

RESEARCH ARTICLE

Forecasting of Long-term Sugar Beet Water Requirement in the Middle Anatolia, Turkey

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ABSTRACT

Turkey's highest sugar beet (*Beta vulgaris* L.) cultivation area is the Konya basin where is located in the Middle Anatolia region. Therefore, sugar beet has socio-economic importance in this region. However, the area faces water scarcity due to less amount of precipitation and high evapotranspiration. Moreover, irrigation is a prerequisite for sugar beet cultivation. Therefore, irrigation management is a vital topic for the area. The Food and Agricultural Organization of the United Nations Penman-Monteith (FAO 56 PM) equation for estimating reference evapotranspiration (ET_o) requires various meteorological data. Unfortunately, it is not possible to ease to reach all these input data. Hence, FAO56 proposes another method called Hargreaves - Samani (HS). In this study, due to limited meteorological data, the HS method is used for estimating ET_o in the Konya basin. For this area, there is a big ambiguity about crop evapotranspiration (ET_c) and the net irrigation requirement (NIR) for sugar beet crop. This study estimates long-term (1986-2015) sugar beet evapotranspiration and net irrigation requirement to give a better idea for sugar beet irrigation management in the Konya basin. Results show that long-term annual sugar beet ET_c reaches between 657 mm and 917 mm in the growing season. NIR ranges from 614 mm to 886 mm in the aforesaid basin.

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Introduction

The Konya basin, Middle Anatolia region, is one of the most important agricultural and agro-industrial regions in Turkey. The climate of the area is typically semi-arid with cold and snowy winters and very hot and dry summers, where the average annual rainfall ranges from 280 to 500 mm. The Konya basin has almost 3 million hectares of agricultural area. Sugar beet (*Beta vulgaris* L.) is the vital commercial crop in this area being the largest producer of Turkey. Sugar beet production is about 35% of total production in Turkey with 115,000 ha sugar beet growing area (Topak et al., 2011). This crop has remarkably high water demand (Fabeiro et al., 2003) and the water consumption is between 900 and 1200 mm during the

growth period (Dunham, 1993; Hills et al., 1990). The biggest problem in the basin is water loss due to high evapotranspiration. Another problem is that the basin faces water shortage due to a lack of water resources and a low amount of precipitation. Thus, the appropriate management of irrigation becomes inevitable for the crop growth - yield as well as the preservation of water resources. As a result, water becomes a limiting factor in terms of crop development and production in the region.

Reference evapotranspiration (ET_o) plays a key role parameter for agricultural and hydrological studies as well as climatological. It is important to estimate accurate results for irrigation scheduling, irrigation and drainage design, crop

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production, managing water resources and environmental assessment (Sharma 1985; Jensen et al., 1990). Many empirical methods for ETo estimation are available but they cannot be applied under different conditions before being used in local conditions (Pruitt and Doorenbos 1977). Moreover, there is not a single applicable ETo method to apply all areas and periods. The choice of suitable method depends on many factors such as climate conditions, availability of data needed, cost, time and difficulties of the method for use. The Food and Agricultural Organization of the United Nations Penman-Monteith (FAO 56 PM) equation has defined as a standard method for estimating reference evapotranspiration (Allen et al., 1998). This method has good results in many different climates without testing in any local calibration because it has already been calibrated and validated worldwide by using lysimeter measures. The FAO 56 PM equation requires accurate weather data, e. g. air temperature, relative humidity, solar radiation, and wind speed. However, all these input data are not possible to reach even in developed countries because of the limited meteorological stations and also collected data present wide gaps and incorrect measurements. Moreover, the instruments are time-consuming to use and has high cost of setting automated weather stations that collect meteorological data (Valiantzas 2013). Therefore, these methods give a limitation to collect meteorological variables. Allen et al., (1998) suggested another equation called Hargreaves - Samani (HS) equation (Hargreaves and Samani 1985) when sufficient weather data are not available to estimate FAO 56 PM. The HS equation needs only daily average, maximum and minimum air temperature and extraterrestrial radiation. Several studies indicated that the HS equation provides accurate estimates of reference evapotranspiration (Todorovic et al., 2013; Sabziparvar and Tabari 2010; Rahimi Khoob, 2008; Berti et al., 2014; Valiantzas 2018).

The principle of crop water requirement calculation depends on ETo and crop coefficient (Kc) values. These values are limited by meteorological and crop physiological conditions. Estimation of crop water requirement on different crops and locations have also been reported in several previous studies. (Tan, 2018; Guo et al., 2015).

According to many studies, there is a good knowledge effect of different irrigation regimes on sugar beet in Middle Anatolia (Topak et al., 2011; Kiyamaz and Ertek 2015; Uçan and Gençoğlan 2004). However, there is large uncertainty about the temporal and spatial variation impacts through the Konya basin. Crop evapotranspiration (ETc) and net irrigation requirement (NIR) are particularly ambiguous for sugar beet cultivation in the area. Therefore, the objective of this study focuses on sugar beet crop evapotranspiration and irrigation requirements in the Konya basin of the Anatolia region of Turkey and demonstrates the water requirement of sugar beet that fluctuates over the years.

Materials and Methods

Climatic Data

The meteorological data sets used for this study correspond to the period from 1986-2015, all being provided by the European Commission MARS database (Micale and Genovese 2004). This network is composed of 74 meteorological stations, but only 25 of these daily maximum and minimum temperatures were used in the present study since only these subset stations are available in the sugar beet plantation area. Locations of the 25 meteorological stations are given in Table 1 and Figure 1 Site elevations range from 919 to 1774 m above mean sea level; Longitude, from 31° 34' 48" W to 33° 46' 48" W; and latitude; from 37° 17' 24" N to 39° 18' 36" N. In Table 1, the annual average values of meteorological stations are reported. The average annual precipitation ranged from 291 to 490 mm; average annual temperature, from 10 to 12 °C. The starting date of the growing season was selected on the 12th of April and the harvesting date of the growing season was selected on the 8th of October (Topak et al., 2011).

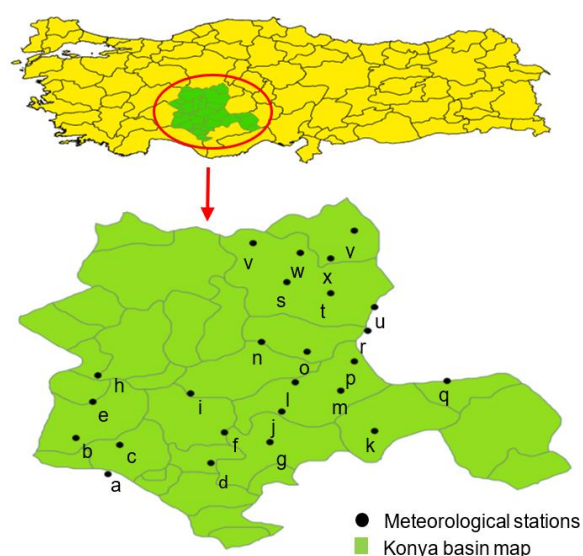


Figure 1. Spatial distribution of the 25 meteorological stations used in the analysis. Numbers represent station codes which are in Table 1

Table 1. Summary of weather station site characteristics used in the study

Station Code	Latitude (°)	Longitude (°)	Altitude (m)	Taverage (°C)	Rainfall (mm year ⁻¹)
a	37.29	31.77	1774	12	296
b	37.55	31.58	1205	11	490
c	37.50	31.84	1149	11	312
d	37.37	32.38	1107	12	291
e	37.81	31.68	1170	11	313
f	37.59	32.46	1098	12	311
g	37.52	32.73	1030	12	311
h	38.00	31.71	1362	10	340
i	37.87	32.26	1431	10	312
j	37.74	32.80	1003	12	311
k	37.60	33.35	1000	12	292
l	37.95	32.88	1009	12	313

Table 1 continued

Station Code	Latitude (°)	Longitude (°)	Altitude (m)	Taverage (°C)	Rainfall (mm year ⁻¹)
m	37.89	33.15	1060	12	308
n	38.24	32.68	997	12	309
o	38.17	32.95	1047	12	315
p	38.10	33.23	1022	12	309
q	37.96	33.78	1090	12	311
r	38.32	33.31	965	12	296
s	38.67	32.83	1030	12	291
t	38.59	33.09	936	12	296
u	38.49	33.35	942	12	310
v	38.95	32.63	1089	11	297
w	38.88	32.91	963	12	335
x	38.84	33.09	919	12	333
y	39.04	33.23	955	12	335

Methodology

The main methodological steps include: (a) selecting meteorological stations that sugar beet planted (b) calculation of ET_o ; (c) estimation of sugar beet ET_c and NIR.

The cultivation area of sugar beet which planted between 2010 and 2017 years was provided by Konya Şeker industry and trade inc. (Konya, Turkey). The company recorded farmers who planted sugar beet. The area which marked in the map that got from the company was determined and then the most suitable meteorological stations were selected.

The reference evapotranspiration (ET_o) was calculated by the Hargreaves - Samani (HS) equation minimum temperature (T_{min}) and extraterrestrial radiation (R_a) for the estimation of ET_o (mm day⁻¹). The equation can be written as (Todorovic et al., 2013):

$$ET_o = 0.0023 \frac{R_a}{\lambda} \sqrt{(T_{max} - T_{min})(T + 17.8)} \quad (1)$$

The coefficient 0.0023 is an empirical coefficient, R_a is the extraterrestrial radiation (mm day⁻¹) calculated according to Allen et al. (1998) and λ is the latent heat of vaporization (MJ kg⁻¹) for the mean air temperature T (°C) given as:

$$\lambda = 2.501 - 0.002361 T \quad (2)$$

Sugar beet evapotranspiration (ET_c), which seasonal sum corresponds to the crop water requirements, was calculated using the single crop coefficient K_c approach:

$$ET_c = K_c ET_o \quad (3)$$

K_c values suggested by Allen et al. (1998). The K_c values for the initial, mid- and end-season growth of sugar beet are 0.35, 1.2 and 0.7.

Net irrigation water requirements (NIR), i.e., the quantity of water necessary for crop evapotranspiration more than effective precipitation (P_{eff}), were calculated through a simplified balance between ET_c and P_{eff} as:

$$NIR = K_c ET_o - P_{eff} = ET_c - P_{eff} \quad (4)$$

P_{eff} was computed as 80% of total precipitation (Tanasijevic et al., 2014)

Results and Discussion

The long-term seasonal ET_c and NIR were computed for all available stations in the sugar beet plantation area in the Konya basin. However, there is a lack of previous research concerning the long-term estimation of ET_c and NIR for the sugar beet in the region. Table 2 shows useful information about 30 years of the maximum, minimum, mean and standard deviation of ET_o , ET_c and NIR values in all districts.

Table 2. Some information about 30 years of maximum (max), minimum (min), mean (mean) and standard deviation (std) of annual ET_o (mm year⁻¹), ET_c (mm season⁻¹) and NIR (mm season⁻¹) in Konya basin

Station Code	ET_{cmax}	ET_{cmin}	ET_{cmean}	ET_{cstd}	NIR_{max}	NIR_{min}	NIR_{mean}	NIR_{std}
1	778	657	725	28	760	614	691	33
2	844	745	795	24	802	698	749	29
3	863	751	804	26	843	703	767	32
4	869	754	809	32	849	708	777	39
5	849	748	796	24	818	700	759	31
6	868	755	801	27	844	709	764	32
7	877	764	810	27	853	717	773	32
8	823	708	768	27	803	662	730	37
9	819	708	757	29	786	660	721	34
10	880	763	810	27	855	713	773	33
11	896	745	821	41	867	699	789	46
12	888	758	813	31	855	708	775	36
13	890	751	816	38	866	690	779	43
14	875	758	811	29	842	708	774	34
15	868	751	806	29	836	697	768	34
16	877	755	810	30	845	693	772	35
17	873	728	808	35	840	666	773	41
18	872	763	814	29	849	696	776	35
19	897	753	816	35	868	696	779	40
20	911	765	830	35	882	698	791	41
21	886	752	817	27	851	686	777	34
22	850	744	790	28	831	678	752	35
23	906	760	818	40	875	655	771	52
24	917	758	826	42	886	654	780	54
25	872	749	809	27	851	650	762	40

Equation (1) was used to estimate reference ET which is derived using 30 years (1986-2015) of daily temperature data. The reference ET of 11 stations were previously studied by Yamaç (2018). Figure 2 shows the long-term annual ET_c of the Konya basin. ET_c calculated by Equation 3. The day length of sugar beet ET_c showed a growing season. The area demonstrated increasing trends in ET_c which was related to reference ET. ET_c ranged between 657 mm in 1997 (Figure 2a) and 917 mm in 2010 (Figure 2x) for 30 years sugar beet plantation area in the Konya basin. The lowest ET_c that given in Figure 2a also showed the lowest ET_o values calculated for the study area. In Figure 2q a sharp decline demonstrated in the years of 1992, 1993 and 1994. Figure 2x showed a sharp increase in the year of 2005, 2006 and 2007. Topak et al. (2011) found that seasonal evapotranspiration for sugar beet varied between 374.5 and 1036 mm depending on different water

regimes. Katerji and Mastrolli (2009) indicated that sugar beet crop evapotranspiration ranged from 731 (clay) to 836 mm (loam) according to different soil textures under Mediterranean conditions. Fabeiro et al. (2003) reported that seasonal evapotranspiration of sugar beet varied between 690 and 897 mm depending on irrigation regimes under drip irrigation applications in Spain conditions. Under different irrigation applications, sugar beet crop evapotranspiration obtained by Barbanti et al. (2007). Their values ranged between 1262 (full irrigation) to 567 mm (deficit irrigation) in Cadriano. Yildirim (1990) indicated that evapotranspiration for sugar beet was 865 mm under full irrigation regimes in Ankara conditions. According to Uçan and Gençoğlu (2004), the evapotranspiration of sugar beet under different irrigation level was between 450 mm (the most water applied) and 1000 mm (the least water applied) in a semiarid region.

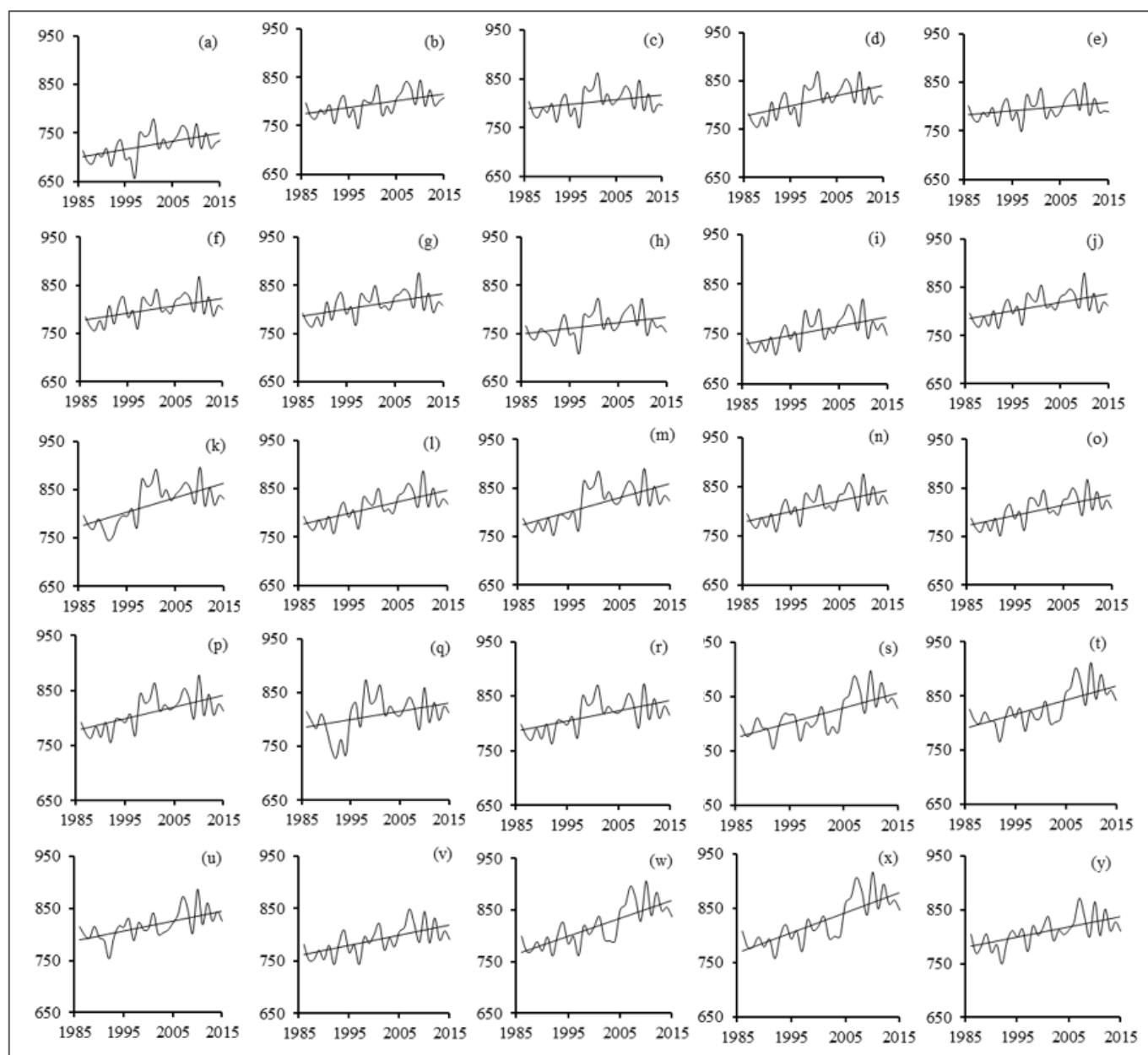


Figure 2. Spatial distribution of crop evapotranspiration between 1985 and 2015. Crop evapotranspiration (mm season⁻¹) on the Y-axis and years on the X-axis. Straight line indicates trends of ET_c

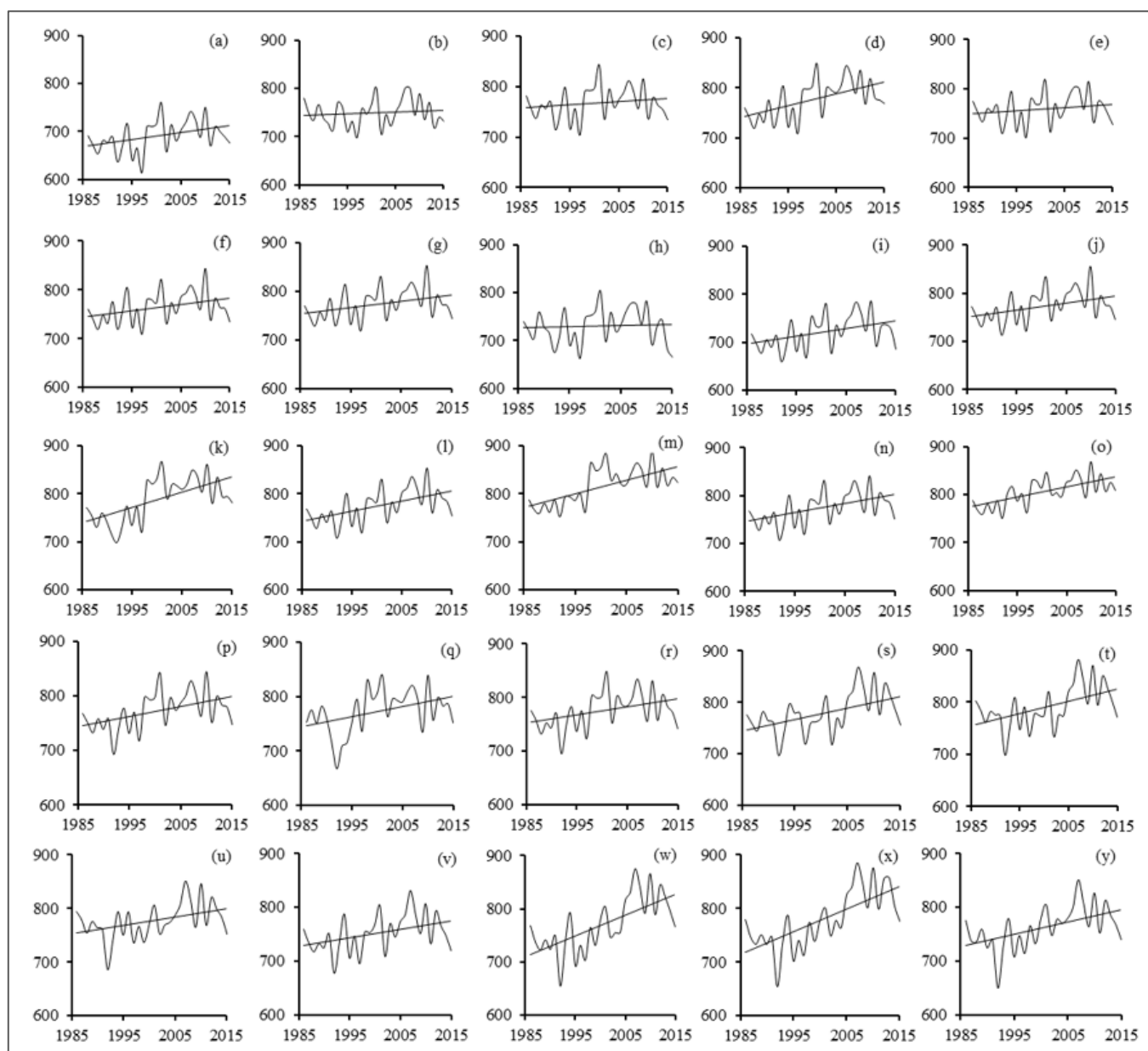


Figure 3. Spatial distribution of net irrigation requirement between 1985 and 2015. Irrigation requirement (mm season^{-1}) on the Y-axis and years on the X-axis. Straight line indicates trends of NIR

The estimation of NIR demonstrated the growing season of sugar beet in the Konya basin (Figure 3). The calculation of NIR obtained by Equation (4). The sugar beet seasonal NIR showed a range from 614 mm in 1997 to 886 mm in 2007. The results of NIR was difficult to compare with previous studies because NIR value is a gap in literature for sugar beet. However, there are some possibilities to make a comparison. Guo et al. (2015) found that the mean net irrigation requirement in the Kaidu-kongqi river basin in China reached 861 mm between 1985 - 2009 years. Rodrigues et al (2003) reported that the average value of the NIR was 826 mm. However, they found that NIR value was 989 mm in very high (drought) climate demand conditions.

According to some limitations, this study needs some improvement in future studies. These are (i) limited meteorological data was used in this study. Therefore, it is required more meteorological data. (ii) this study needs

different ETo models to make the comparison to find out the most suitable for the region (iii) it is a necessity to direct measurement of ETo for choosing the appropriate model for each meteorological station.

Conclusion

In this study, a simplified method was employed for the estimation of water requirements in the Konya basin. Accordingly, these results show increasing trends in ETo, ETc, and NIR. This increase implies that future water requirements could rise for sugar beet cultivation in the region. Therefore, controlled and regulated irrigation management and modern irrigation techniques should be developed and monitored in the near future.

The findings of this study are focused on the last 30 years of behaving of sugar beet water requirement in the Konya

basin. However, the results given here are not enough to address a solution for water management. These results need a link to into a complex framework including bio-physical, socio-economic and policy issues. The analysis presented here does not consider other cultivation parameters of the sugar beet in an area. Other cultivation parameters need to be analyzed in the long-term to give a better idea for sugar beet production. After all, this is the first study to estimate water and irrigation requirements in the long term in the Konya basin with all aforesaid uncertainties. This preliminary study can be extended to other sugar beet planting areas for further studies to generate the basis of decision support systems for sugar beet crop management.

Future studies are needed to focus on: (i) the estimation of ETo with different models (ii) the detection of water availability in the region (iii) the analysis of future water and irrigation requirement using Global Circulation Models with different emission scenarios (iv) the consideration of weather and crop parameters in the region (v) the adaptation of new technologies and methods for better agricultural production and water management.

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