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Utilization of water budget model for early season forecasting of Sorghum yield and optimum sowing date in Gadaref mechanized rain fed areas-Sudan

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ABSTRACT:

Forecasting crop yield well before harvest is crucial for food security planning decisions especially in regions characterized by climatic uncertainties. Many countries use the conventional technique of data collection for crop monitoring and yield estimation on ground-based visits and reports. These methods are subjective, very costly, time consuming and prone to large errors due to incomplete ground observations. Simulation models for the plant-soil-atmosphere systems show promise for assessing the effect of soil water on production. Development of reliable crop production models with minimal data has been a major thrust area in agricultural research. These models are intended to relate the effect environmental parameters to crop yield and production. Several crop models are potentially useful for application on semi-arid region, but a few of the more important ones that have been or could potentially be used for decision support. Grain sorghum is the main staple food for human and animal consumption in the Sudan. It is mainly cultivated in the rain fed mechanized farming system in Gadaref area and southern Blue Nile areas. Agriculture related decision-making processes often require reliable crop response models to assess the impact of specific land management decisions at farm, region, or national levels. For food security planning purposes it is essential to predict early in the season (at planting time) crop yield and to develop methods to improve and sustain crop productivity. This study investigates the potential to predict crop yield responses under varying soil and land management conditions by applying three different adaptive techniques: Hence, this study is directed to provide a procedure for establishment and early forecasting of sorghum crop yield and its biological environment by employing RAINBOW, CROPWAT, and CROP BUDGET software's under different scenarios of rainfall levels and distribution. Although the records of available yield data is not fully complete and vary in accuracy the applied models are found to be capable to fairly predict crop yield at various levels of soil moisture. It is found that yield improvements can be achieved by adopting early crop sowing in the first decade of July after the onset the early 100mm rainfall and disappearance of cracks.

Keywords: Yield Forecasting**,** Sorghum Sowing Date, water balance, Mechanized rains fed,

INTRODUCTION

Sudan's area is about 2.5 million km2, extending over different climatic zones from the desert (0-100 mm rain) in the north to the humid zones (800-1600 mm rain) in the south (Farah *et al*. 1996). Out of this area, 87 million ha are cultivable land (Buraymah, 2000). Of the total cultivable land, rain-fed agriculture occupies about 15 million ha; of which 9 million ha are in the traditional agriculture while the rest is in the mechanized agriculture. Water stress represents the main factor limiting crop yield under dry land farming conditions. In the dry land, farming system of Sudan Grain Sorghum (Sorghum bicolor L. Moench) is the dominant multi-purpose summer cereal crop. To increase production, rains fed farmers have two options: extensive systems, which expand the area planted, or intensive systems, which increase inputs on a planted area in order to increase yields. To meet immediate food demands, farmers in much rain fed areas have expanded production into marginal lands. These fragile areas are susceptible to environmental degradation—particularly erosion—from intensified farming, grazing, and gathering. This problem may be especially severe in areas of Africa where the transfer from extensive to intensive systems was slower than in other regions (Allen 1998).

The environmental consequences of area expansion make crop yield growth a better solution to increasing production. Sustainable intensification of rain fed agriculture development can increase production while limiting environmental impacts.

The future outlook for Changes in rain fed yields is dependent on policy and investment decisions on agricultural research, increase investment in rain fed areas ,effective rainfall use through improved water management,, water supply infrastructure, and other water resource investments, as well as the pace of water demand management improvement and farmers' decisions regarding on-farm management and adoption of new technologies.

Sorghum (Sorghum bicolor (L.) Moench) is the main staple food crop in Sudan and comprised 80% by weight of the cereal crops grown in the Sudan in both 2004 and 2005 (FAO/WFP. Crop and Food Supply Assessment Mission to Sudan, 15 February 2006). Grain sorghum, a well-adapted crop for central Sudan, is grown extensively under irrigated and dry land conditions. Sudan is self sufficient in sorghum production and is able to export some, in years of good production. Tens if not hundreds traditional varieties of this crop are known. Varieties exist as a function of farmers' preferences, resistance to pests and of course, agro-climatic zones. Yields of the dry land sorghum are strongly influenced by plant-available soil water content at planting and by growing season rainfall. Sorghum is a vigorous annual crop that varies between 0.5 to more than 2.0 m in height. It is adapted to a wide range of environmental conditions but is particularly adapted to drought. Sorghum is well adapted to dry conditions due to morphological and physiological characteristics, such as an extensive root system, waxy bloom on the leaves that reduces water loss, and the ability to stop growth in periods of drought and resume when conditions become favorable again. The root system consists of fibrous adventitious roots that are normally concentrated in the top 0.9 m of soil but may extend to twice that depth and can extend to 1.5 m in lateral spread. The crop is also tolerant to water logging and can be grown in very heavy textured soils or in high rainfall areas. It is, however, primarily a crop of hot, semi-arid tropical environments with 400 to 600 mm rainfall that are too dry for maize. It is adapted to poor soils and can produce grain on soils where many other crops would fail. It is adapted to high summer temperature, particularly where soil moisture is adequate. The crop thrives well in the temperature range of 16° to 40°C, through its performance is optimized at a mean temp of 27°C. It is suited to low / moderate rainfall; sorghum water requirement set the 500 mm - annual isohyets as its northern limit

It is essential for purpose of formulating a sound policy for food security in the country to predict the yield of Sorghum crop early in the season. The methods and techniques used in the past to estimate crop yield includes statistical correlation of yield with rainfall and direct crop cutting and sampling. Both methods were unsatisfactory. These because, yield is function of other climatic and soil factors beside rainfall availability. Use of crop cutting technique which is employed each season as a joint work between The Federal Ministry of Agriculture and Food Agricultural Organization of the United Nation (FAO) is criticized by its lateness, its high costs and consumption of time and efforts.

Agricultural production in the Gadarif State, eastern Sudan, is principally dry land cereals, sorghum, and pastures lands and is completely dependent on rainfall which is low, highly variable and poorly distributed. To optimize crop production in this dry land agricultural region, it is necessary to understand the effect of annual variation in precipitation -in terms of stored water within the effective root depth- on crop growth. Analysis of soil water effects on crop production requires simultaneous considerations of climate variables, crop growth and soil water availability over the complete growing season.

Between 1977/1978 and 2000/2001 the average yields in semi-mechanized and traditional areas declined by 2.0 percent and 1.1 percent per annum, respectively. The causes may be due to the lack of appropriate soil and water management practices. Determination of the length of growing season for rain fed farming system in a certain climatic zone starts by the onset of adequate rainfall that can satisfy at least half of the amount of evapotranspiration. The traditional production system in the rain fed sector relies on delayed seeding as a weed control measure. However, in most years delayed seeding result in reduced yield of sorghum. When plotting field yields against seeding date it was found that once soil moisture condition are suitable for planting (100 to 150 mm of rainfall), each week of delay in seeding result in an average of 360kg/ha decrease in yield. This has a major implication on production in the sector. The economic benefits derived from weed control through delayed seeding are less than losses resulting from delayed seeding. Agricultural research corporation reported that the optimum sowing date of sorghum crop is (15 – 30) July (Abdel Rahman, *et al*., 2005). As such, late sowing results in short growing period and thereby reduced crop yields. However, determination of the optimum time to satisfy crop water demand need to be determined via accurate, practical and user-friendly water balance model. As given before, to achieve this target the available models are hardly used in the past. Due to the spatial and temporal variability of rainfall, it is necessary to supplement rainwater by irrigation water from permanent source or to harvest and store the excess rainwater to satisfy the crop water need in the time of water deficit. In particular, this study selected Sorghum crop, due to its importance, as a focus to achieve twofold specific objectives: to predict expected sorghum yield in the rain fed areas of Gadaref-Sudan using RAINBOW,CROPWAT, and BUDGET Programs ,climate, soil and crop data and to estimate optimum sowing dates for Sorghum crop from long term climatic records.

MATERIALS AND METHODS

Study area: Rain fed semi-mechanized farming system was developed under the auspices of the government as mechanized crop production schemes in 1945 on generally alkaline clays and loams, which are not suitable for cultivation by hand or by oxen. While farms of about 42 hectare were initially based on share cropping with the government, this was not successful, and in 1953 farms were transformed into government leasehold. The area under this system of management increased rapidly and by the beginning of the 1970s was estimated to have reached two million feddan. It has spread to about 14 million feddan in the states of El Gedaref, Blue Nile, Upper Nile, White Nile, Sinnar, and Southern Kordofan (Nuba Mountains). Semi-mechanized farms are now usually well over 1,000 feddan as a result of amalgamations of leases and family partnerships. The government also allocated large tracts of land (between 2,100 and 42,000 hectare) to Sudanese and foreign investors (mainly from the Gulf countries). Land preparation, seeding, and most threshing on these farms are mechanized, whereas weeding, harvesting, and some threshing are done by seasonal labor. According to Elsafi (2007), the result of this expansion into un-demarcated areas was:

(i) Agricultural mechanization was introduced without proper land use planning and without coordination between agencies and institutions concerned with agricultural development.

(ii) A lack of control led to the introduction of tractors and agricultural machinery which proved unsuitable to local conditions.

(iii) Continuous cultivation of sorghum led to soil fertility being depleted and deterioration in yields, particularly in marginal rainfall areas in the north.

Figures (1) present areas for both irrigated and rain fed crops. Figure (2) presents the production in t/ha of these crops. Both areas and yields over time are presented for those crops which are predominantly rain fed (sorghum, sesame and millet), where it can be seen how variable both areas and yields per ha are on a year on year basis, and how this variability has become more marked in recent years. Over the last 35 years cultivated areas have increased by over 50%, but while sorghum yields have increased very slightly, sesame and millet yields have declined very substantially. Comparison of potential, research and farmer yields for sorghum crop reveals that potential genetic yield under optimal growing conditions is 2.5 for open pollinated varieties, and 3.0 for hybrid varieties and the research yield under a standard set of practices and research management is 2.3 for open pollinated varieties, and 2.7for hybrid varieties, and 0.8 as average yield on farmers/tenants' fields.

In the rain fed mechanized farming system rain fall is seasonal and mono- model and extends from July to October. Land preparation, seeding, and most threshing on these farms is mechanized, whereas weeding, harvesting, and some threshing are done by seasonal labour. Wide Level Disc is used for post harvest land preparation, pre-planting cultivation, sowing, and weeding as a combined operation. Crop rotation, fertilizer (mainly urea), herbicide application, and pest control are used in limited scale. Recently, the Federal Ministry of Agriculture issued a directive that compels each farmer to grow trees in an area equivalent to ten percent of his farm. Domestic water is obtained from dug pond (Hafir) or transported by tanker or Lorry. Fuel is stored in the field before onset of rains. The area under this system of management increased rapidly and as shown in fig (2) it has spread to 588,000 hectare in the states of El Gadaref, Blue Nile, Upper Nile, White Nile, Sinnar, and Nuba Mountains in Southern Kordofan (Figure (3).

Location: Gadaref State extends between latitudes 12º 40´and 15º 45N and longitudes 33º 34´and 37º 10´ E over 75263 km2. It is located in the Southern part of Kassala State in Eastern Sudan and the boundary of Ethiopia and Eritrea, and from Eastern direction and Southeast the State of Gazira and Sennar and shares the boundary with Khartoum State in the southeast (Figure 5). Its elevation is about 600 meters above the mean sea level. It lies between major tributaries of Blue Nile, the Rahad River and Atbara River. The State stretches from north to south over three climatic zones (Saxton 1986) with higher summer temperatures and warm winters. Rainfall is always in the summer, and most of the rain falls within the period of May to October, when the unstable air of equatorial origin reaches far northward. The climatic zones, as described Saxton 1986and Buraymah (2000) are:

- Arid zone, with rainfall varying from 200-400 mm,
- Semi-arid zone, with rainfall varying from 400-600 mm and
- Dry monsoon zone, with rainfall varying from 600-800 mm.

The above described rainfall status, together with the suitable nature of the vast stretches of dark cracking soils (Vertisols) throughout the area make Gadarif Sate to be the main state in rain fed crop production in Sudan (Elramlawi *et al*., 2007). Rainfall varies from South to North and most of the rain falls in summer in the period of May to October when the unstable air of equatorial origin reaches north. The climatic zones are classified into arid zone (200-400mm rainfall), semi arid zone (400-600 mm rainfall) and the dry monsoon zone, (600-800 mm rainfall). The temperature is high in summer and warm in winters, the lowest temperature occurs during January (15ºC) and the highest in April reaching 46ºC. The relative humidity varies between 24% in April and 73% in August Figure (4).

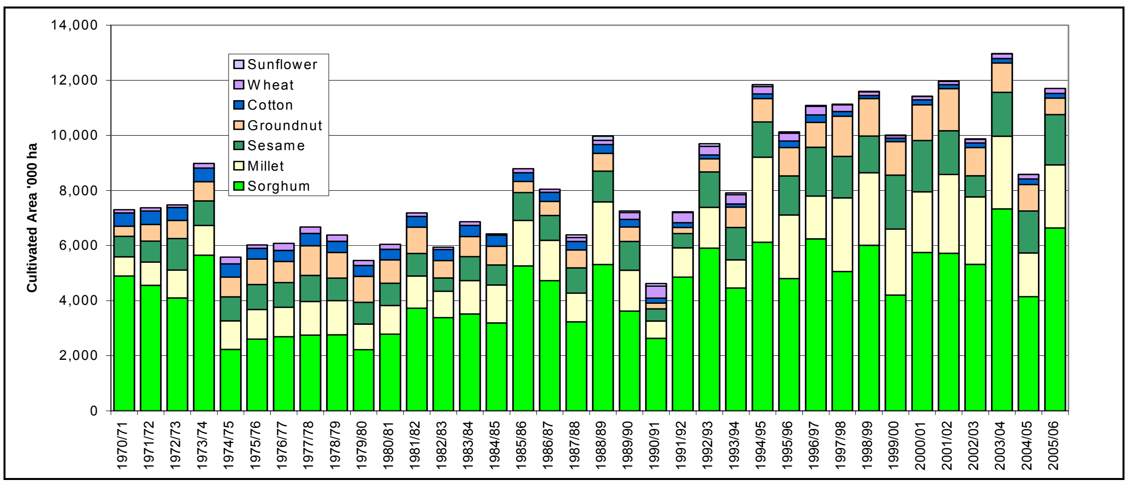

Fig 1 Area Cultivated for Major Crops

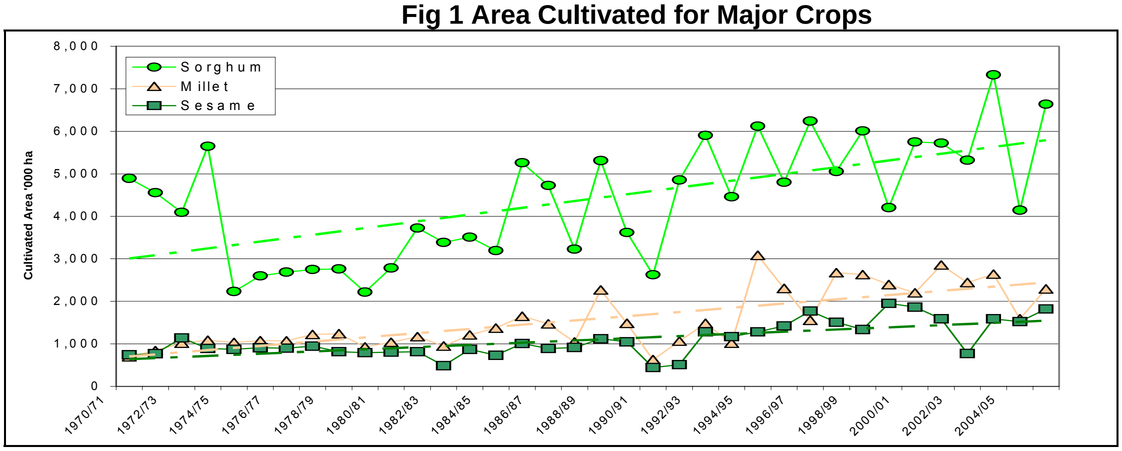

Fig 2 Areas Harvested of Sorghum, Millet and Sesame

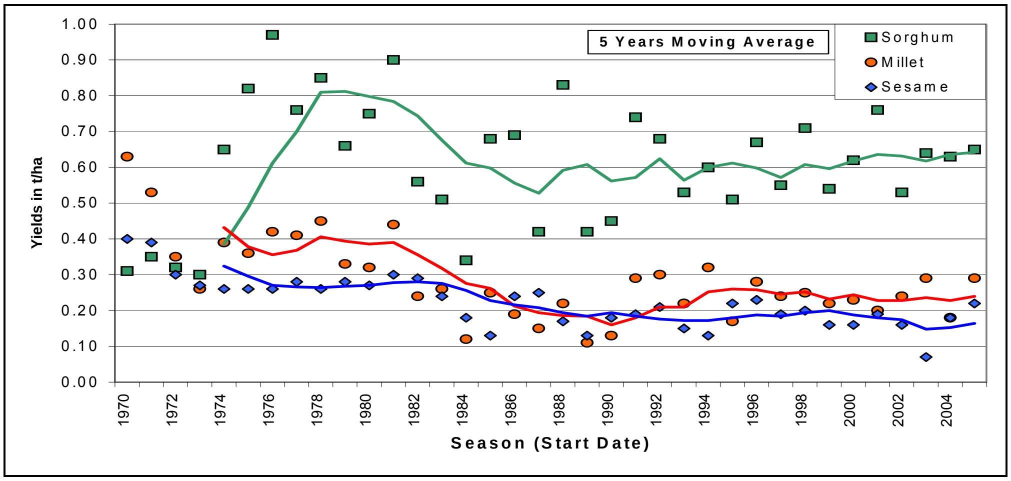

Fig 3 Trends in Yields for Sorghum, Millet and Sesame

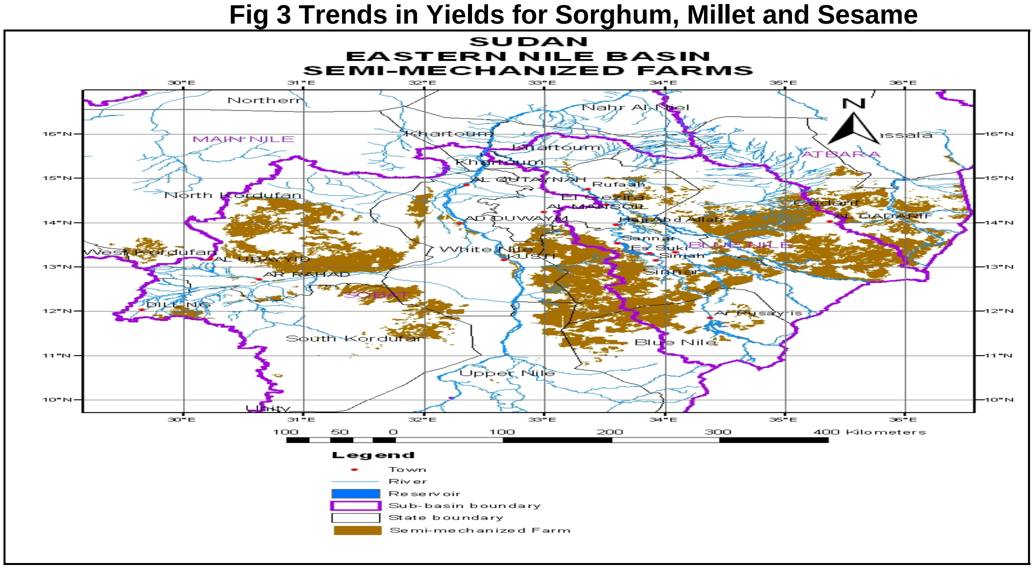

Fig. 4 Location of Rain fed semi-mechanized farming schemes

Description of the employed models:

RAINBOW is a software package for hydro-meteorological frequency analysis and testing the homogeneity of historical data sets. In RAINBOW the user can select a Normal, Log-Normal, Weibul, Gamma, Gumbel, Exponential or Pareto distribution. Apart from graphical methods (Probability plot and a Histogram of the data superimposed by the selected probability function) for evaluating the goodness of fit, RAINBOW offers also statistical tests for investigating whether data follow a certain distribution (Chi-square and the Kolmogorov-Smirnov test). When the goodness-of-fit is inadequate, one can either select another distribution or attempt to normalize the data by selecting a mathematical operator to transform the data. RAINBOW allows also to analyze time-series with zero or near zero events (the so called nil values) by separating temporarily the nil values from the non-nil values. By calculating the global probability, the nil and no-nil rainfall are combined again. When the probability distribution can be accepted, the user can view the calculated events that can be expected for selected probabilities or return periods. Frequency analysis of data requires that the data be homogeneous and independent. The restriction of homogeneity assures that the observations are from the same population. RAINBOW offers a test of homogeneity which is based on the cumulative deviations from the mean. By evaluating the maximum and the range of the cumulative deviations from the mean, the homogeneity of the data of a time series is tested.

FAO CROPWAT program (FAO 2000) has been used to calculate crop water requirements and net irrigation requirements. The CROPWAT model is a simple water balance model that simulates crop water stress conditions and estimates yield reduction based on well-established methodologies for determining crop evapotranspiration (FAO 2000) and yield responses to water (FAO 2000). This model has been used to simulate yield reduction percentage as a result of the decrease in evaporation rate.

The input data for the model are monthly climatic parameters including maximum and minimum temperature, humidity, sunshine and wind speed. The program first uses the Penman- Monteith method to calculate the reference crop evapotranspiration (ETo) then, in order to account for the effect of crop characteristics on crop water requirements, crop coefficients (Kc) are used and relate to specific stages of growth. Four distinct stages of growth are generally used: an initial stage, crop development, mid season and late season. The yield response factor Ky and the depletion fraction (p) were also estimated for selected crops by the FAO. The basic calculation procedure in this empirical model is:

$$1-Ya/Ymax = ky\ (1-Eta/Etm)$$

Where:
Ya: actual yield,
Ymax: maximum yield,
Ky: yield response factor,
Eta: actual crop evapotranspiration,
Etm: maximum crop evapotranspiration

This formula enables the degree of sensitivity to water to be taken into account in estimating yield reductions for various crops and growth stages based on the soil moisture status.

BUDGET program is composed of a set of validated subroutines describing the various processes involved in water extraction by plant roots and water movement in the soil profile (in the absence of a water table).The estimation of the amount of rainfall lost by surface runoff is based on the curve number method developed by the US Soil Conservation Service (USDA, 1994; Rallison, 1980; Steenhuis *et al*., 1995).

During periods of crop water stress the resulting yield depression is estimated by means of yield response factors. By selecting appropriate time and depth criteria irrigation schedules can be generated. Irrigation schedules can be generated by time and depth criteria as described by Smith (1985) and used in the irrigation scheduling software packages IRSIS (Raes *et al*., 1988) and CROPWAT (Smith, 1990).

The input consists of: climatic data (reference evapotranspiration, rainfall); crop parameters (parameters describing crop development, sensitivity to water stress and root water uptake); soil parameters (initial soil water and salt conditions in the soil profile); irrigation data (water quality, salinity, irrigation intervals and water application depths or criteria to generate irrigation schedules). By specifying and selecting a few appropriate crop parameters in a Menu driven environment, the program creates a complete set of parameters that can be displayed and updated if additional information is available. BUDGET contains a complete set of default characteristics that can be selected and adjusted for various types of soil layers. The program is suitable: To asses crop water stress under rain fed conditions; to estimate yield response to water; to design irrigation schedules; to study the building of salt in the root zone under a verse irrigation conditions; and to evaluate irrigation strategies.

Data collection: The data collected includes:

Meteorological data: The mean monthly data of maximum and minimum temperatures, rainfall, relative humidity, wind speed, bright sunshine hours and evaporation for Gadaref Meteorological station for the period of 30 years (1975-2004).

-Soil Data : Meheissi (1998) described the soil of the area, given in table (1), as dark brown moist and dry, clay, weak to moderate coarse prismatic structures breaking into coarse and medium angular and sub angular blocky structure, very hard when dry and firm when moist.

Table (1) Soil physical properties:

Soil depth cm	Mechanical analysis				Bulk density (gm/cm)			Cole	Water retention at %		Water available		H.C cm/h	Porosity %
	Cs	Fs	si	c	Air dry	O.D.	1/3 bar		f.c 1/3bar	DWP 15bar	Wt %	Volume		
0-15	1	2	28	69	1.79	1.73	-	-	48.3	24.7	23.6	33.4	0.23	32.45
15-45	2	2	28	68	1.88	1.88	1.03	0.22	48.5	24.8	23.7	34.2	0.72	33.58
45-80	2	2	28	69	1.85	1.87	1.1	0.22	50.9	26	23.9	36.1	0.43	30.19
80-110	2	2	28	68	1.84	1.81	1.4	0.2	53.3	27.2	26.1	37.3	0.30	30.57
110-150	1	2	27	69	1.85	1.88	1.6	0.2	52.2	26.6	25.6	37.7	0.25	30.81

(Source: Meheissi, 1998)

Table (2) Crop data

<table>
<tr><td>Total</td><td>Late (Llate)</td><td colspan="2">Mid (Lmid)</td><td colspan="2">Dev. (Ldev)</td><td>Init (Lini)</td><td>Stages</td></tr>
<tr><td>130</td><td>30</td><td colspan="2">45</td><td colspan="2">35</td><td>20</td><td>Length of stage (days)</td></tr>
<tr><td>-</td><td>0.55</td><td colspan="2">1-1.1</td><td colspan="2">-</td><td>-</td><td>Kc</td></tr>
<tr><td colspan="7">1-2</td><td>Max. crop height (h)(m)</td></tr>
<tr><td colspan="7">1-2</td><td>Max. rooting depth (m)</td></tr>
<tr><td colspan="7">0.55</td><td>Depletion fraction(for ET _ 5 mm/day) p</td></tr>
<tr><td colspan="7">18</td><td>Max ECe dS/m</td></tr>
<tr><td colspan="8">yield response factor (Ky)</td></tr>
<tr><td rowspan="2">Total Growing period</td><td rowspan="2">Ripening</td><td rowspan="2">Yield formation</td><td rowspan="2">Flowering Period</td><td colspan="4">Vegetative period</td></tr>
<tr><td>Total</td><td colspan="2">Late</td><td>Early</td></tr>
<tr><td>0.9</td><td>0.2</td><td>0.45</td><td>0.55</td><td>0.2</td><td colspan="2">-</td><td>-</td></tr>
</table>

Source: (Allen *et al*., 1998)

Crop data: Grain sorghum (Sorghum bicolor L. Moench) in Gadarif state (rain fed agriculture) usually planted in July and harvested in November with following properties:

Maximum yields of high-producing varieties adapted to the climatic conditions of the growing season , adequate water supply , and high level of agricultural inputs is 3.5-5ton/ha. Sensitive Growth Periods for Water Deficit: Flowering and yield formation are more sensitive than vegetative period. However, the vegetative period itself is less sensitive when followed by ample water supply.

- Length of crop development Stages, crop coefficients(Kc), mean maximum plant heights, Maximum effective rooting depth, maximum depletion factors, Maximum crop salt tolerance levels and Yield response factor (Ky); shown in table (2)(Allen *et al*., 1998).

Data Analysis: BUDGET software (Raes, 2003) is used as a main tool to attain study objectives. Input data need to be prepared as prerequisite to use BUDGET software. Two-computer models ETo and RAINBO (Raes, *et al*., 1996) are used to achieve this target.

Data Analysis using descriptive statistics: The data were analyzed using descriptive statistics such as Chi-square statistical test (X2) to distinguish between the estimated yield at different sowing date, three level of initial soil moisture content and four level of rainfall probability of exceedance.

RESULT AND DISCUSSION

Application of Budget Software: In order to employ Budget Model, to fulfill the study stated objectives, it is a pre-requisite to prepare the rainfall and potential evapotranspiration input data by following the required format given in chapter three.

Probability Analysis: RAINBOW program; used for calculating the probability of exceedance of Gadarif rainfall using Normal and Gumbl Probability methods. As shown in Figure (6) and (7) both the Normal probability and Gumbl methods represent rainfall distribution fairly enough (R2>0.9) figure (5) and (6). However, Normal probability method is chosen as main input for the analysis of the data collected for 30 years (1975-2004) (Raes, *et al*, 2001). Consequently, rainfall distribution and probability of exceedance and return period (Table 3) were used to estimate the expected yield, determine the optimum crop sowing date and design the optimum water harvesting and storage facility.

To certain rainfall variability in the study area the classification system suggested by (Raes, *et al*, 2001) is used. Table (4) shows that the yearly rain fall can be divided into five events (very wet years, wet years, normal years, dry years, and very dry years that represent <20%, 20-40%, 40-60%, 60-80% and >80% probability levels respectively. These results are in agreement with the results reported by (Elsafi, 2007) for the same study locality. Many scholars consider this variability in rainfall as the main cause of low yield obtained in rain fed farming (Elramlawi, *et al*, 2007; O&T Agdevco LTD, 1993).

To determine the design probable year at each probability level (of 20-40-60-80 %) both rain fall and ETo data of the specific month (May to November) for each one of the thirty years were analyzed by RAINBO program (table 5).
The figure shows that the mean reference evapotranspiration (ETo) is temporarily variable and ranges between 4.5mm in winter to 7.7mm in summer.

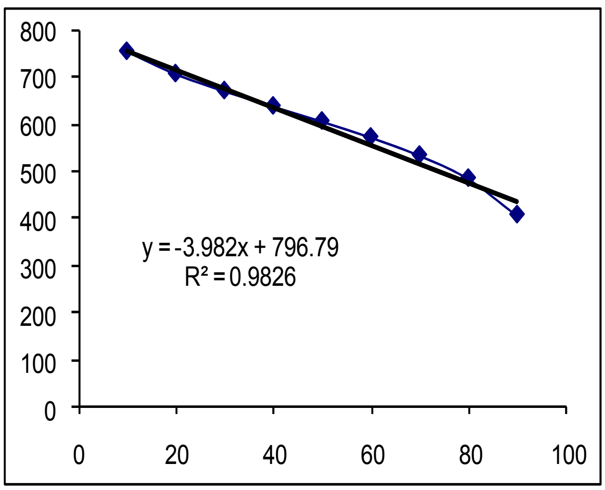

Fig 5 Normal method

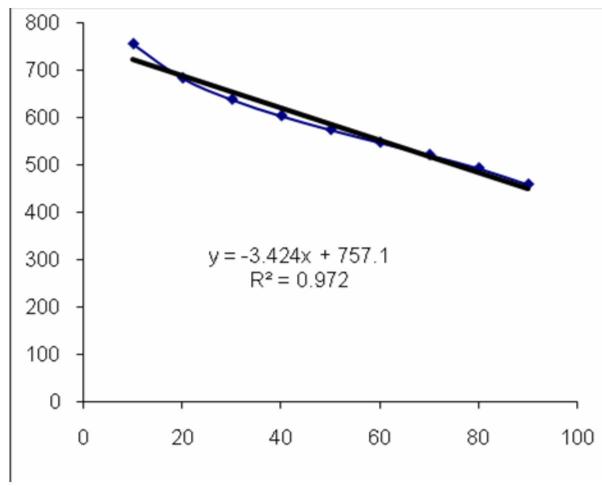

Fig 6 Gumbl method

Table 3: Rainfall probability of exceedance using normal distribution method

Return period Years	Probability of exceedance %	Event
10	10	754.6
5	20	707.2
3.33	30	671.1
5.5	40	638.5
2	50	606.6
1.67	60	572.9
1.43	70	534.5
1.25	80	485.6
1.11	90	408.2

Table 4 Rainfall years divided into five events:

Years	Rain fall (mm)	Type of years	Years	Rain fall(mm)	Type of years
1979	778.6	Very wet	1988	577.5	Normal
1985	714.5	Very wet	1992	596.8	Normal
1993	777.3	Very wet	1997	590.3	Normal
1999	802.1	Very wet	1998	584.5	Normal
2002	753.8	Very wet	1982	526.2	Dry
1996	737.9	Very wet	1987	503.4	Dry
1989	770.2	Very wet	1990	563.9	Dry
1994	669	Wet	1995	528.5	Dry
2000	644.1	Wet	2001	505.9	Dry
2003	646.6	Wet	2004	560.9	Dry
1975	610.8	Normal	1976	448	Very dry
1980	598.4	Normal	1977	428.1	Very dry
1981	624.1	Normal	1978	398.2	Very dry
1983	590.8	Normal	1984	322	Very dry
1986	604	Normal	1991	424.8	Very dry

Table 5 Values of ETo and Rainfall at specific probability level:

Nova	Oct	Sep	August	July	June	May	Probability	Return period
5.4	5.4	5.6	5	9.5	6.7	7.5	20% ETo	5
0.8	79	113.9	286	259.4	116.4	46.2	RAIN	
5.3	5.2	5.4	4.8	7.4	6.5	7.2	40% ETo	2.5
0	49.6	91.6	228.7	209.3	87.1	29.9	RAIN	
5.2	5.1	5.2	4.7	5.6	6.2	7.1	60% ETo	1.67
0	22.8	72.5	179.4	166.3	61.8	15.6	RAIN	
5.1	4.9	5	4.5	3.5	6	6.8	80% ETo	1.25
0	0	50.2	122.1	116.2	32.5	0	RAIN	

Potential Evapotranspiration (ETo): Figure (7) shows the monthly ETo calculated from the long-term climatic records of El Gadaref Town using Penman-Monteith (FAO) and ETo software.

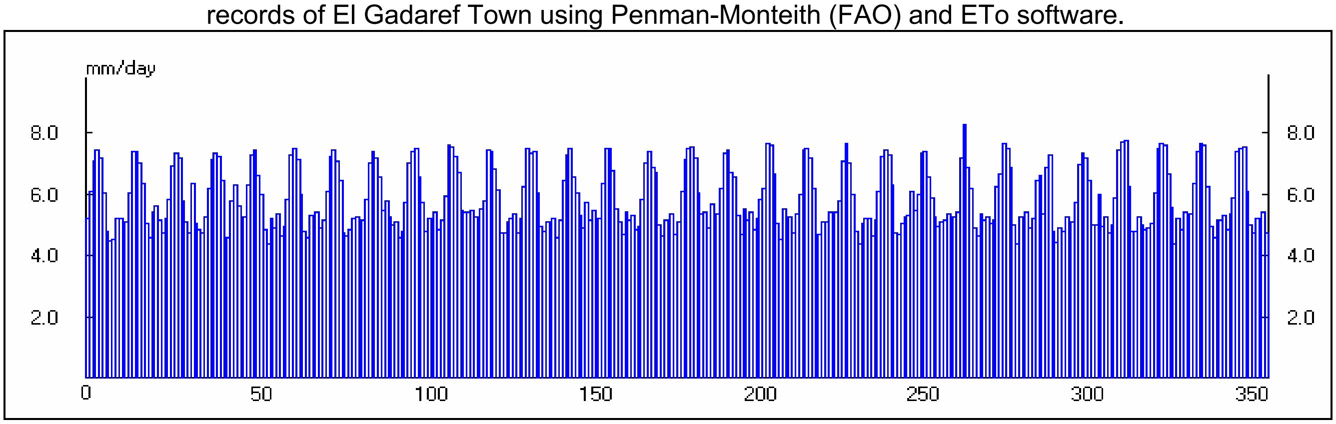

Fig (7) Monthly Gadaref Potential Evapotranspiration (ETo)

Table 6 Average crop yields (kg/feddan) and area planted (000 feddan) for 2005/06 as compared to 2003/04, 2004/05 and (1996/7 -2000/01 average).

Sudan				2005/06			2004/05			2003/04			1996/97-2000/01			Year / Crop
05/06	04/05	02/03	96-01	TrR	McR	Irrigat.	TrR	McR	Irrigat.	TrR	McR	Irrigat.	TrR	McR	Irrigat. *	
274 124	265 74	269 122	249 119	279 121	211 147	778 400	215 71	196 124	873 150	246 114	240 168	740 135	201 116	211 179	802 229	**A.Yield (kg/fed)** Sorghum
204534	15282	19949	16112	7741	11607	1105	6124	8209	949	8324	10608	1017	5755	9337	1020	**B. Area (000fed) Sorghum**

***** Irrigat.= Irrigated, McR= Mechanized Rainfed, TrR= Traditional Rainfed.
Source: Ministry of Agriculture, Khartoum, Sudan. April 2006.

Yield prediction: If one examines yield of rainfed sorghum (the most important food crop in Sudan), the trend has remained stagnant or has declined1 during the last decade. The trends in Table 6 reveal the decline in yields and minimal differences between average sorghum yields in the fertile semi-mechanized areas and the less fertile traditional farming areas during 1996-2006. The reasons need to be explored but they almost certainly include (i) a reduction in fertility in areas that have been continually cropped for decades in the semi-mechanized areas without fallow and no conservation practices; (ii) the well-documented expansion of sorghum cultivation into marginal areas (both semi-mechanized and traditional) where the probability of substantial destruction of soil structure, soil erosion, and hence low yields is close to 100 percent; and (iii) in the traditional rainfed sub-sector, particularly, the low yields reflect a serious lack of support services such as research, extension, high yielding varieties, certified seeds, pest and weed control, fluctuation of rain fall and credit for smallholders.

Estimate of grain yield is one of the main objectives in the studies of crop yield modeling. Table (7) and figure 8 shows the actual yield (Ya) and estimated yield (Ye), at probability level of exseedance of 20, 40, 60 and 80% for the predicted design years.

The discrepancy between the Ya and Ye, may be explained by the differences in agriculture inputs used or error in data collection (FAO, 2000). Recall that the model is based on the assumption of ideal agronomic practices and no short of inputs. However, the reality is different and actual yields are repeatedly reported to be less than expectations (O&T Agdevco LTD, 1993).To narrow the difference between the model results and the actual yield the given regression equation of figure (8) can be used with confidence (R^2=0.89) to calibrate the estimate of the real yield.

Sowing date: The graphical relation between rainfall (which represent water supply) and ETo (which represent crop demand) were usually used in clay soil to determine the optimum crop growing season (Adam. 2002). Table (8) depicts optimum sowing date estimated graphically and those predicted by the developed model at three levels of initial soil moisture, and four probability levels of ETo and rainfall. It is evident from table (8) that:- At lower initial moisture level (at permanent welting point PWP) the result of the model and the graphical solution do not agree what even.

-The probability of the rain moisture status (high, medium or low). This indicates that an initial moisture level above the PWP is a prerequisite to start sowing of sorghum crop. This result is in agreement with actual farmer practices. Farmer in study area usually sow their crop after cracles disappeared by rain water. In similar trend ten years of studies of optimum sowing date in somas project indicated that the suitable soil moisture to start sowing is 100% to 150% of rainfall and each week of delay in seeding results in an average of one bag per feddan decrease in yield.

At medium initial soil moisture level the optimum sowing date comes late in severely dry years 80% probability. For initial wet years (20% probability) both the graphical solution (figure 9) and model result (table 8) agreed in recommending sowing sorghum crop during the last decade of July.

The farmer general practice is to delay sowing so as to mechanically weed their field. However, report from semis project (O&T Agdevco LTD, 1993) confirm that the economic benefit derived from weed control though delayed seeding are less than losses resulting from delayed seeding. In order to plan planting the merest scenario of dry years (60% rainfall probability & 80% ETo probability) is shown in table (8) and graphically in figure (10).

This case of sowing at the recommended initial moisture level (50% of total available water) but at dry condition support early planting at the 1st decade of July and agree with (O&T Agdevco LTD, 1993) recommendation of early planting.

- When there is high initial soil moisture level (75%) in dry years both the graphical solution (figure 11) and the model result recommended planting the crop late in the first decade of August.

The model bar chart of figure (12, 13 and 14) indicate that if there is early rainfall that fill the soil moisture reservoir to 75% (150mm) it may be possible to delay sowing to early August but since rainfall can must be assured it is advised to sow in early weeks of July.

Similar advice hold if early rainfall is sufficient to fill 50% of the soil moisture reservoir (no cracks) and even the years is dry. The established practice in Sudan central clay plains is generally to sow sorghum crop in the first two decades of the month of July but actual date to start sowing at dry years is function of the onset early rainfall. As general role if early rains are very high the crop shall be subjected to water bonding and un aerobic conditions hence, it is advices to delay sowing.

In contrast during normal rainfall conditions highest yield is expected by the model with early July sowing (figure 12).

Table (8) model results do not agree in all cases with those obtained by the graphical solution. This can be attributed to the fact RAINBO model is based on crop coefficient and crop evapotranspiration while the graphical solution depends on only potential evapotranspiration.

Table 7 Actual and Estimated Yield (at 50%initial water content and sowing at 21July)

Ratio %	Actual Yield (kg/ha	Estimated Yield (kg/ha)	Probability
21.5	737.1	3430	20%
20.8	605.4	2905	40%
16.7	492.2	2940	60%
15.8	360.5	2275	80%

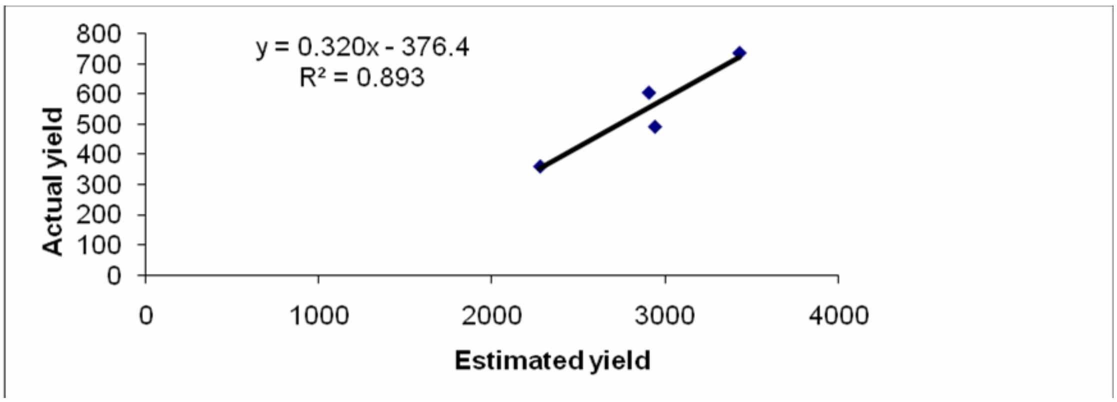

Fig (8) Relationship between Actual and Estimated Yield

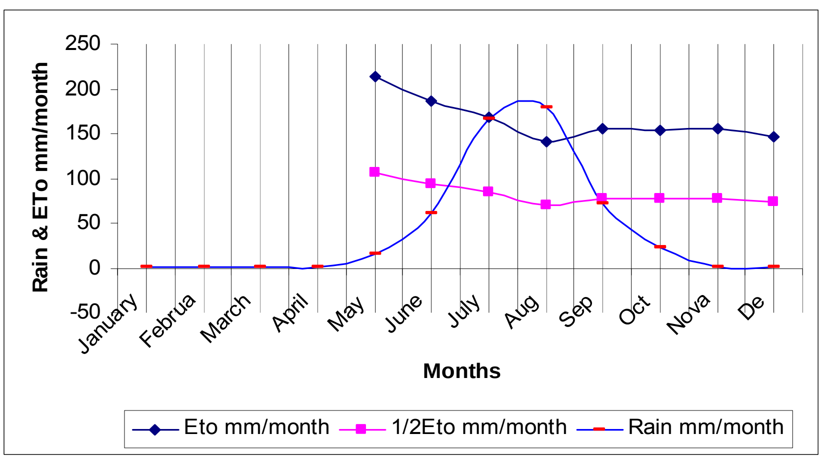

Fig 9 Rainfall and ETo at probability (20, 40) % respectively

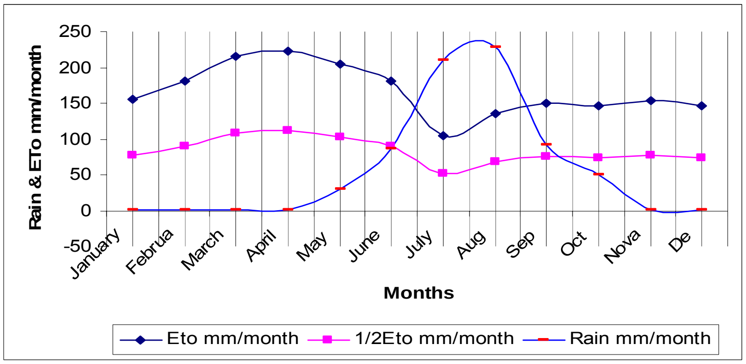

Fig 10 Rainfall and ETo at probability (60, 80) % respectively

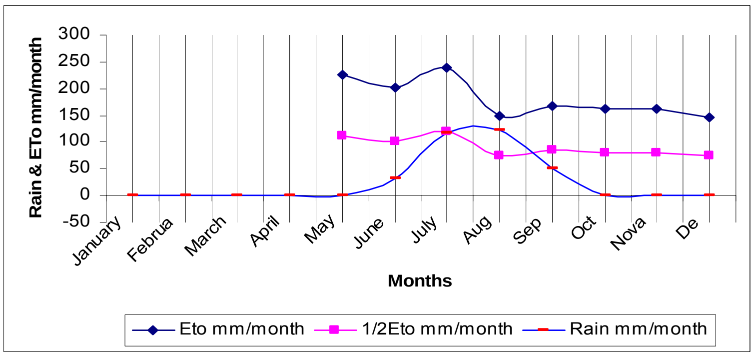

Fig. 11. Rainfall and ETo at probability (80, 20) % respectively

CONCLUSIONS

Even though there were some differences between actual and estimated sorghum grain yield, the overall results of the model application were reasonable (R^2 = 0.89). The BUDGET program is not a 100% indicator to specify the actual yield. This calls for revising BUDGET program by adding additional modules to consider other factors of production (e.g. diseases).

At medium initial soil moisture level the optimum sowing date comes late in severely dry year's 80% probability. For initial wet years (20% probability) both the graphical solution and model result agreed in recommending sowing sorghum crop during the last decade of July

At dry condition the results obtained support early planting at the 1st decade of July. When there is high initial soil moisture level (75%) in dry years both the graphical solution and the model result recommended planting the crop late in the first decade of August.

There is a lack of information related to phonological and physiological aspects of different variety of sorghum crop in different agro-climatic zones of Sudan. Therefore, it is very important to carry out a scientific research to specify root depth, crop coefficient, depletion factor and water-yield response factor in accordance with the length of different growing periods.

By linking a robust soil water model with crop water productivity subroutines, the expected crop development and yield for a specific growing condition can be estimated with a curacy. The employed procedure is very useful for the design and evaluation of irrigation strategies and for the planning of rain fed agriculture. Use of the procedure, for the case of Sudan, shows that there is significant potential to increase cereal production through rainfall water management and other means. Therefore, investments in agricultural infrastructure and research are an essential complement to efforts to improve water use efficiency through investments in water management and infrastructure. Improved water management and crop productivity in rain fed areas would relieve considerable pressure on irrigated agriculture and on water resources. The estimated yield values clearly show that sorghum are being produced under conditions of water stress, with a pronounced effect on yields. This means that different crop and soil water management practices need to be adopted, such as: (i) maximum use of rainfall (early planting, water harvesting, runoff reduction, etc.); (ii) minimizing water loss (evaporation reduction by mulching or rapid crop cover, wind shields, minimum tillage, weeding etc.); and (iii) being water-efficient (planting low water consuming crop species, adapting fertilization to the water available, optimal planting and seeding, selection of varieties that can complete their cycle within the length of the climatic growing period, etc.). These strategies allow a better use of the available water at the farm level. The government should also take responsibility for formulating and implementing policies that will help the agricultural activities of the country to adapt to water stress conditions.

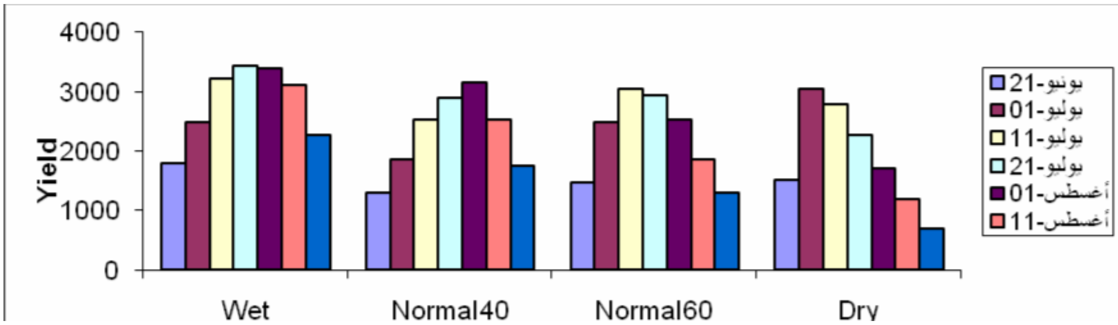

Fig. 12 yield in different Rainfall probability (sowing at 50%TAW soil moisture content)

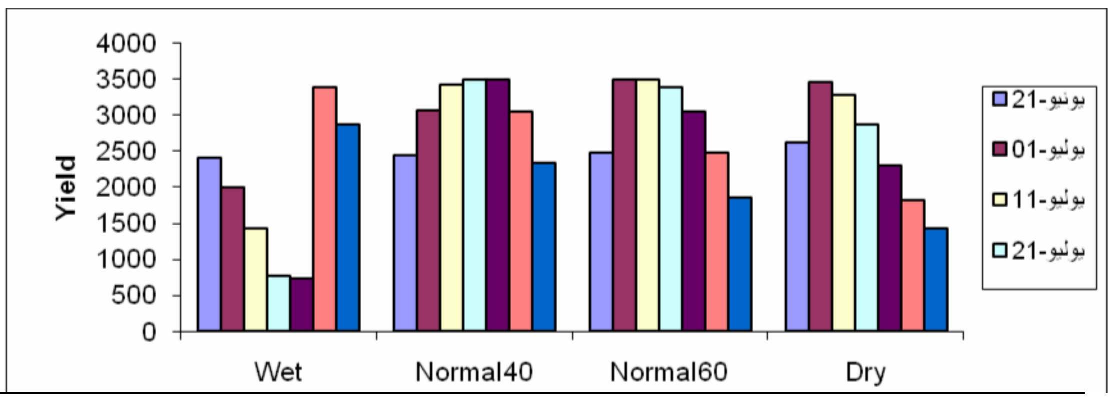

Fig 13 yield in different Rainfall probability (sowing at 75%TAW soil moisture content)

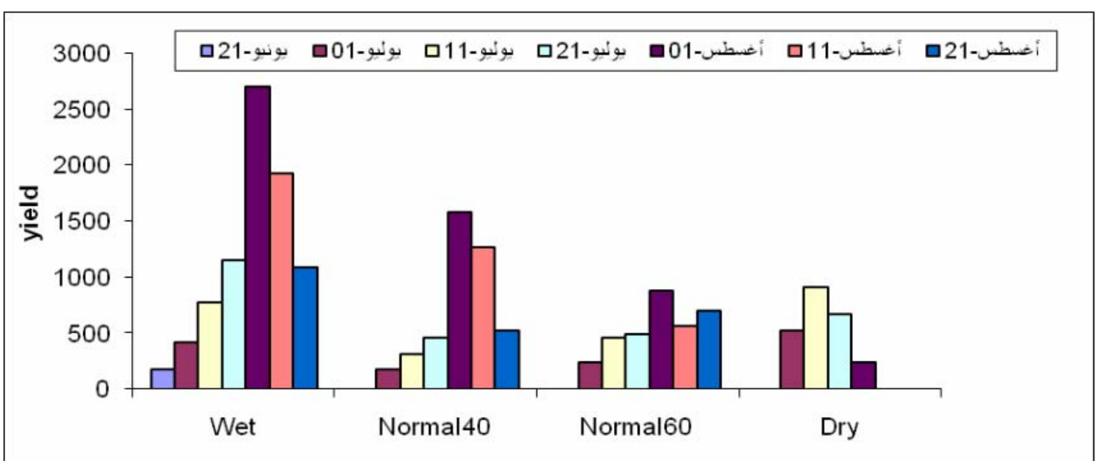

Fig 14 yield in different Rainfall probability (sowing at pwp)

Table 8. the sowing date obtained by model and graphical method:

Graph	Model	Probability %		
Sowing date	Sowing date	Eto (mm/month)	Rainfall(mm/month)	I.W.C
25 /6– 25/7	1/8	20	20	50
11/7 -1/8	11/7 -1/8	40		
25/6 – 15/7	1/8	60		
25/6 – 20/7	1/8	80		
5/7– 8/8	1/8	20	40	
3/7 – 3/8	1/8 -11/8	40		
2/7 – 21/7	21/6 - 21/7	60		
1/7 – 15/7	21/7	80		
5/7 –18/7	1/8	20	60	
14/7 –15/8	11/8	40		
25 /6– 10/7	11/7	60		
1/7 - 11/7	1/7 - 11/7	80		
1/8	1/8	20	80	
1/8	1/8	40		
21/7	1/8	60		
14/7 -27/7	1/7	80		
25 /6– 25/7	11/8-21/8	20	20	75
11/7 -1/8	11/8	40		
25/6 – 15/7	11/8 - 21/8	60		
25/6 – 20/7	11/8	80		
5/7 – 8/8	21/7 - 1/8	20	40	
3/7 – 3/8	11/7 - 1/8	40		
2 /7 – 21/7	11/7 - 1/8	60		
1/7 – 15/7	1/8	80		
5/7 –18/7	1/8	20	60	
14/7 –15/8	21/7 - 1/8	40		
21/6 - 1/7	21/6 - 1/7	60		
1/7 – 15/7	21/6 - 21/7	80		
1/8	1/8	20	80	
1/8	1/8	40		
21/7	11/7	60		
14/7 -27/7	1/7	80		
25/6 – 25/7	1/8	20	20	PWP
10/7 –1/8	21/8	40		
25/6 – 15/7	21/8	60		
25 /6– 20/7	21/8	80		
5/7 – 8/8	1/7	20	40	
3/7 – 3/8	11/7	40		
2/7 – 21/7	11/8 - 21/8	60		
1/7 – 15/7	11/8 - 21/8	80		
5/7 –18/7	21/7	20	60	
14/7–15/8	11/7	40		
25/6 – 10/7	11/8 - 21/8	60		
1/7 – 15/7	21/8	80		
1/8	21/8	20	80	
1/8	21/8	40		
21/7	21/8	60		
14/7 -27/7	21/8	80		

I.W.C=Initial water content **Eto** = Potential evapotranspiration

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