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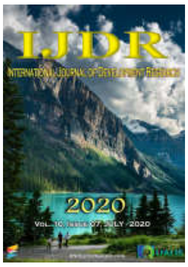

RESEARCH ARTICLE **OPEN ACCESS**

MODEL BASED IRRIGATION WATER APPLICATION OF MAIZE (ZEA*MAYS* L.) TO IMPROVE WATER PRODUCTIVITY IN IRRIGATED AGRICULTURE

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ABSTRACT

Under the semiarid and arid climate of Eastern Europe, accurate estimation of crop water requirement and irrigation scheduling is important for water management and planning. The objectives of this study were to estimate maize water requirement and irrigation scheduling in variable climatic conditions. CROPWAT model is decision support system developed by United Nations Food and Agriculture Organization (FAO) and it is used as a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements, irrigation scheduling, and also allows helps in planning and decision making in the areas where water resource availability is varying and scarce. The study result indicated that Maize seasonal amounts of irrigation requirements varied from 439.5 to 615.0 mm. Maize actual daily evapotranspiration (ETa) varied from 0.12 to 4.13 mm and from 0.27 to 4.68 mm in 2010 and 2011 respectively. Net irrigation schedule for all growing periods in 2010 was zero for initial and late but for development 138.9 mm and 45.9 mm for mid-stage of the growing period. However, 2011 were zero, 83.7 mm, 178 mm, and 98.2 mm in initial, mid, and development and late stages respectively. Besides in the study area, 2010 was the wettest year but 2011 was determined as the driest year this may cause adverse conditions on maize crop yields quantity and quality. Irrigation requirements for maize should be adjusted to the local meteorological conditions for optimizing maize irrigation requirements and improving maize water productivity under such climatic variable conditions.

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INTRODUCTION

Maize (Zea mays L.) ranks as the most important crop worldwide in terms of grain production; although wheat and rice are the most important for direct human consumption. Maize seeds are consumed by humans directly or after processing, and are often the main component of animal feed [30]. Vegetable oil, sugar syrup, alcohol as biofuel, and feedstock for the manufacturing of plastic are commonly derived from maize seeds. The area devoted to maize and the yield per hectare have been increasing over time, total production was 819 million tons in 2009[9]. It is grown, however, extensively in temperate regions for grain [12] as well as for silage. The common water application methods include furrow and center pivot irrigation.

Seasonal maize water use varies according to evaporative demand of the atmosphere, and hence according to climate, time of season when the crop is grown, life cycle length of the crop, and water availability [13]. For well-irrigated situations, seasonal ET ranges from less than 500 to more than 800 mm, the typical seasonal ET of a cultivar of medium-season length grown in a temperate climate at latitude of 35o to 40o being around 650 mm [29]. The water consumes contains approximately 80% of globe's agricultural lands water consumption [23, 30]. Irrigation played main role for long time in nourishingincreasingof population and will undoubtedly play still greater role in the future. Irrigation provides about 40% of world's food from 17% of the cropped area [27]. The main source of income and food security is the irrigated agricultural land among rural population [3, 30] and also the risk of expensive inputs which wasted as a result of moisture stress can be decreases by application of irrigation [1]. Satisfying crop water requirements, although it maximizes production from the land unit, does not necessarily maximize the return per unit volume of water [22]. [25] and [21]pointed out that the concept of agricultural productivity has been the volume of the yield per unit of land but the new concept has to be based on the scarcity of water. So, the productivity per unit of water requires being the basic point for measuring of agricultural productivity in developing countries. Therefore, in an effort to improving water productivity, there is an increasing interest in judicious application of irrigation water, an irrigation practice which controls different aspects of water supply to improve growth and yield, and to develop the economic efficiency of crop production and food safety [18]. Therefore; the main purpose of this study is to estimate the reference evapotranspiration (ET0), crop water requirement and irrigation scheduling for Maizein the study area.

MATERIAL AND METHODS

Study Area: The study was carried in horticultural technology department farm at Szent Istvan University (47°35’ ′N, 19°21’ E), Gödöllő city, Hungary of Eastern Europe. The site was rather flat, at an elevation of 204 m above sea level. Various physical properties of the soil at the experimental site are presented in soil data and soil attributes file of CROPWAT8 model below. The experimental field is composed of brown forest soil, with a mechanical composition of loamy sand and sandy clay, and the subsoil water is below 5 m and the infiltration rate is high due to soil particle porosity. The meteorological data were collected from Aszód meteorology station which laydown 14.9 kilometers away from Gödöllő with the 162.4 m, 47^0, 39’ N and 19^0, 28’ E; altitude, latitude and longitude respectively. All information was provided by the Hungarian Meteorological Service.

Selection of Model: CROPWAT model is a computer program used as a decision support tool that was developed by the Land and Water Development Division of UN Food and Agriculture Organization [8]. It is an empirical process-based crop model that is used to calculate crop water and irrigation requirements and permits to developirrigation schedules under different management conditions and the calculation of water supply schemes for various crop patterns [14; 31] from soil, climate and crop input data. Besides; the program can also be used to estimate crop performance under both rainfed and irrigated conditions based on calculations of the daily soil water balance.

It can used at the field scale and large scale; to evaluate farmer irrigation practice and to establish water supply schedules for different cropping patterns within an irrigation scheme for different cultivars as well respectively [10]. The advantages of CROPWAT are its simplicityand easiness to use and the program is linked to less intense data requirements. The model is a powerful simulation tool which analyzes complex relationships of onfarm parameters (crop, climate, and soil) for assisting in irrigation management and planning. This model is extensively used in the field of water management throughout the world because it is mainly used for estimation of the crop evapotranspiration, irrigation scheduling and agricultural water requirements with different cropping patterns for irrigation planning and decision support in water management [19].

Conceptual Framework and Model Input Data: Daily climatic data has been used to calculate ETo for each year using Penman-Monteith method from a computer based run smoothly the software CROPWAT8 [1]. Rainfall attribute window has data specifics which the software needs for it to have other methods also for calculating effective rainfall if other users want to use for calculations.

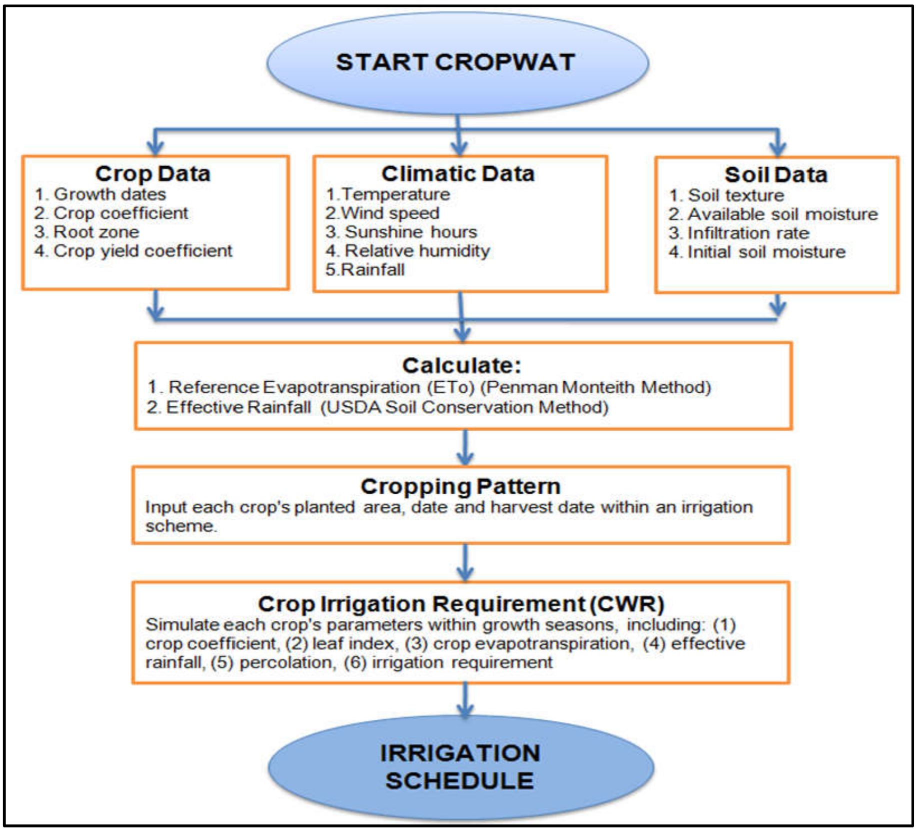

Figure 1. Conceptual Platform of CROPWAT Model

Input Crop Data: Crop datafor Maize crop characteristics used as input parameters are mainly length of the growth cycle, crop factors, rooting depth, critical depilation factor, yield response factor for each growth stages are specified in Table 1.

Reference Evapotranspiration (ET_0): The reference evapotranspiration ETo was calculated by FAO Penman-Monteith method, using decision support software CROPWAT8 developed by FAO, based on FAO Irrigation and Drainage Paper 56 named FAO56[1].

Table 1. Kc values, critical depletion and yield response factors for Maize

Kc and Yield Factors	Scientific name	Growing stages (day)				Additional factor
		Initial season	Mid-season	Late- season	Development	NA
Kc values	Zea mays L.	0.3	1.2	0.35	NA	
Critical depl. Fraction.	Zea mays L.	55	55	0.8	Na	
Yield response F.	Zea mays L.	0.4	1.3	0.5	0.4	1.25

Source: *Departments of Horticulture and Crop production, Szent Istvan University and FAO (1998).*

Table 2. Soil properties

Soil layers (cm)	Sand (%)	Silt (%)	Clay (%)	Field capacity (v %)	Wilting point (v %)	Bulk density (g cm–3)
0–32	82.3	8.4	9.3	16.8	7.3	1.57
32–75	78.1	8.6	13.2	17.5	7.7	1.64
75–138	77.7	6.8	15.5	18.4	8.2	1.73
138–150	86.1	5	8.9	12.9	5.8	1.54

Source: *Department of Horticulture, Szent Istvan University.*

Table 3. Soil and specific characters related to water

Soil Characteristics	Calculated Values
Total available soil moisture (FC-WP):	98 mm/meter
Maximum rain infiltration rate	90 mm/day
Maximum rooting depth	200 centimeters
Initial soil moisture depletion (as% TAM)	0%
Initial available soil moisture	98 mm/meter

Source: *Department of Soil sciences and Department of Horticulture, Szent Istvan University.*

Soil Data and Specific Characteristics: The soil data attribute has their particular data properties to be entered for the software to work accurately. It has the following blanks such as the soil name data, total available soil moisture (FC-WP), maximum rain infiltration rate, maximum rooting depth, and the initial available soil moisture. The soil types had chosen according to FAO soil triangle and soil laboratory characteristics [29]. According to following soil properties and soil triangle, all layers have loamy sand texture. Therefore, the soil under study could meet the medium soil characteristic FAO soil database and international standards. To calculated the total available soil moisture for Cropwat8 model, it's needs to use the total available soil water (TAW) formula that will be computedfrom the soil permanent wilting point (PWP) and at field capacity (FC)) using the following expression:

$$Equation\ 1: TAW = \frac{(\mathrm{FC}-\mathrm{PWP})}{100} * BD * Dz$$

Where: TAW is total available soil water (mm/m), FC and PWP in % on weight basis, BD is the bulk density of the soil in gm cm^{-3}, and Dz is the maximum effective root zone depth in mm. Optimal irrigation regime will be applied at 100 % ASMD and hence 100% ETc, RAW to bring the soil root zone depth back to FC. The ASMD, RAW is the amount of water that crops can extract from the root zone without experiencing any water stress. The RAW could be computed from the expression:

$$Equation\ 2: RAW = p * TASW$$

Where, RAW is the readily available water in mm; p the critical soil moisture depletion in % and TAW is the total available water in mm/ m.

[. FAO56 adopted the Penman-Montieth method as global standard to estimate ETo from meteorological data. The Penman Monteith equation integrated in the CROPWAT program is expressed by the following equation.

$$Equation\ 3: ET_0 = \frac{0.408\ \Delta(Rn-G)+\gamma\frac{900}{T+273}U2(es-ea)}{\Delta+\gamma(1+0.34u2)}$$

Where: ET_0 is reference evapotranspiration (mm day^{-1}), T, G and Rn are daily mean temperature °C at 2 m height, soil heat flux density (MJ m^{-2} day^{-1}) and net radiation value at crop surface (MJ m^{-2} day^{-1}) respectively. Also, u2, e_s e_a, (es–ea), D and c represent wind speed at 2 m height (m s^{-1}), saturated vapour pressure at the given temperature (kPa), actual vapour pressure (kPa), saturation vapour pressure deficit (kPa), slope of the saturation vapour pressure curve (Pa/°C) and psychometric constant (kPa/°C), respectively [1]. According to Djaman et al. [6, 7] being a significant part of the hydrological cycle, the ET0 will have its important impacts on ecosystem models, water uses by agriculture, humidity/aridity conditions and runoff due to precipitation estimation. The ET0 was calculated using FAO Penman-Monteith method which is one of the most precise equations and CROPWAT8 model is based on this equation:

Irrigation Requirements and Scheduling

Irrigation requirement is total amount of water needed for maize production but Irrigation scheduling should be used to determine exactly when to irrigate and how much water to apply. In irrigation scheduling of maize, fundamental factors (crops data, climate & soil) have to be considered [4] and [5]. For instance, fibrous root system of maize is usually shallow rooted and the majority of the root system of maize is located in the upper, cultivated layer of the soil and it takes up the majority of its nutrient from there; therefore, this layer has to be constantly kept damp with irrigation. Hence; in a uniformly wetted profile, 70 percent of the water and nutrients are removed from the upper half of the root zone. Thus, when monitoring the top 75 to 100 cm, at least 80 percent of the active root zone is managed [17] as indicated in figure 2 above. Irrigation scheduling using crop water use or ET calculations based on major factors with the help of CROPWAT model [16] and [15]. Making use of estimated water use rates using a checkbook type routine is an excellent method of determining when to irrigate. A soil water estimate is necessary at the start of the scheduling period for each field. This soil water measurement is treated like money in the bank. Daily use amounts are deductions and rainfall and irrigation amounts are deposits. This way the amount of soil water is known at all times. Observing the trend in values can help growers anticipate precisely when to irrigate. CROPWAT software program is available to calculate water use rates from weather data, soil & crop data. It is recommended to use ET based scheduling or monitor soil water on a regular basis.

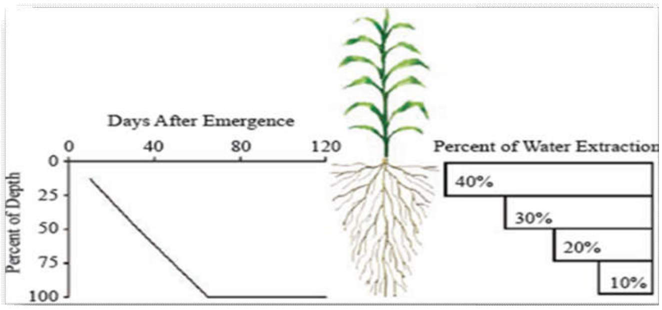

Figure 1. Effective root zone soil water extraction and plant root development patterns [17]

RESULTS AND DISCUSSION

Crop Water Requirement and Irrigation Scheduling: The result indicated that the lowest minimum temperature was -18^{o}C and -15^{o}C on winter season and the highest maximum temperature reached to 35^{o}C and 36^{o}C in summer for 2010 and 2011 respectively. As it has been supported by [24], the highest ET$_0$ was recorded July (4.13 mm/day) and August (6.68 mm/day) followed by June in 2010 and 2011 respectively as indicated under Anex-3(Fig.1). Besides it has been observed that, 2010 was wet year relative to 2011 because the amount of rainfall and effective rainfall recorded was decreased by 40 % and 45 % respectively. Hence 2010 was the wettest and 2011 the driest year since 1901(Anex-3, graph-1). Crop coefficient (Kc) values of maize were as follows in 2010: initial stage (0.30) for 27 days, the development stage (0.38-0.92) for 47 days, mid-season stage (1.08-1.12) for 55 days, and the late season stage (1.02-0.44) for 40 days (Annex-2, table 1). The Kc values of maize were for 2011: initial stage (0.30) for 27 days, development stage (0.39-0.98) for 47 days, mid-season stage (1.16-1.20) for 55 days, and the late season stage (1.10-0.45) for 40 days (Annex-2, table 2). It has observed that four times scheduled irrigation for maize in different days of growing season in 2010. The net irrigation for initial & Development was zero whereas 138.9 and 45.9 mm for mid and late stage respectively as indicated in table 5 and Figure 3 below. The total gross irrigation and actual irrigation requirement was 264 mm and 186.4 mm respectively. Furthermore, the actual water use by crop was 439.5 mm that this amount had applied 252.6 mm by effective rainfall and 184.8 as total net irrigation.

Table 3. Maize daily irrigation schedule for 2010.

Date	Day	Stage	Rain	Depl	Net Irr	Gr. Irr	Flow
			mm	%	mm	mm	l/s/ha
3-Jul	80	Mid	0	61	47.5	67.9	0.1
13-Jul	90	Mid	0	60	46.7	66.7	0.77
22-Jul	99	Mid	0	57	44.7	63.8	0.82
23-Aug	131	End	0	59	45.9	65.6	0.24
30-Sep	End	End	0	2			

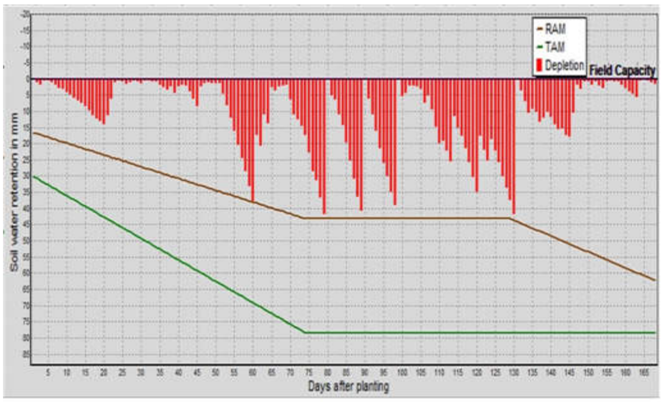

Figure 2. Irrigation scheduling maize, 2010

The irrigation scheduling in 2011 was eight times within maize growing periods; no irrigation event at initial sage but two irrigation events in development stage (83.7 mm), four events in mid stage (178 mm) and two irrigation events in late stage with net irrigation of 98.2 mm as indicated in table 6 and figure 4 below and it is supported by [14]. Moreover, the actual water use by crop was 614 mm that this amount had applied 196.4 mm by effective rainfall and 359.9 mm as total net irrigation. The total gross irrigation and actual irrigation requirement was 514.10 mm and 417.6 mm respectively.

Climate Variability and Water Productivity of Maize: Climate has significant role for the success of agricultural production. Most of crops are dependent to weather to provide energy and water for their life continuation and also an adverse weather can cause yield losses, especially during critical growing stages [11] & [20]. Therefore, there is a highest difference between precipitation and evapotranspiration on July - August and then evapotranspiration drops down gradually on September (Graph A). During high evapotranspiration period, the plant needs high amount of water application which is important to be clear more for the better irrigation scheduling and further implementation, and/or better soil moisture management to avoid the yield reduction due to crop water stress.

It has been understood that July is very important time in the vegetation period of maize. Maximum plant water requirements are in July, which highlights the role of the July precipitation [21]. The general precipitation features of a given year can modify the overwhelming role of the July precipitation (graph A & B). Therefore, maize could be strongly affected especially during maturing stage on dry July of wettest 2010 year and wet July of driest 2011, as it can be seen on the irrigation scheduling.

Table 4. Daily irrigation schedule for 2011

Date	Day	stage	Rain	Depl	Net irr	Gr.Irr	Flow
			mm	%	mm	mm	l/s/ha
16-Junary	63	Dev	0	56	39.9	57	0.1
24-Junary	71	Dev	0	57	43.8	62.6	0.91
7-July	84	Mid	0	57	44.8	64.1	0.57
13-July	90	Mid	0	56	44.1	63	1.22
8-Augest	116	Mid	0.9	57	45	64.2	0.29
16-Augest	124	Mid	0	56	44.1	62.9	0.91
24-Augest	132	End	0	62	48.5	69.3	1
3-Sepember	142	End	0	63	49.7	71	0.82
30-Sepember	End	End	0	74			

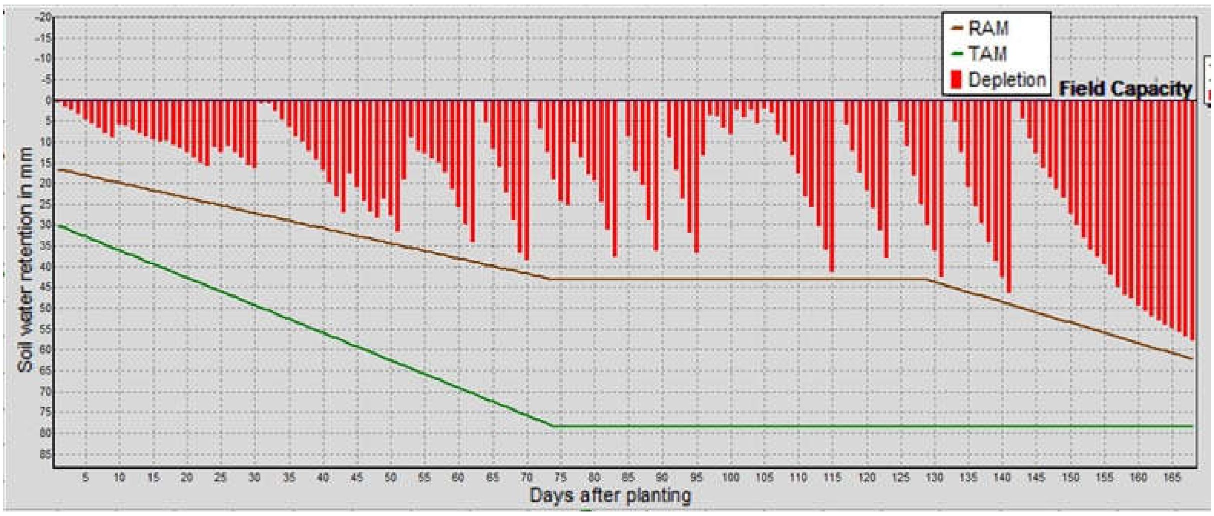

Figure 3. Irrigation scheduling for maize, 2011

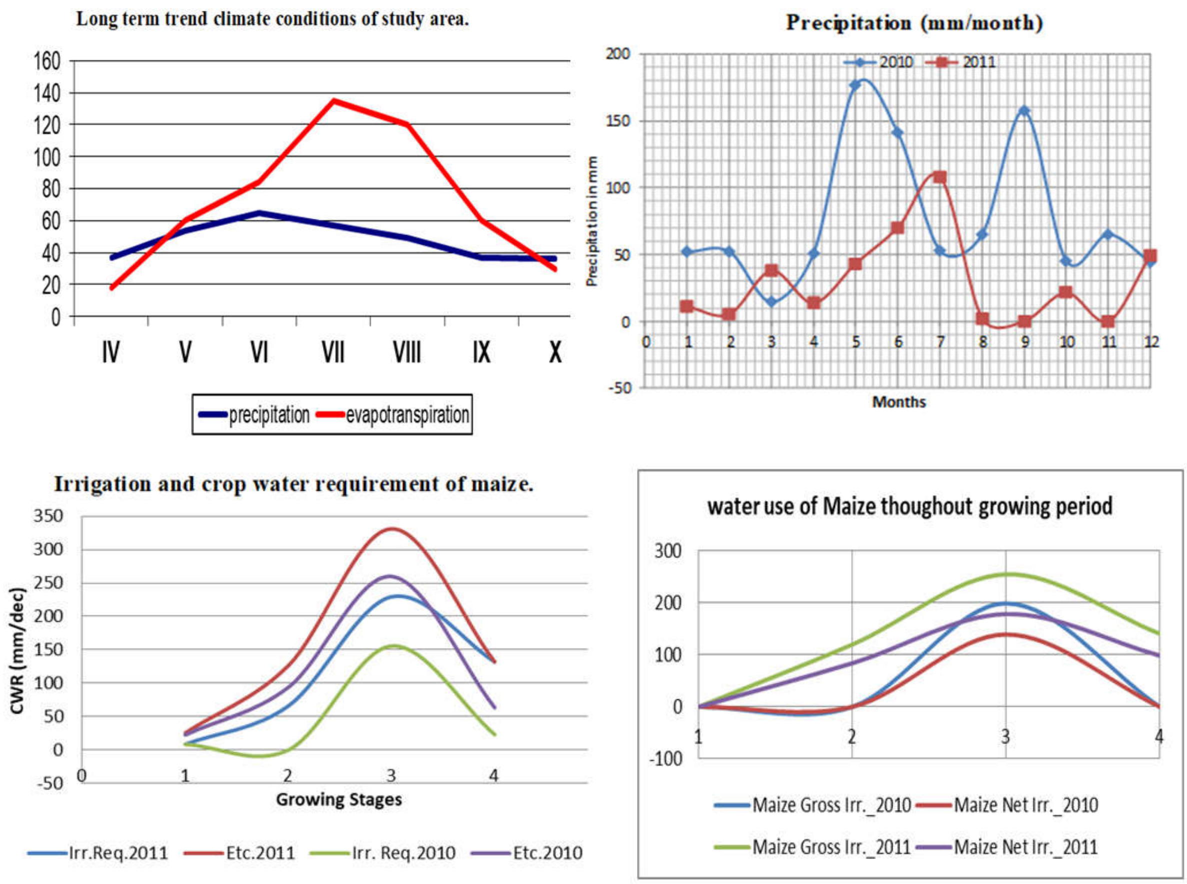

Figure 4: A. long term trend of climatic condition of study area (top left), B. Cascaded monthly precipitation (top right), C. Irrigation & crop water requirement of maize (bottom left) and D. Water use of maize throughout growing the period (bottom right)

Moreover, net irrigation requirement has been recorded to be 184.8mm for the wettest year whereas 359.9mm for the growing period of maize in the driest year (graph D) and this result is revealed by [26]. This result indicated that there is 48.9% increment of maize net irrigation water requirement for crop production in 2011. Therefore, even in a year with high precipitation sum, dry spells can occur, which could have a large effect on the water and crop productivity.

Conclusion and Recommendation

The study showed that, the climatic condition had various effect on crop $ET_{0,}$ crop water requirement, irrigation requirement and crop irrigation regime. Thus, the maximum average ET_0 was 4.13mm in 2010 and 4.69mm for 2011 while the total precipitation for 2010 and 2011 were 916.3mm, 362.6mm respectively. This study showed that there were 40 percent decrease of rain in 2011 with a wet July compare to 2010 with a dry July. Therefore, 2010 and 2011 nominated as the wettest and driest years respectively, since 1901. The irrigation water needs haven't shown such a large difference as it can be observed at the precipitation. It can be explained by the different as the year characteristics of the July precipitation. As far as the plants are sensitive to the precipitation sum in July, therefore, precipitation in this month has a strong effect on the irrigation water demand. To be effective and efficient in irrigation, scheduling has to be always based on both observation data and model output. Since; irrigation needs higher investment costs and could have substantial maintenance costs, it is very important to operate the whole system with the optimal cost benefit ratio. Therefore, it is recommended to establish measuring stationsin the nearby the area we would like to irrigate. This is usually not very high cost in comparison to the irrigation prices and potential yield losses. The measured variables have to fulfill the input requirements of the model planned to use. Because if we do not have enough data, then our model cannot model; sometimes even not parameterize several processes.

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REFERENCES

Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M., (1998): Crop evapotranspiration-guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56, FAO, Rome, Italy, 300p.

Araya, A.; Kisekka, I.; Vara Prasad, P.V.; Gowda, P.H., (2017): Evaluating optimum limited irrigation management strategies for corn production in the Ogallala aquifer region. J. Irrig. Drain. Eng., 143, 04017041.

Barker, R., (2002): Recent development in irrigation management in Asia and the Pacific. Report of the APO seminar on organizational change for participatory irrigation management. Philippines, (Tokyo: 23-27 October 2000 (SEM-32-00).

Broner, I. 2005. Irrigation: Irrigation scheduling. Fact Sheet No. 4.708. Colorado State University Extension –USDA. 2 pp. [Online] Available: http://www.ext.colostate.edu /pubs /crops/04708.pdf

Chen, F.W.; Liu, C.W.; Chang, F.J., (2014): Improvement of the agricultural effective rainfall for irrigating rice using the optimal clustering model of rainfall station network. Paddy Water Environ. 12, 393–406.

Djaman, K.; Balde, A.B.; Sow, A.; Muller, A.B.; Irmak, S.; N'Diaye, M.K.; Manneh, B.; Moukoumbi, Y.D.; Futakuchi, K.; Saito, K., (2015): Evaluation of sixteen reference evapotranspiration methods under sahelian conditions in the Senegal River Valley. J. Hydrol. Reg. Stud. 3, 139–159.

Djaman, K.; Irmak, S., (2013): Actual crop evapotranspiration and alfalfa- and grass-reference crop coefficients of maize under full and limited irrigation and rainfed conditions. J. Irrig. Drain. Eng., 139, 433–446.

FAO (2009): CropWat 8.0, edited, land and water development division. Food and Agriculture Organization of the United Nations, Rome.

FAO (2011): FAOSTAT online database, available at link http://faostat.fao.org/. Accessed on December 2011.

FAO (2014): FAO Water Development and Management Unit 2013. Food and Agriculture Organization of the United Nations, Rome.

Fodor, N. (2010): The agro-ecological potential of Hungary and its prospective development due to climate change, research institute for soil science and agricultural chemistry, Budapest, Hungary.

GAEZ. (2011): Global Agro-Ecological Zones ver. 3.0, FAO, IIASA.

George, B., Shende, S., and Raghuwanshi, N. (2000). Development and testing of an irrigation scheduling model. Agricultural Water Management, 46(2), 121–136.

Gowda T.P, Manjunaththa S.B, Yogesh T.C and Satyareddim S.A (2013). Study on Water Requirement of Maize (Zea mays L.) using CROPWAT Model in Northern Transitional Zone of Karnataka. Journal of Environmental Science, Computer Science and Engineering and Technology 2(1): 105-113.

Henggeler, J.C., M.D. Dukes and B.Q. Mecham. 2011. Irrigation scheduling. pp. 491-564. In Stetson, L.E. and Mecham, B.Q. (eds.). Irrigation (6th ed.). Irrigation Association. Falls Church, VA.

Igbadum, H.E.; Mahoo, H.F.; Tarimo, A.K.P.R.; Salim, B.A., (2006): Irrigation scheduling scenarios studies for a maize crop in Tanzania using a computer-based simulation model. Agric. Eng. Int. CIGR Ejournal, 8, 1–27.

Kranz, W.L., S. Irmak, S.J. van Donk, C.D. Yonts and D.L. Martin. 2008. Irrigation management for corn. [Online] Available: http:// www.ianrpubs.unl.edu / epublic / pages / publication D.jsp? publication Id=1004

Levidow, L.; Zaccaria, D.; Maia, R.; Vivas, E.; Todorovic, M.; Scardigno, A., (2014): Improving water-efficient irrigation: Prospects and difficulties of innovative practices. Agric. Water Manag., 146, 84–94.

Malikian A., Gasemi H., Ahmdian A., (2009): Evaluation of the efficiency of Cropwat8 model for determining plant water requirement in arid region, Zabol University, Iran. http://jdesert.ut.ac.ir/pdf_36341_b5506d9c85fe0387ce84d4132b117cfa.html

Mika, J., Lakatos, M. (2008): Extreme weather tendencies in Hungary: One empirical and two model approaches. – In:

Sigro, J., Brunet, M., Aguilar, E. (ed) Regional climatic change and its impacts, Tarragona, Spain, pp. 521-531.

Molden, D., Oweis, T., Steduto, P., Bindraban, P., Hanjra, M.A. and Kijne, J. (2010) Improving agricultural water productivity: between optimism and caution. Agricultural Water Management 97, 528–535.doi: 10.1016/j.agwat.2009.03.023.

Nischelm. J., J. Cordes, B. Riewe and R. Hohm. 2011. Current irrigation management practices study 2007 – 2009.Alberta Agriculture and Rural Development. Lethbridge, AB. 36 pp.

Oweis, T. Zhang, H and Pala, M. (2000): Water uses efficiency of rainfed and irrigated bread wheat in a Mediterranean environment. Agronomy Journal 92: 231-238

Peter, J.R., (2004): Participatory irrigation management, international network on participatory irrigation management, (Washington, DC: INWEPF/ SY/2004(06).

Tabari, H.; Marofi, S.; Aeini, A.; Talaee, P.H.; Mohammadi, K., (2011): Trend analysis of reference evapotranspiration in the western half of Iran. Agric. For. Meteorol. 151, 128–136.

Takashi, K., (2001): Globalization and management of water resources: Development opportunities and constraints of diversified developing countries.

Thimn Gowda P., Manjungaththas.B., Yogesh T.C. and Sunil A. (2013): Study on Water Requirement of Maize (Zea mays L.) using CROPWAT8Model in Northern Transitional Zone of Karnataka. University of agricultural sciences, Karnataka, India.

United Nations Development Programme (UNDP), (2004): Water governance for poverty reduction. Key issues and the UNDP response to millennium development goals. Retrieved from:http://www.undp.org/water.

United Nations Environment Programme (UNEP), (2012): Measuring Water Use in a Green Economy. A Report of the Working Group on Water Efficiency to the International Resource Panel. Nairobi, Kenya.

United States Department of Agriculture – Natural Resources Conservation Service (USDA-NRCS). 2004.Irrigation water management (IWM) is applying water according to crop needs in an amount that can be stored inthe plant root zone of the soil. [Online] Available: www.wy.nrcs.usda.gov/technical/soilmoisture/soilmoisture.html

Zhiming F, Dengwei L and Yuehong Z (2007). Water Requirements and Irrigation Scheduling of Spring Maize Using GIS and CROPWAT model in Beijing-Tianjin-Hebei Region. Chinese Geographical Science 17(1): 56-63.

APPENDICES

Annex-1: *Daily Reference Evapotranspiration*

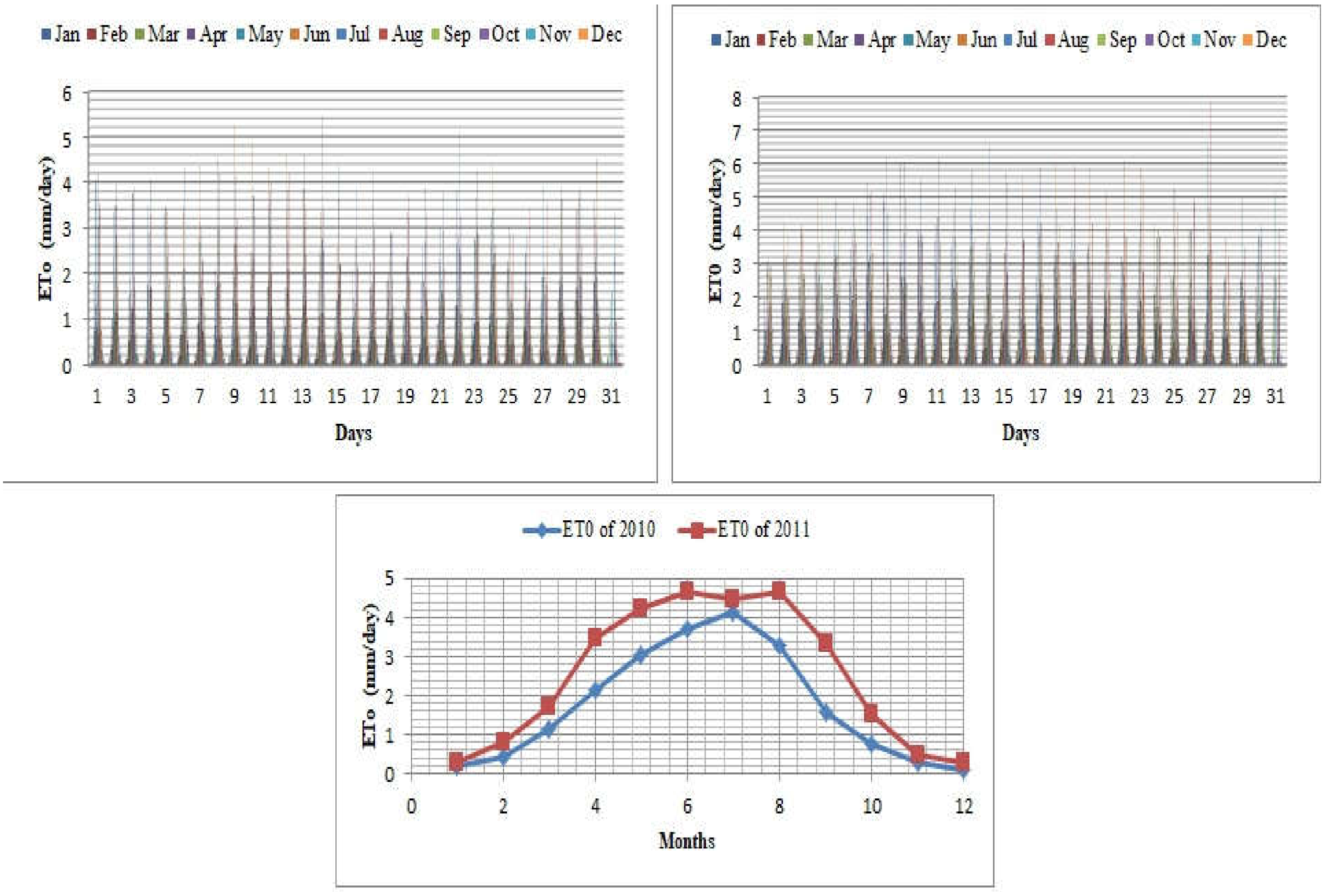

Figure 5. Daily Reference Evapotranspiration (ETo) of 2010 (bottom left), 2011(bottom right) and mean monthly of both year (bottom center)

Annex-2: *Decadal CWR and Irrigation Requirement*

Table 1. Decadal crop water requirements for maize in 2010

Month	Decade	Stage	Kc	ETc*	ETc	Eff rain	Irr. Req.
			Coeff	mm/day	mm/dec**	mm/dec	mm/dec
Apr	2	Init	0.3	0.68	4.1	21	0
Apr	3	Init	0.3	0.85	8.5	0	8.5
May	1	Init	0.3	0.99	9.9	30	0
May	2	Dev	0.38	0.83	8.3	50.3	0
May	3	Dev	0.56	2.01	22.1	39.8	0
Jun	1	Dev	0.74	2.82	28.2	35.9	0
Jun	2	Dev	0.92	3.53	35.3	48.7	0
Jun	3	Mid	1.08	3.83	38.3	15.9	22.5
Jul	1	Mid	1.12	5.02	50.2	3.2	47
Jul	2	Mid	1.12	5.16	51.6	0.6	51
Jul	3	Mid	1.12	3.75	41.3	37.6	3.7
Aug	1	Mid	1.12	3.85	38.5	19.9	18.6
Aug	2	Mid	1.12	3.98	39.8	26.9	12.9
Aug	3	Late	1.02	3.03	33.3	10.3	23
Sep	1	Late	0.82	1.45	14.5	52.4	0
Sep	2	Late	0.63	0.89	8.9	26.2	0
Sep	3	Late	0.44	0.66	6.6	17.3	0
				Total:	**439.5**	**436.1**	**187.2**

Table 2. Decadal crop water requirements for maize in 2011

Month	decade	stage	Kc	Etc	Etc	Eff rain	Irr.Req
			coeff	mm/day	mm/dec	mm/dec	mm/dec
April	2	Init	0.30	0.96	5.70	3.80	2.6
April	3	Init	0.30	0.89	8.90	4.50	4.4
May	1	Init	0.30	1.09	10.90	9.30	1.5
May	2	Dev	0.39	1.59	15.90	18.00	0
May	3	Dev	0.59	2.86	31.40	12.60	18.8
June	1	Dev	0.79	3.19	31.90	34.50	0
June	2	Dev	0.98	4.72	47.20	0.00	47.2
June	3	Mid	1.16	5.82	58.20	23.10	35.1
June	1	Mid	1.20	6.24	62.40	7.00	55.4
June	2	Mid	1.20	7.22	72.20	37.20	35
June	3	Mid	1.20	2.91	32.10	39.20	0
Aug	1	Mid	1.20	4.94	49.40	2.30	47.1
Aug	2	Mid	1.20	5.68	56.80	0.00	56.8
Aug	3	Late	1.10	5.67	62.30	0.00	62.3
Sep	1	Late	0.87	3.45	34.50	0.00	34.5
Sep	2	Late	0.66	2.42	24.20	0.00	24.2
Sep	3	Late	0.45	1.10	11.00	0.00	11
				Total:	615.00	191.50	435.9

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