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Sunflower Crop Irrigation in Autonomous Regions: Case of Hetao District; Inner Mongolia, China

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Abstract

Irrigation is a main factor for agricultural development, given the place occupied by agriculture and the weight of the food bill. Suitable researches on irrigation are necessary for this operation and for better water resources managements. . Hetao Irrigation District has uneven climate distribution and irregular basis water during the agricultural year. It faces major water shortage problem, low and irregular rainfall. The Yellow River is the second largest River in China. The River basin is an area with severe water scarcity, with less than 500 m3 per capita per year, accounting for 81 % of the total water use, the head stream of the Yellow river basin becoming drier due to climate change.. The increased water abstraction for industrial, domestic and hydropower uses exacerbate water scarcity in the basin. Due to this water scarcity conditions the middle and low reaches of the river dried up 21 times during 1972-2008, with 226 days of no flow in 1997. The current research aims at providing an optimal irrigation scheduling to sunflower crop, by supplying the right amount of water at the right time, in order to increase crop yield and achieve 70% field efficiency. The results shows that, The water deficit vary between 2.8 mm/day to 3.09 mm/day from 2001 to 2008; crop water requirements between 247.4 mm and 392.7 mm and net irrigation water requirements between 300.8 to 459.3 mm

Keywords: Reference evapotranspiration; ArcGIS, Cropwat; Optimal Irrigation Scheduling; Sunflower

1. Introduction

Inappropriate irrigation and drainage systems have resulted in rising groundwater levels which have the potential to trigger salt accumulation in the soil profile and have a negative effect on crop production (Quadir et al., 2009). In addition, limited precipitation, high evaporation and inadequate soil and water management have contributed to increase salinity. Therefore, effective techniques for controlling soil salinity and increasing water productivity should be developed to crop with these challenges (Dong et al., 2010a and Dong et al., 2010b). Annual average water diversion from the Yellow River is 5.165 billion m^3 (from 1980 to 2000), which account for about 1/10 of average annual river discharge of 53.5 billion m^3 measured at Huayuankou station from 1956 to 2000. However due to the impacts of human activities and climate change, runoff within the Yellow River basin has decline significantly during the past fifty years (Fu et al., 2004; 2007). The global and regional projections showed warming trends are likely to continue in the region during the 21st century (Houghton et al., 2001; Nijssen et al., 2001) which will further decrease runoff and exacerbate water resource shortage in the basin.

To reduce soil salinity and increase crop yield, flood irrigation has always been used. The surface irrigation techniques result in an excessive intake of water. The flood irrigation leads to use of more than 90% of diverted water to produce the crop. Sunflower 'Helianthus annuus L.' is one of the important economic crops in this area, although sunflowers are classified as a salt-tolerant crop, they are also sensitive to salinity in the growth and development stages, especially during the emergence and early seeding stages. Reducing root salinity is one beneficial strategy to improve sunflower emergence and stand establishment in saline fields. The present research used Geographic Information System (GIS) for spatial analyses and CROPWAT software version 8.0 to develop irrigation schedule based on the time to irrigate and the amount of water required. To accomplish the indicated purpose the following objectives were set: (1) to estimate monthly evapotranspiration during crops growing season from climatic data using CROPWAT model version 8.0; (2) to determine effective rainfall using USDA SCS method; (3) to determine crop water requirement and develop an optimal irrigation scheduling in the Hetao Irrigation Districts; (4) to analyze and compare the optimization and the traditional method to reduce water losses in Hetao Irrigation District; (5) To determine the irrigation water supply for sunflower crop in terms of frequency and irrigation depth, assuring optimal irrigation crop growth and efficient water use. Result from this study will provide important information for further studies on irrigation scheduling in the Hetao irrigation District.

2. Study Area

The Hetao Irrigation District is located (N 40.1°-41.4°E 106.1°-109.4°) in the western part of Inner Mongolia Autonomous Region, North China, (Figure 1). The area is characterized with a typical continental climate, being very cold in winter with little snowfall and very dry in summer. Average annual temperature is about 5.6 -7.4°C. Most parts of the study area is plain with the elevation slightly higher in the south-west and lower in the northeast (a.s.l. 1028 -1062 m), except for a mountain region in the north-west of Dengkou County (a.s.l. 1059-

2012 m). Besides, in the central and southern part of Dengkou County, there is an extensive area of sandy land and Gobi desert. The groundwater table ranges from 0.8 to 2.6 m annually, and the soil texture is silt-clay loam with salinity (Yu et al., 2010). About 75% of the District has mild to moderate soil salinity and 25% has severe soil salinization. Hetao is one of the three largest irrigation Districts in China, covering an area of 1.12Mha, major part (570,000 ha) of it is irrigated land. In the Shahaoqu Experimental Station soil texture, salinity, and groundwater were considered as a representative of the region's hydrogeology. The site receives 136 mm of annual precipitation and potential evaporation is 1938 mm. The average number of sunlight hours per month is 266 h. Cumulative annual solar radiation is about 6000 MJ m-2. Soils begin freezing in the second half of November and freezes to a depth of about 1.0–1.3 m, and completely thaw in the middle of May. The duration of freezing-thawing is about 180 days. Sunflower is predominant crop in the irrigation district. The growing season for sunflower is planted in late May, and harvested in mid-September (Augustin, et al, 2015).

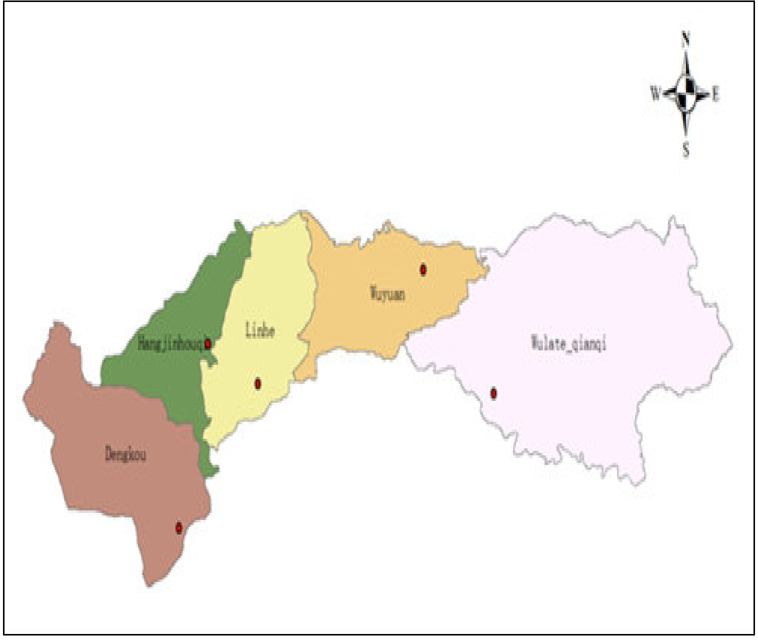

Figure 1: Hetao Study area

3. Methodology and Data collection

The project database was created in a three steps processes. The steps are: designing the database, automating and gathering data, and managing the database. These data was processed in multi-platform software (Arc catalog, Arc/Info and ArcGIS ...) to develop a rich base of hydrogeological data for manipulation, updating and personalized viewing different results.

Sunflower (Helianthus annus L.) is one of the most important economic crops in Hetao area. Under conventional tillage regimes, several techniques, such as inorganic fertilizer, soil amendments, and mulching with different materials, have been used to increase sunflower yields (Qadir et al., 2000 and Chen and Dong, 2008). However this field practices have always followed abundant water input. Conversely, mismanagement of fertilizer and water application results in salt accumulation (Darwish et al., 2005). The sunflower root system is dense in the upper 20 cm of the soil layer, with a trend toward rooting downward (Hu et al., 2013). Therefore, maintaining soil salinity levels within acceptable crop production limits in this layer should be the primary goals of soil and water management (Bezborodov et al., 2010). Mulching with different materials has been demonstrated to reduce water evaporation (Li et al., 2013 and Pabin et al., 2003), improve fallow efficiency and increase the amount of stored soil water available for plant use (Wang et al., 2001), and reduce salt build-up in the soil (Pang et al., 2010). Carter (1998) observed that mulching results in higher soil moisture during the entire crop growth period and provides the best opportunity for increasing crop productivity. Deep tillage with no mulch (CK,) deep tillage with straw mulch SM and. Combined application of straw mulch and burying of a maize straw layer (12 ttha-1) at a depth of 40 cm (SM + SL). Except the second half of the growing season, soil moisture at the 0-40 cm depth was higher with SM + SL than CK. Furthermore, straw mulch and straw layer (SM + SL) promoted sunflower growth, as indicated by taller plants and greater leaf area indexes.

Table 1: Sunflower Crop data

Dry crop Data: (File: Hh-Sunflower CRP)					
Crop Name Sunflower:		Planting Date: 18/05			Harvest: 24/09
Stage	initial	Dev.	Mid.	Late	Total
Length (days)	25	35	45	25	130
Kc values	1.15		1.25	0.35	
Rooting depth (m)	0.3		1.5	1.5	
Critical depletion (p)	0.55		0.55	0.55	
Yield response (f)	0.4	0.8	0.6	0.3	0.95
Crop height (m)			2		
CROPWAT 8.0					

3.1 Modelling

It is known that there are many methods for calculation the crop water requirements and irrigation water requirement such as direct method (water balance) and indirect method (energy balance). Cropwat 8.0 is a computer program for calculating crop water requirements and irrigation requirements based on soil, climate and crop data is used in this research. In addition, the program allows development of irrigation schedules for different management conditions and calculation of scheme water supply for different crop patterns. It can also be used to evaluate farmer's irrigation practices and estimate crop performance under both rain-fed and irrigated conditions (Augustin, et al, 2015). All calculation procedures used in cropwat 8.0 are based on two FAO publications of irrigation and drainage series, namely, No. 56 "crop evapotranspiration-Guidelines for computing crop water requirement"(1998) and No. 33 titled "Yield response to water requirements" (1979)

Once all the data are entered, cropwat 8.0 windows automatically calculating and the results are showed in table form or in graphic form. The output parameters for each crop in the cropping patterns are: Reference crop evapotranspiration (ET_0) (mm/day); Crop Kc: average values of crop coefficient for each time step;Effective rain (mm/day): the amount of water that enters the soil; Crop Water Requirements, CWR or ETm (mm/dec); Irrigation Water Requirements: IWR (mm/dec); Total Available Moisture, TAM (mm); Readily Available Moisture, RAM (mm); Actual crop evapotranspiration, Etc (mm); Ratio of actual crop evapotranspiration to the maximum crop evapotranspiration. ETc/ETm; Daily soil moisture deficit (mm); Irrigation interval (days) & irrigation depth applied (mm); Lost irrigation (mm), irrigation water that is not stored in the soil (i.e either surface runoff or percolation); Estimated yields reduction due to crop stress (when ETc/ETm) fall below100 %.

Table 2: Cropwat model

Data	Input	Output
Climate	ET_o calculated with PenmanMonteith Rainfall Data	Crop Water Requirements Irrigation Requirements
Crop	Kc, crop description, maximum. rooting depth, % Area covered by plants	Actual crop Evapotranspiration
soil	Initial soil moisture condition and Available Soil moisture	Daily Soil Moisture Deficit Irrigation Scheduling
Irrigation	Irrigation Scheduling Criteria	Estimation Yield Reduction due to crop stress

The evapotranspiration (ET_0) was computed by Penman-Monteith Model, which is based on the FAO guidelines No. 56 of the irrigation and drainage series "crop evapotranspiration-guidelines for computing crop water requirement" (FAO, 1998). FAO-56 PM ET_0 equation by Allen et al. (1998), is given in equation (1):

$$ET_0 = \frac{0.408\Delta(R_N - G)\gamma(\frac{900}{T+273})u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

Where:

ET_0 = the grass reference evapotranspiration (mm/day); R_n = the net radiation at the crop surface (MJ/m);
e_s = the saturation vapor pressure (kPa); e_a = the actual vapor pressure (kPa);
$e_s - e_a$ = the saturation vapor pressure deficit (kPa); Δ = the slope vapor pressure curve (kPa/°C); and γ = the

psychometric constant (kPa/°C).

All these variable turn around the water balance (Fabien Langlois, 2006) written in the following general form:

$$CWR = K_C^{*}ET_0 \qquad (2)$$

Effective Rainfall: After ET estimation, using Penman-Monteith the effective rainfall was calculated with the following formula based on monthly rainfall, USDA-SCS method.

$$P_{eff} = \frac{P_{int}(125 - 0.2P_{int})}{125} \qquad (3)$$

Or when rainfall is below 250 mm, effective precipitation (mm) is calculated using equation

$$P_{eff} = 125 - 0.2P_{int} \qquad (4)$$

Where:
P_{eff} = effective precipitation (mm); Pint = soil water content per day (mm).
The following equation is a water production function and can be applied to all agricultural crops, i.e. herbaceous, trees.

$$1 - \frac{Y_a}{Y_m} = K_y\left(1 - \frac{ET_a}{ET_m}\right) \qquad (5)$$

Where: Y_m and Y_a are the maximum and actual yields, ET_m and Et_a are the maximum and actual evapotranspiration. The response factor performance (K_y), is a yield response factor representing the effect of a reduction in evapotranspiration on yield losses.

4. Results and Discussion

4.1 Evaporation

The values of monthly average reference evapotranspiration by FAO formula is between (0.47 to 3.08 mm) in 2008. The peak month for the climate demand (ET_o) is Jun with a daily average of 5.8 mm. table 3 show the annual evaporation data in Hanghou from 2000 to 2009. The latitude and longitude are N 40.15 and E 107.88 and the values from January through December of the average monthly evaporation recorded during the study period at this location, ranging from 15.4 mm in January (2005) and 406 mm in February (2008). The evaporation data were obtained from agro-meteorological station in Hetao. As shown In Figure 2, the annual evaporation map show the lower value of Hanghou and a general tendency for lower evaporation values of Qiangqi to the East and higher values to the Wuyuan, Linhe and Dengkou to the West.

CROPWAT was used to calculate the average monthly reference evapotranspiration (ET_0) values using the Penman-Monteith method. The ET_0 during the year 2008 was between 0.47 mm/day to 0.92 mm/day in January to April and 5.73 mm/day to 5.47mm/day during the months of May to July. The crop factor Kc (Table 1) is influenced by irrigation methods and production practices such as irrigation intervals, ground cover at full growth stage and the wetted area. Development of CROPWAT illustrates the variation of crop factor for the sunflower during the growing period from late May to September.

Total monthly effective rainfall during the growth period of sunflower in this study is varied between 1.4 mm to 58.1 mm, with peak rainfall during the month of July. The effective rainfall was 150.3mm calculated using CROPWAT reference evapotranspiration which is far less than crop water requirements (392.7). In addition, the reliability and the distribution of the effective rainfall in the study area is not guaranteed. This is a clear evidence for the need to irrigate for sustainable agriculture. Crop water requirements are affected by rainfall, temperature, humidity, wind speed and radiation. A high intensity of irradiation results in a high rate of water evaporation from soil and plant surface. Table 4, shows application to 100 % of field capacity with irrigation at 100 % depletion achieved 70 % of field efficiency. Also the run 6 with an application of 40 mm (more convenient for sunflower) at critical depletion given optimal irrigation, so the yield reduction was “zero”. These met conditions and data for the optimal irrigation treatment (with no stress water applied). Second step with water stress consisted of application at 40 mm after 40 mm depletion, 40mm every 7 days, 40 mm every 10 days, and application of 35 mm every 10 days. The last step had 1.2%, 1.2%, 2.1%, 2.2% yield reductions respectively.

Table 3: Hanghou evaporation data from 2000 – 2009

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Evap. (mm)	1926.3	1984.9	1939.7	1898.9	2027.8	1970.1	2058.5	1820.9	2631.3	2197.8

4.2 Water supply

The deficits is provided for sunflower crop expressed in mm/month: 39.6 (May), 89.2 (Jun), 122 (July), 97 (August), 45.6 (September).(in Table 4); the IrrReq between 247.4mm/dec and 392.9mm/dec. Net irrigation requirements are a weighting by percentage of surface of the deficits of each crop. The adopted date of plantation was 18/05, while the dates of harvest were automatically calculated according to the total duration of the crop specified on the level of the crop duration stages (24/09). Also specify the percentage of surface occupation, not to be exceeded 100%.

Table 4: Comparison of Irrigation Water Requirements, Yield reduction and Cropping intensity for sunflower simulated in summer (varying the rooting depth). Example of year 2008

Parameters of comparison	Run$_1$	Run$_2$	Run$_3$	Run$_4$	Run$_5$	Run$_6$
Total gross irrigation (mm)	656.1	629	1029	685.7	600	571.4
Total net irrigation (mm)	459.3	440	720	480	420	400
Total irrigation losses (mm)	0	0	202.3	27.6	0	0
actual water use by crop (mm)	525.5	519	518.9	513.8	513	525.5
Potential water use by crop (mm)	525.5	526	525.5	525.5	526	525.5
Yield reduction (%)	0	1.2	1.2	2.1	2.2	0
Fiel efficient (%)	70	70	70	70	70	70
Timing and Application	full replenishment at critical depletion	application at 40 mm after 40 mm depletion	40mm every 7 days	40 mm every 10 days	apllication of 35 mm every 10 days	Application of 40 mm with critical depletion

Table 5: water supply in the irrigation area example of year 2008

Scheme supply
Eto station: Hanghou2008
Cropping Pattern: Hhcornpatt.2008
Rain station: Hanghou

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Hhsflower2008	0	0	0	0	39.6	89.2	122	97	45.6	0	0	0
Net scheme irr.req.												
in mm/day	0	0	0	0	1.3	3	3.9	3.1	1.5	0	0	0
in mm/month	0	0	0	0	39.6	89.2	122	97	45.6	0	0	0
in l/s/h	0	0	0	0	0.15	0.34	0.45	0.4	0.18	0	0	0
Irrigated area (% of total area)	0	0	0	0	100	100	100	100	100	0	0	0
Irr.req. for actual area (l/s/h)	0	0	0	0	0.15	0.34	0.45	0.4	0.18	0	0	0

Cropwat 8.0

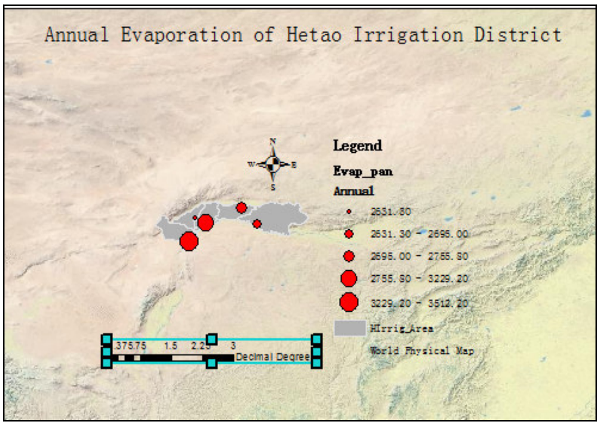

Figure 2: variation of Hetao evaporation from 2000 to 2008

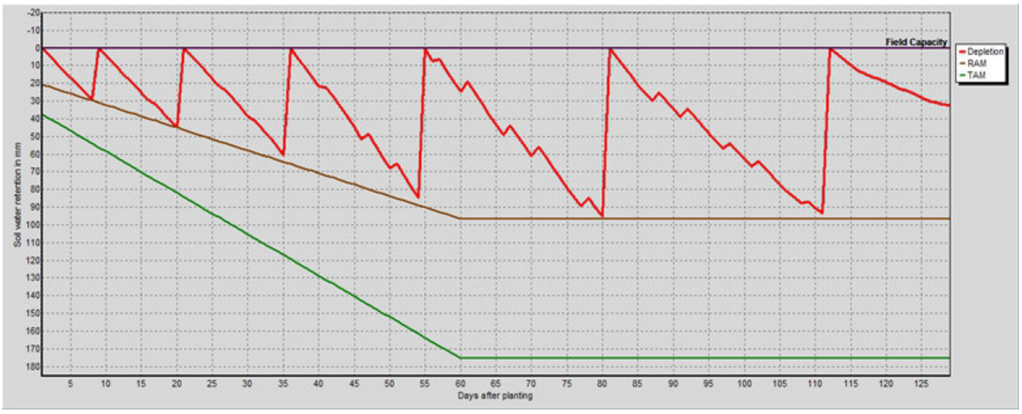

Figure 3: Optimal irrigation full replenishment at critical depletion example of calculation 2008

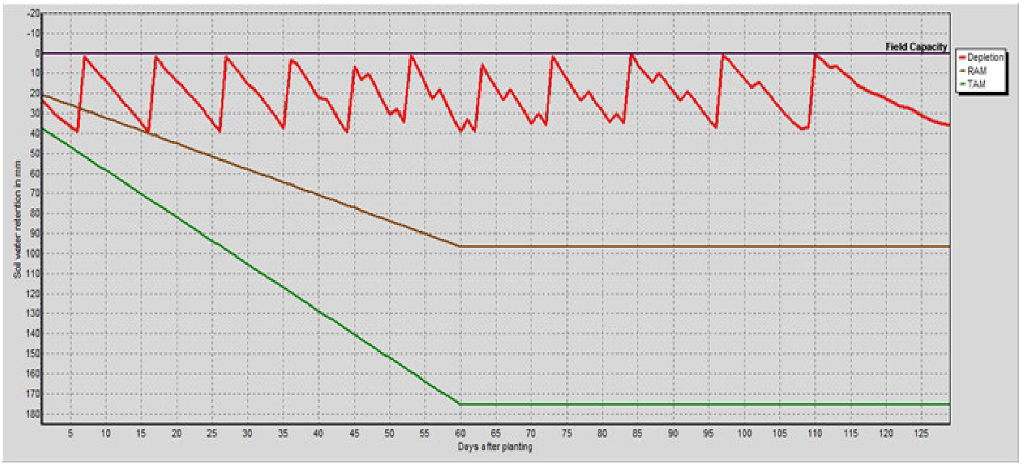

Figure 4: Irrigation scheduling with water stress condition example of 2008

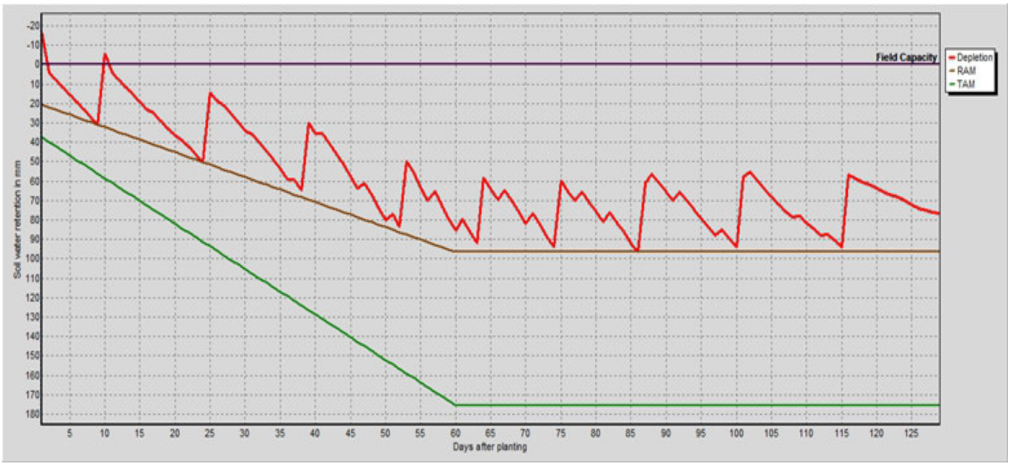

Figure 5: Run 6 application 40mm with critical depletion (optimal scheduling)

6. Conclusion

Irrigation scheduling and deficit irrigation can be considered as effective measure in water scarcity condition; it also determines yield reductions and achieves the field efficiency to 70%. Agriculture depends on various parameters. According to the study that has been carried out, this Cowpat turns out that the software is adapted to calculate the crop yield in defined conditions. In particular, it was more applicable to irrigation calculations (for which it was originally made) that yield rainfed conditions.Finally ArcGIS helped to develop a base of hydrogeological data for manipulation, updating the data and personalizing viewing different results. The project database was created in a three steps process. The steps are: designing the database, automating and gathering data, for the database, and managing the database.

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