mm)	Number of irrigations	Amount per irrigation (mm)	
A	2	70	10	56	700
B	2	70	7	80	700
C	2	70	5	104	700[(a)]

[(a)] 40 mm of irrigation water was added to the last irrigation to make up for the total of 700 mm.

Table 2. Effects of Irrigation practice on the mean fresh weight, dry weight and Water Use Efficiency of Fodder sorghum grown during "Kharief" (June, July, August - 1982).

Irrigation Treatment	Total water used in the season mm	Yield Dry weight trans/ha	Water use efficiency Kg ha^{-1} mm^{-1}
A. (Every 10 days at 70 mm)	420	15400	36.7
B. (Every 15 days at 105 mm)	420	14300	34.0
C. (Every 20 days at 140 mm)	420	12300	29.3

Table 3. Water Use Efficiency (Kg ha^{-1} mm $^{-1}$) of fodder sorghum (dry matter basis) for the different treatments in experiments No.1 & No.2. Treatments A, B and C irrigated every 7, 10 and 13 days, respectively. Values in parentheses are standard errors of means.

Treatments	Water use efficiency	
	Experiment 1 (1982)	Experiment 1 (1983)
A	85($^{+}$4)	86(+3)
B	74(+6)	79(+2)
C	65(+9)	74(+7)

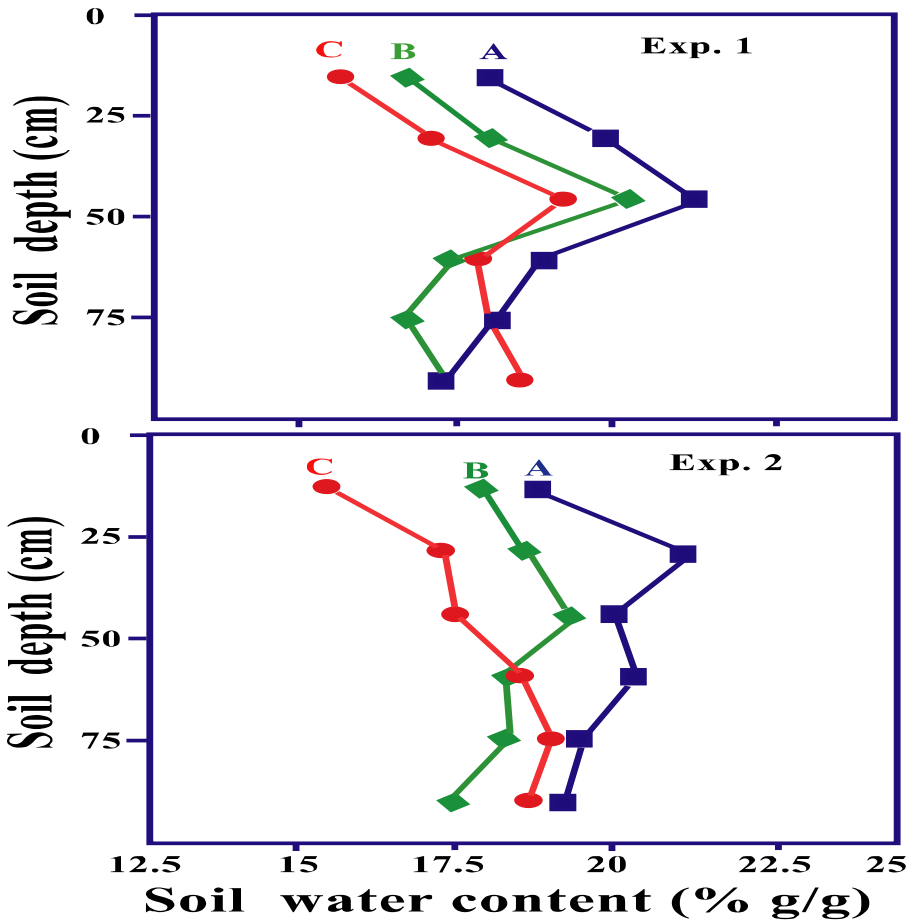


Figure No.1 Relationship between soil moisture content and soil depth

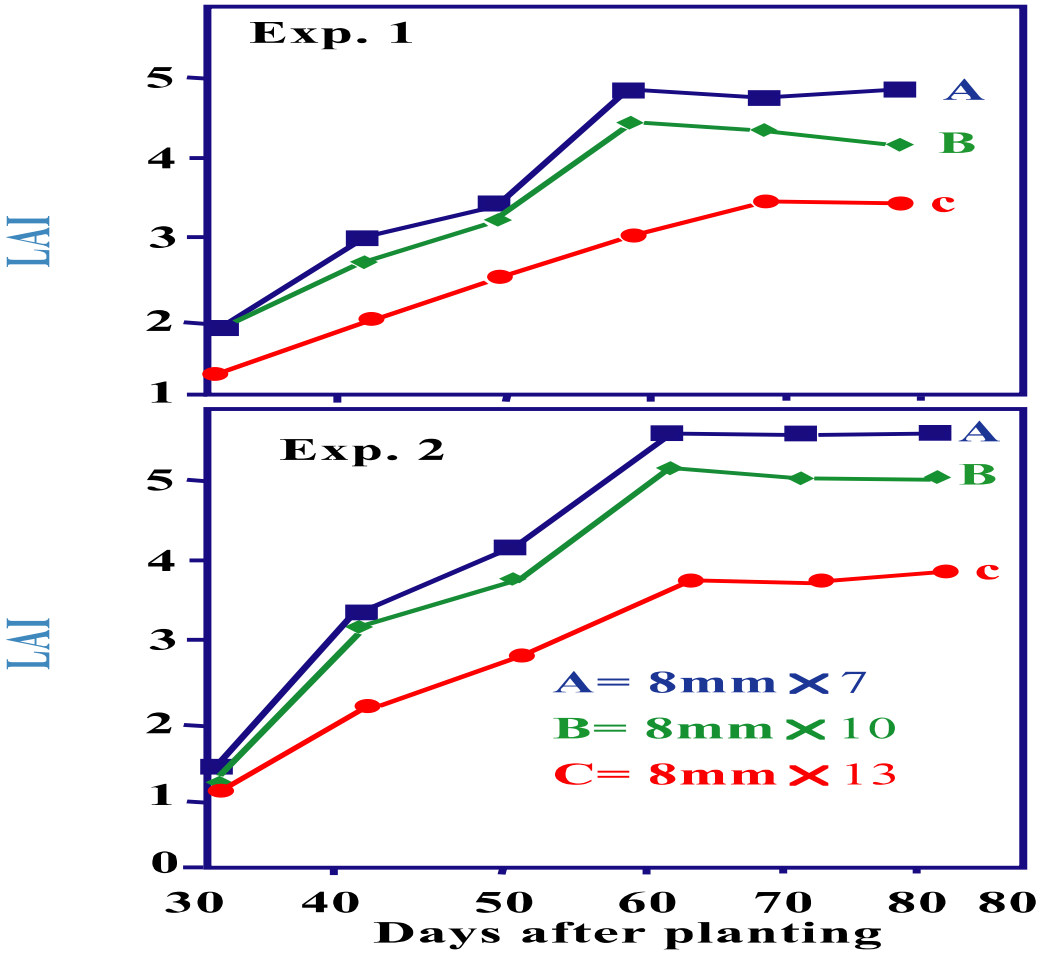


Figure No.2 Relation between plant age (days after sowing) and Leaf Area Index (LAI)

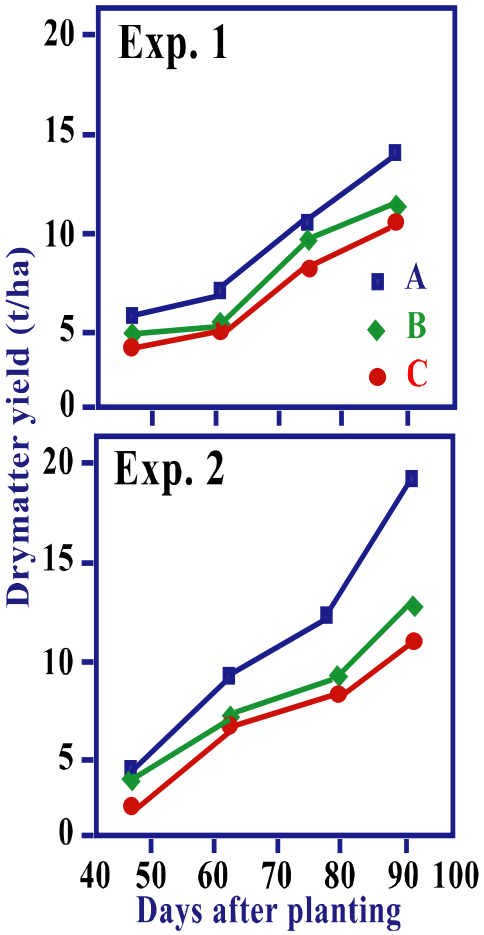


Figure 3. Dry Matter Yield under Three Water Regimes (A,B & C)

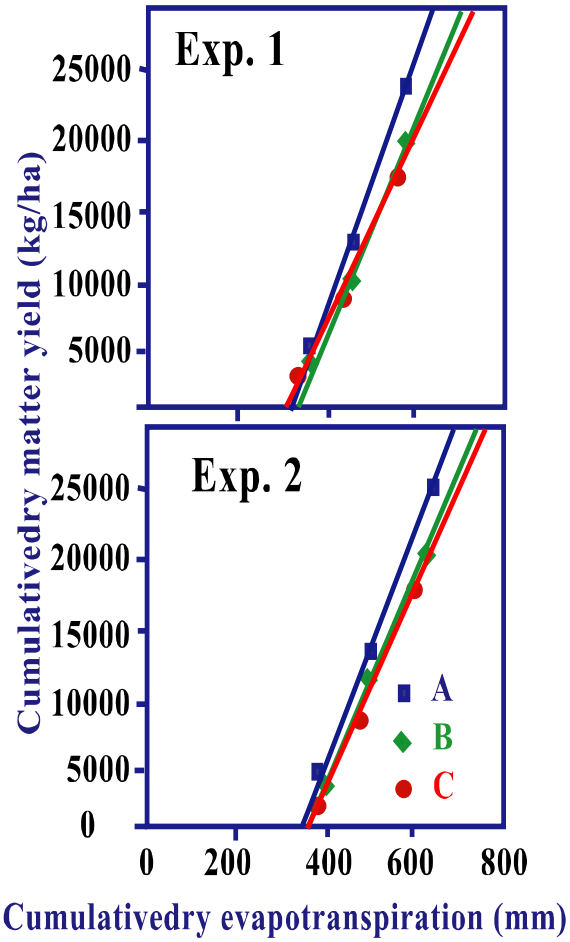


Figure. 4 Cummulative dry matter yield Kg ha^{-1} versus Cumulative evapotranspiration (mm)

Treatment A = 7 days irrig. interval at 8mm per day.
Treatment B = 10 days irrig. interval at 8mm per day.
Treatment C = 13 days irrig. interval at 8mm per day.

Experiment No (3)

Comparisons Between the Direct, Calculation and correlation Methods for Estimating Evapotranspiration

Objective:

1) To study the effects of irrigation amount and frequency on the production of fodder sorghum.

2) To compare actually measured evapotranspiration with different calculation and correlation methods.

Treatments: as shown in Table (1)

Replications = 4, Randomized Block Design. Experimental period from 15 October 1978. (71 days).

Table 1 . Irrigation amounts and Intervals for the Different Treatments.

Treatment	Irrigation Interval days	Number of irrigations	Amount per Irrigation mm	Total Irrigation mm
A	10	6	70	420
B	15	4	105	420
C	20	3	140	420

NOTE: The Daily rate of water application was the same for the three treatments which was 7 mm/day.

Results

Results are presented in Table No 2-No 4 and Fig. (1) and (2).

Table 2. Water loss by evapotranspiration (Et) in three-day periods from fodder sorghum expressed as percentage of Total water storage to 90 cm depth for the treatment irrigated every 10 days and 70 mm per irrigation.

Irrigation Number	Percentage(Et) Days			Total Et %
	Days 1-3	Days 4-6	Days 7-9	
1	16	18.0	12.0	46
2	13.7	16.1	10.5	40.3
3	15.3	17.4	13.2	45.9
4	14.9	18.9	12.2	46.0
5	14.0	16.7	12.0	42.7
6	12.8	15.4	9.0	37.2

Table3. Relationship between actually measured evapotranspiration Et (over ten day periods) and calculated potential evaporation by the revised perman formula(E_0) .

Plant age (days after sowing)	Et/E_0 (crop factor)
21	0.44
31	0.57
41	0.80
51	0.87
61	0.88
71	0.89

Table 4. The effect of three irrigation treatments on the production of fresh and dry weights of fodder sorghum.

Treatment	Fresh weight Tons/ha	Dry weight tons/ha
A. irrigation every 10 days at 70 mm/irrigation	36.0	15.4
B. irrigation every 15 days at 105 mm/irrigation	34.3	14.3
C. irrigation every 20 days at 140 mm/irrigation	29.3	12.3

N.B. The Daily rate of water application was the same for the three treatments = 7 mm/ day.

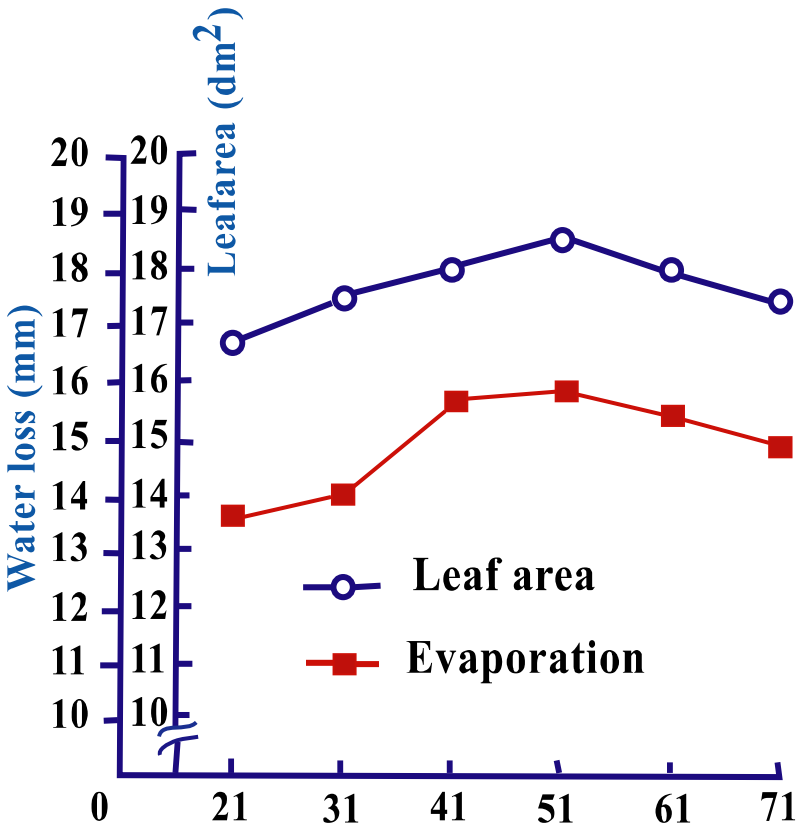


Figure 1 Relationship of Leaf Area (dm^2), plant age (days after sowing) and cumulative evapotranspiration (mm).

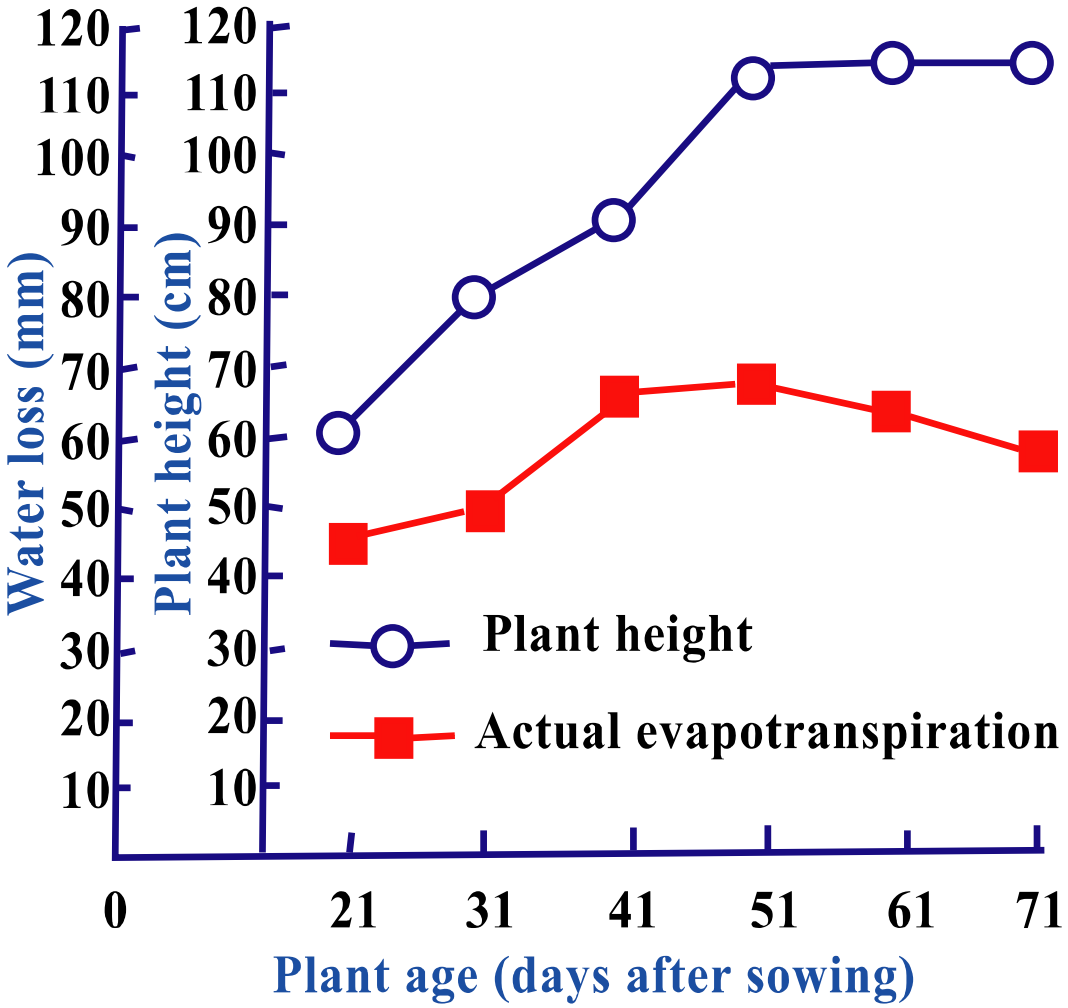


Figure 2. Relationship between Plant Height (cm), plant age (days after sowing) and cumulative evapotranspiration (mm).

Experiment No (4) & (5)

The Effects of Different Irrigation and Nitrogen Fertilizer Levels on Growth and yield of Fodder sorghum

Objectives:

The objectives of this study were:

1) To compare the effects of four levels of Nitrogenous fertilization of 40, 80 and 120 kg/ha applied at three intervals of irrigation namely after 7, 10 and 14 days intervals, with irrigation amounts of 50, 75 and 100 mm respectively on the growth, yield , and water use efficiency of fodder sorghum (Abu Sabien).

2) To determine actual evaporanspiration of sorghum (Et) and then use Penmen evapotranspiration (Eo) as calculated by Adam 2005. The crop factor (Kc) was calculated from the relation:-

$$Kc = \frac{Et}{E}$$

Results

The results are summarized in Fig. (1) and Tables No.1 to NO.5.

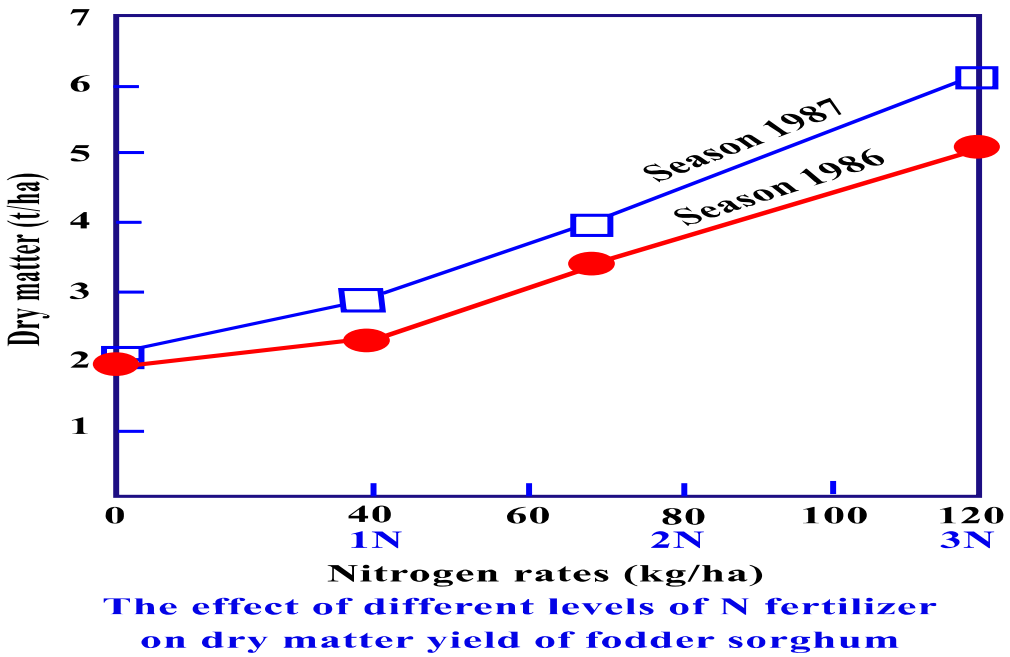


Figure 1. The effect of different levels of N-fertilizer and 7-days irrigation interval on dry matter yield of Fodder Sorghum

Table 1. Water use efficiency (M^3 of water used to produce one kg of dry matter) of the three irrigation intervals and the four nitrogen fertilization levels during the period May 1986 to August 1986 for fodder sorghum(yield and water use per plot were converted to value per ha.

Treatment	Nitrogen fertilization levels			
	ON	IN	2N	3N
	Water use Efficiency (M_3 water /kg dray matter)			
A	2.89	1.17	0.85	0.64
B	2.67	2.00	1.19	0.83
C	5.83	3.99	2.85	1.81
Mean	3.46	2.39	1.63	1.09

N.B .

A = 7 –day interval
B = 10 –day interval
C= 14 –day interval

ON = Control
IN = 40 kg N/ha
2N = 80 kg N/ha
3N =120 kg N/ha

Note :

1. Smaller numerical values of WUE, calculated by this definition correspond to higher WUE [smaller volumes of water were used to produce one kg dry matter].

2. The higher the level of fertilizer with seven day interval of irrigation (A), the higher was the WUE followed by irrigation every 10 days (B) and the lowest WUE was with 14 days irrigation interval.

Table 2. Water use efficiency (M^3 of water used to produce one kg of dry matter) of the three irrigation intervals and the four nitrogen fertilization levels during the period March 1987 to May 1987 for fodder sorghum (yields and water use per plot were converted to value per ha .

Irrigation intervals	**Nitrogen fertilization levels**			
	ON	**IN**	**2N**	**3N**
	Water use Efficiency (M_3 water /kg dray matter)			
A	1.74	1.03	0.73	0.55
B	2.63	1.69	1.19	0.75
C	4.44	2.77	2.18	1.74
Mean	3.94	1.83	1.37	1.01

N.B .

A = 7 –day interval ON = Control

B = 10 –day interval IN = 40 kg N/ha

C= 14 –day interval 2N = 80 kg N/ha

3N =120 kg N/ha

2 Smaller numerical values of WUE, calculated by this Method correspond to higher WUE [smaller volumes of water were used to produce one Kg dry matter.

2 The higher the level of fertilizer with seven day interval of irrigation (A), the higher was the WUE followed by the treatment irrigated every 10 days and the lowest WUE was with 14 days irrigation interval.

Table3. Actually measured evapotranspiration for fodder sorghum (Et) compared with (E0) first season. May 1986 to August 1986.

Crop Age (days after sowing)	**Et crop mm/day**	**Penman E_0 (*)**	**$K_c = Et/E_0$**
31	7.5	8.2	0.91
41	7.5	7.9	0.95
51	7.5	7.6	0.99
61	7.5	6.9	1.09
71	7.5	6.7	1.12

(*) From Adam 2005.

Table 4. Actually measured evapotranspiration for fodder sorghum (Et) of the second season 1987 and (Eo) as calculated by Adam 2005, and the crop factor.

Crop Age	Et crop mm/day	Penman E_0/day	Et/E_0 (crop factor)
31	7.9	8.2	0.96
41	8.3	7.9	1.05
51	8.3	7.6	1.09
61	8.3	6.9	1.20
71	9.2	6.7	1.33

Table 5. All-Year Round Irrigation Schedule for fodder sorghum in Khartoum State.

Month	E_o mm/day	CWR (mm/day) Stage of growth			CWR
		KC1 25 days	KC2 50 days	KC3 75 days	
Jan	5.7	5.7 × 0.4	5.7 × 0.8	5.7 × 1.3	CWR
Feb	6.2	6.2 × 0.4	6.2 × 0.8	6.2 × 1.3	M^3 per irrigation per
Mar	7.6	7.6 × 0.4	7.6 × 0.8	7.6 × 1.3	feddan for irrigation
Apr	8.0	8.0 × 0.4	8.0 × 0.8	8.0 × 1.3	interval of (x days)
May	8.2	8.2 × 0.4	8.2 × 0.8	8.2 × 1.3	
Jun	7.9	7.9 × 0.4	7.9 × 0.8	7.9 × 1.3	**CWR=Eo×Kc×x×4.2**
Jul	7.6	7.6 × 0.4	7.6 × 0.8	7.6 × 1.3	
Aug	6.9	6.9 × 0.4	6.9 × 0.8	6.9 × 1.3	
Sep	6.7	6.7 × 0.4	6.7 × 0.8	6.7 × 1.3	
Oct	6.7	6.7 × 0.4	6.7 × 0.8	6.7 × 1.3	
Nov	6.2	6.2 × 0.4	6.2 × 0.8	6.2 × 1.3	
Dec	5.4	5.4 × 0.4	5.4 × 0.8	5.4 × 1.3	

Eo = mean potential evaporation/day (mm) (After Adam 2005).
K_c = Crop factor (for fodder sorghum at different stages of growth.
CWR = Crop Water Requirements (M^3/Feddan), where
1mm = 4.2 M^3/Feddan.
CWR =Eo × Kc.

Actual Eo should be calculated from a prepared programme based on the relevant meteorological data. Otherwise, the values of E_0 prepared by Adam 2005 can be used (in this case the error will be less than 10%).

Discussion for the Results of Five experiments on fodder sorghum

1. The data of the first experimental (Exp.1) which was conducted for two seasons showed that irrigation every 10 and every 13 days resulted in lower

available soil water than frequent irrigation delivered every seven days. The study showed that fodder sorghum exhausted available water in the soil to 60 cm depth. Similar results were reported by Bremrer et.al (1986) from a deep podozolic soil profile.

2 Frequent irrigation of 7 days intervals favoured the measured attributes of growth e.g. crop height leaf area and biomass production as shown by the difference in dry matter yield.

3. The highest water use efficiency WUE was obtained by light and frequent irrigation (every seven days and 56 mm/irrigation), compared with the other two water regimes.

Experiment 3, which was conducted for two seasons also showed that 7 day interval of irrigation with 120 kg N ha^{-1} produced the highest yield of dry matter and also the highest water efficiency in both seasons.

Fodder Maize

Three experiments were conducted, the first two were carried out during 1971/ 1972 and the third one in 2005.

Experiments No 1 & 2

Irrigation Requirements of Maize in Tropical Environment

Objective: To study the response of fodder maize and seed production to four different irrigation treatments:

1. Irrigated every 5 days at 40 mm/irrigation = 8 mm/day
2. Irrigated every 10 days at 55 mm/irrigation = 5.5 mm/day
3. Irrigated every 15 days at 70 mm/irrigation = 4.7 mm/day
4. Irrigated every 20 days at 82 mm/irrigation = 4.1 mm/day

Materials and Methods

The Irrigation System: as described by **El Nadi** 1969
The irrigation treatments were introduced after 30 days 33 days after sowing for the kharief and winter experiments respectively.

Soil Moisture Determination:
Soil moisture was determined by the soil moisture neutron probe at the depths of 30, 45, 60, 75 and 90 cm below the soil surface.

Treatments: As shown in Table (1)

Experimental design: Randomized block Design replicated four times.

Variety: The recommended Variety at that time was Hudaiba 113 supplied by Hudaiba Research studies. Two Experiments were conducted (1) Kharief between 11/8/1971 – Nov 1971.
(2) A winter experiment between 16/11/1957 to March 1972.

Results

Results are shown in Tables No 1 to No 3.

Table 1.Water received during the season.

Treatment	First experiment				Second experiment			
	Before treatments plus rain mm	After treatment rain mm irrigation mm		Total mm	Before Treatments mm	After treatment mm	Total mm
A	253	17	360	630	150	560	710
B	253	17	220	490	150	385	535
	253	17	140	410	150	280	430
D	253	17	82	352	150	246	396

N.B. The rainy season ended before the beginning of the second experiment.
N.B. Comparing amount of water for D/B = 400/53 = 80%
Reduction in yield of D/B = 600/1200 = 80%

T

Table 2. Components of final yield of the first experiment (means were based on four plots/ treatment).

Treatment	Number of ears per plot	Grain yield per plot Kg	Grain yield per ha Kg	Liter weight g	Weight of air dry shoots per plot* Kg
A	123	4.823	3014	760.5	16.308
B	92	1.921	1200	705.5	16.251
C	72	1.335	834	689.0	15.346
D	65	1.016	635	676.0	14.270
S.E.	9.2	0.387		12.2	0.507

*Weight of air dry shoots (moisture content about 11%) included all the aerial parts except he grain.
Moisture content for the grain was about 10%.

Table 3. Components of yield of the second experiment (means were based on four plots/treatment).

Treatment	Number of ears per plot	Grain Yield		Liter weight	Weight of air dry shoots*
		Per plot Kg	Per ha kg	g	kg
A	178	10.489	6556	797.7	20.030
B	145	7.125	4453	738.4	16.516
C	126	5.581	3488	721.5	14.944
D	122	3.977	2486	708.2	14.505
S.E.	6.5	0.651		12.4	1.792

*Weights of air dry shoots (about 11% moisture) included all the aerial parts except the grain. Moisture content of the grain was about 10%

N.B.: $\frac{\text{Yield of D}}{\text{Yield of B}} = \frac{2500}{4500}$ = 50% reduction

Experiment No 3.

Effects of Irrigation Interval and Sowing Methods on Productivity and Water Use Efficiency of Fodder Maize (Zea Mays. L.)

Experimental Site and Irrigation System:
The site was the Demonstration Farm Fac. of Agric. and the irrigation system was the traditional canal system.

Soil moisture Determination: By the gravimetric method at depths of 30 and 60 cm.

Treatments: irrigation every seven days (W_1) and every 14 days (W_2).
The irrigation treatments were combined with different sowing methods: on the flat (F), on Ridges (R) and on flat Ridges (M) (Mustabas 80cm wide).
Thus the Treatments were:

(1) FW_1
(2) FW_2
(3) RW_1
(4) RW_2
(5) MW_1
(6) MW_2

Experimental design: split plot design with the irrigation treatment as main plot and the sowing method as sub-plot with three replications.

Objective
To study the productivity and water use efficiency of fodder maize under two irrigation intervals and three sowing methods.

Results

The results are shown in Tables No1 to No 4 and figures 1, 2 & 3.

Table 1. Soil moisture depletion by maize, grown under two different irrigation intervals and three different sowing methods.

Crop Age (days after sowing)	Irrigation After 7 Days			Irrigation After 14 Days		
	Moisture depletion/day (mm)			Moisture depletion/day (mm)		
	F	R	M	F	R	M
35	4.9	4.0	5.0	4.4	2.5	4.1
49	8	6.8	6.6	6.0	3.0	4.65
63	3.8	5.0	3.9	3.3	2.9	2.7

Table 2. The effect of the irrigation interval and sowing method on fresh weight production (tons/ha) of fodder maize after 49, 63 and 77 days (final harvest).

Treatment	49 days			63 days			77 days		
	W1	W2	Mean	W1	W2	Mean	W1	W2	Mean
			a			a			a
F	33.7	18.7	26.20	42.5	20.9	31.7	41.0	29.2	35.1
			a			a			a
M	30.6	24.2	27.4	40.9	27.0	33.9	39.4	20.2	29.8
			a			a			a
R	28.6	14.3	21.42	41.3	18.6	30.0	34.1	22.0	28.1
	a	a		a	b		a	a	
Mean	31.0	19.0		41.52	22.16		38.18	23.81	
L.S.Dw	14.00	L.S.Dm	8.36	17.98	L.S.Dm	9.62	20.15	L.S.Dm	7.44
L.S.Dw m	11.82	CV(a)%	28.80	13.61	CV(a)%	27.36	10.52	CV(a)%	32.05
CV(b)%	25.12			22.31			18.02		

Table 3. The effect of the irrigation interval and sowing method on dry weight (ton/ha) of fodder maize harvested 49, 63 and 77 days after sowing (final harvest).

Treatment	49 days			63 days			77 days		
	W1	W2	Mean	W1	W2	Mean	W1	W2	Mean
			a			a			a
F	6.7	4.4	5.5	9.5	4.9	7.2	11.0	8.2	9.6
			a			a			ab
M	6.8	5.1	6.0	8.8	6.2	7.5	9.8	6.3	8.1
			a			a			b
R	5.6	3.0	4.3	9.3	4.0	6.7	9.3	5.7	7.5
	a	a		a	a		a	a	
Mean	6.33	4.18		9.19	5.02		10.03	6.70	
	ns		ns	ns		ns			
L.S.Dw		L.S.Dm			L.S.Dm		4.29	L.S.Dm	2.04
	2.38		1.79	6.04		1.70			
L.S.Dw m	2.54	CV(a)%	22.36	2.41	CV(a)%	41.94	3.09	CV(a)%	26.55
CV(b)%	25.64			18.03			20.61		

Means with the same letters are not significantly different at LSD 5%.

Table 4. Average Growth Rate (A.G.R.) irrigated at two different intervals and three sowing methods.

Treatment	Average Growth Rate (A.G.R.) kg/ha/day
FW_1	197.8
MW_1	154.3
RW_1	266.4
FW_2	34.3
MW_2	72.9
RW_2	72.9

The highest values for Average Growth Rate were obtained under the irrigation interval of seven days and the treatments RW_1 and FW_2 and the lowest A.G.R. was for the treatment FW_2. However, MW_2 and RW_2 gave the same A.G.R.

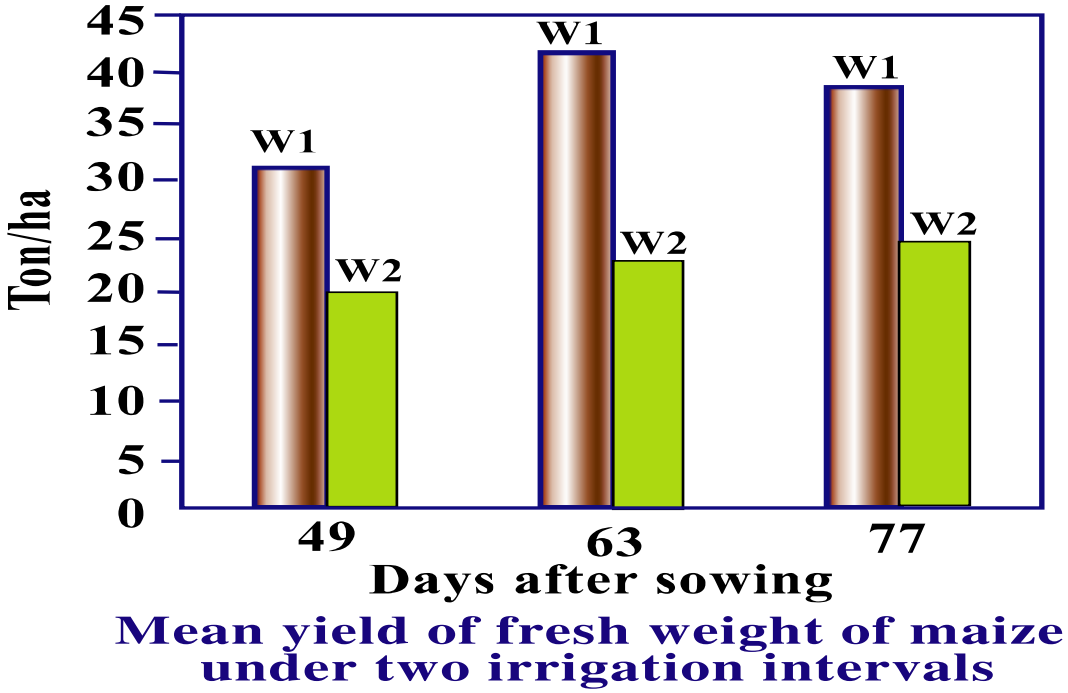


Figure 1
Mean yield of fresh weight of maize under two irrigation intervals

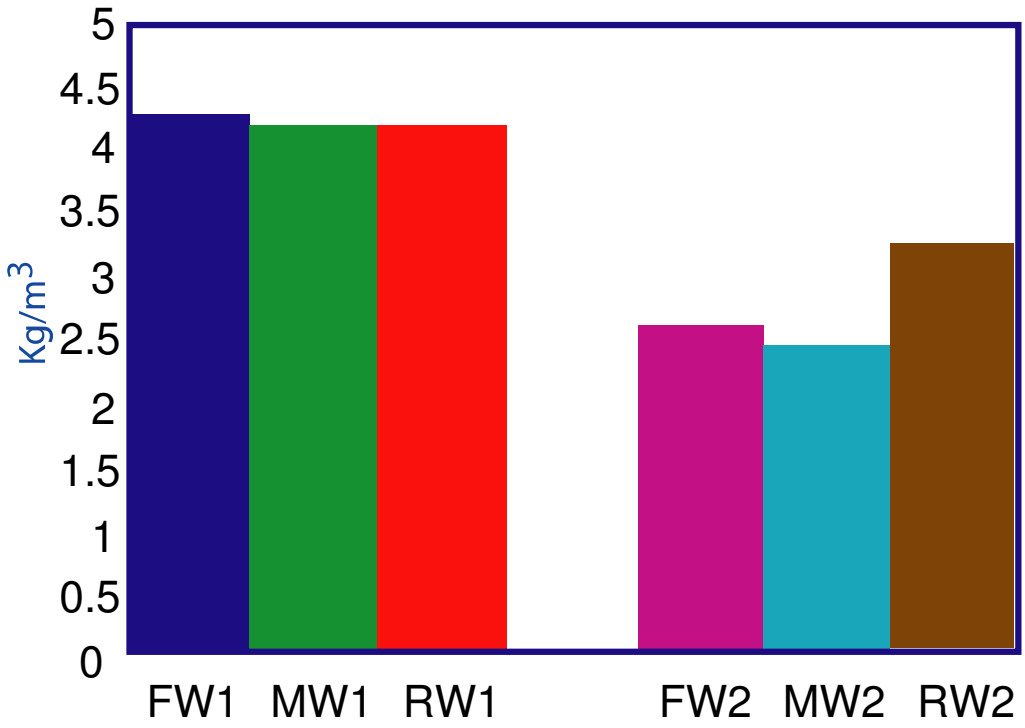


Figure 3 Water Use Efficiency under two irrigation intervals and three sowing methods

Recommendations

On the basis of the results of the five mentioned experiments the following recommendations are made:

1. The best yield of fodder sorghum can be obtained by irrigation of 7mm/day delivered every 7 days in four of the five experiments and interval of 10 days in **experiment No 3** in which the compared intervals were 10, 15 and 20 days.
2. The actual crop water requirements, (CWR), depends on the weather conditions prevailing in the growing season.
3. Seven day irrigation interval and the application of 120 Kg N/ha (3N) resulted in the highest yield of fodder sorghum and the highest water use efficiency.
4. Irrigation every seven days at 40mm (light and frequent) is recommended for fodder production of maize. This applies for kharief sowing (July/August) and also for winter sowing (Nov./Dec.). Allowance for rains for the kharief sown crop should be made whenever rain showers occur.
5. The experimental data showed that CWR can be estimated by the following relation:

$CWR = Eo \times C_f$.

Where Eo (mm) = cumulative daily potential evaporation during the irrigation interval.

C_f = the relevant crop factor for the stage of crop growth, the value of which was less than unity up to the age of 51 days after sowing

and more than one unity at the age between 61 and 71 days.This has been clearly demonstrated in experiments No 3, 4 & 5.

6. A similar irrigation schedule, (as shown in Table No 5 of Experiments 4 & 5), can be made for other crops by using the appropriate values for Eo, Kc and the irrigation interval X.
7. Provided that the crops are of similar physiological age (i.e. similar Kc), the CWR determined in any location (e.g. Khartoum State) can be used as a reference value. Therefore the CWR of the same crop grown in any other location in the Sudan can be calculated for the Relation:

$$\textbf{CWR in the new location} = \textbf{Reference CWR} \times \frac{\textbf{Reference Eo}}{\textbf{Eo for the New Location}}$$

8. In order to complete the requirements of the all-year-round irrigation schedule, the available soil moisture capacity of the soil of the different irrigated farms should be determined for the grown crops (with different effective rooting depths). This will determine the length of the irrigation interval (X).

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