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CRITICAL THRESHOLD TEMPERATURES AND RAINFALL IN DECLINING GRAIN YIELD OF DURUM WHEAT (*Triticum durum* Desf.) DURING CROP DEVELOPMENT STAGES

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ABSTRACT

The effects of maximum temperature, rainfall and growing degree day on grain yield of durum wheat (*Triticum durum* Desf.) were studied during the period of available years (2005-2017) in the study sites. A polynomial equation was described the relationship between grain yield, maximum temperature and rainfall for four growing stages of winter wheat. The nonlinear relationships were used from time-series variations in temperatures, rainfall and yields. The maximum positive effects of rainfall (R^2=0.72*) on grain yield was in the mid-season stage (heading, anthesis and grain filling) of the crop. However, there was a negative effect of temperature more than 30°C on grain yield. The highest negative effects (R^2=0.31 through 0.86*) of maximum temperatures were in the crop development stages (vernalization and tillering). The yield might decrease about 2.5% for every 1°C increase in the growth period based on the daily mean temperature of 12.4°C for all the study locations. The critical maximum temperatures on threshold values declining yield and positive effects of rainfall on grain yield varied according to the altitudes and longitudes.

Keywords: climate change, critical maximum temperature, crop development stage, durum wheat (*Triticum durum* Desf.*)*, growing degree day.

INTRODUCTION

Wheat is one of the most important and basic food sources for humans. It provides about 21% of the world's food supply and is grown on about 200 million hectares of farmland globally (Russel et al., 2014). Durum wheat (*Triticum durum* Desf.) is grown in many countries and the study region in this article is also the most important durum wheat-growing region.

Temperature and rainfall play more crucial roles in yield of wheat even if solar radiation, relative humidity and wind in climatic factors are also important in crop yield (Kheiri et al., 2017). All these have significant effects on crop yield in cereals when cultivated in rain-fed conditions (Başçiftçi et al., 2012). Any change in climatic conditions thus significantly affects agricultural production systems. An evaluation and understanding of crop-climate relations for various conditions might be very useful and great importance to ensure the sustainability of food production for regional crop yield prediction and for determining effective management practices (Yu et al., 2014; Wang et al., 2018).

Limiting and/or changing climatic factors might cause changes in both crop yields and growth stages. Thus, the wheat yield varies frequently from year to year due to the effect of management practices and weather conditions (Yu et al., 2014). Rising temperatures accounted for about a quarter of the 27% fall in the water-limited yield potential for wheat. The negative effects of climate change, such as the decrease in rainfall and the rise in temperature, could be more severe in hot and dry areas (Sivakumar et al., 2005). According to Yu et al. (2014), wheat yields were significantly correlated with rainfall, maximum and minimum temperatures, and solar radiation during the vegetative stage. Changes in rainfall amount and distribution can significantly affect the wheat agroecosystems. Wheat production

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under rain-fed conditions will, thus, become more challenging depending on climate change (Tataw et al., 2016). In the reproductive stage, only maximum and minimum temperatures showed significant correlations with the relative detrended yields, and no effects of precipitation and solar radiation were found. Many researchers showed that the cumulative effect of daily air temperature in the long term was an important indicator for crop yield and plant growth potential (Schwartz et al., 2006). Temperature is, thus, also the main limiting factor for plant growth, especially at high latitudes and in temperate zones (Grigorieva et al., 2010). Various climatic indicators and/or indexes based on air temperature, which determine the heat accumulation necessary for plant development, have been proposed for use primarily in agricultural management processes (Gavilán, 2005).

On the other hand, the growing degree day (GDD) is a useful climate-impact indicator, as it provides needed information and data to users and farmers whose activities require them to manage climate risks and some opportunities. In addition, the GDD could provide insight from historical trends and help with estimating the effects of climate change or fluctuation on present-day agricultural practices (Easterling and Kates, 1995). The GDD method using the mean air temperature computed as the average of the maximum and the minimum is used commonly in agricultural and phenological research (Matzarakis et al., 2007; Fealy and Fealy, 2008).

In this study, the effects of rainfall and changing temperature on the yield were evaluated considering four critical development stages in terms of consumptive water use for durum wheat (*Triticum durum* Desf.) grown in the South-eastern Anatolia Region of Turkey. Critical maximum threshold temperatures on declining of grain yield were estimated. Similarly, GDDs for these crop development stages and for the entire season were calculated and discussed.

MATERIAL AND METHODS

Study area

The study areas were in the South-eastern Anatolia Region of Turkey (Figure 1). Climatological and yield data in four sub-areas (Cizre, Kilis, Gaziantep and Siverek) were used for the calculations and evaluations. The climatic data (daily maximum, mean temperatures and rainfall) during the period of available years were obtained from the General Directorate of Meteorology in Turkey (DMI, 2019). Thus, well-processed and quality-checked data were used for the study. Climatic data were available for 13 years (2005-2017), 12 years (2006-2017), 11 years (2007-2017) and 8 years (2010-2017) for Cizre, Siverek, Gaziantep and Kilis, respectively. Wheat grain yield data for each study area were obtained from the State Statistical Institution of Turkey (TUIK, 2019).

Crop development stages

The wheat growing season was divided into four critical stages considering consumptive water use according to the crop factor (Kc) approach depending on the type and growth stage of the crop and climate. The critical crop stages are given in Table 1. The Kc for a given crop varies over the growing period due to differences in crop evapotranspiration during the crop's various growth stages. The length of each stage for wheat depending on the crop development stages and the study site is given in Table 2. The growing period can be divided into four distinct growth stages: initial (stage I), crop development (stage II), mid-season (stage III) and late season (stage IV).

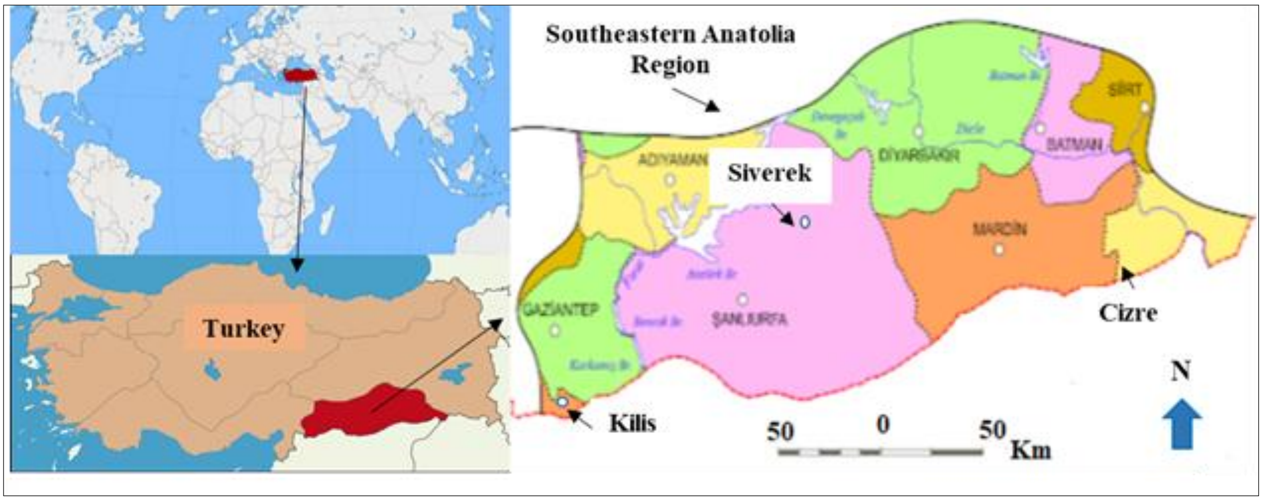

Figure 1. Study sites in South-eastern Anatolia Region of Turkey

Table 1. Definition of the crop development stages in terms of consumptive water use

I. stage:	The initial stage (I) begins from the planting date to approximately 10% ground cover of the plants. It includes the stages of sowing and emergency.
II. stage:	This stage (II) is defined as crop development stage. It starts from 10% ground cover of plants to the effective full cover of the plants. The effective full cover for many crops occurs at the initiation of flowering. This stage includes also vernalization, tillering and beginning of stalking stage. This stage is, thus, the longest stage for wheat.
III. stage:	It is defined as mid-season. The mid-season stage (III) runs from effective full cover to the starting of maturity. This stage includes heading, anthesis and grain filling stages. Thus, this stage starts from stalking stage to dough formation.
IV. stage:	It is defined as last season. The late season stage (IV) starts from the beginning of maturity to harvest or full senescence. In another word, it starts from dough formation to harvesting date.

Table 2. Crop critical development stages and length of growing season of wheat according to consumptive water use for the study locations (TAGEM, 2018)

Study sites	Lat.†	Long.†	Alti.† (m)	Stage I	Stage II	Stage III	Stage IV	Growing season (days)
Cizre	37°20’N	42°12’E	386	30 Oct-30 Nov (30 days)	30 Nov-20 Mar (111 days)	20 Mar-30 Apr (40 days)	30 Apr-1 Jun (30 days)	211
Siverek	37°45’N	39°19’E	695	15 Oct-15 Nov (30 days)	15 Nov-21 Mar (126 days)	22 Mar-30 Apr (40 days)	1 May-1 Jun (30 days)	226
G.Antep	37°05’N	37°22’E	842	15 Oct-15 Nov (30 days)	15 Nov-21 Mar (126 days)	22 Mar-30 Apr (40 days)	1 May-1 Jun (30 days)	226
Kilis	36°47’N	37°06’E	689	15 Oct-15 Nov (30 days)	15 Nov-21 Mar (126 days)	22 Mar-30 Apr (40 days)	1 May-1 Jun (30 days)	226

†: https://earth.google.com/web

Estimation critical level for maximum temperature and rainfall

A quadratic (polynomial) equation appropriately described the relationship between grain yield and maximum temperature and rainfall for four growing stages. This regression model was used by Schlenker and Roberts (2009) to determine the effects of total rainfall on log-yield estimation maize, soybean and cotton. They defined nonlinear relationships from time-series variations in temperatures and yields. They defined harmful temperature above threshold value which grain yield decline. Thresholds for max. temperature and min. or max. rainfall that grain yield started to decline were estimated from fitted curves. Similarly, critical growing-degree days (CGGD) for max. yield and yield loss at +1°C increase at mean daily temperature derived from CGGD were estimated. Quadratic (polynomial) of the form is: $GY=a+bt+ct^2$ and $a+br+cr^2$ for max. temperature and rainfall, respectively, where GY is grain yield (kg ha^{-1}), t is temperature (max. temperature during each stage) or time (GGD from sowing), r is rainfall, and a, b and c are regression coefficients. Thus, instantaneous rate of regression curve, dGY/dt or dr, could be calculated from the derivative of polynomial: dGY/dt or $dr=b+2ct$ or $b+2cr$ and at max. grain yield dGY/dt or dr=0, max. temperature or rainfall, critical max. temperature or rainfall at max. GY was calculated from the equation: $0=b+2ct$ or $b+2cr$.

Growing degree days

For the purpose of calculating GDDs, the equation (Eq. 1) used widely among agronomists and researchers focused on small grain cereals, such as wheat, was used (McMaster and Wilhem, 1997).

$$GDD = \frac{T\max + T\min}{2} - T_{base}$$

where,

T_{max} is the maximum temperature (°C) of the day;

T_{min} is the minimum temperature (°C) of the day;

T_{base} is the temperature below which the process of interest does not progress.

Thus, the base temperature was considered zero (0) for wheat (McMaster and Wilhem, 1997).

Statistical analysis and evaluation

The maximum and minimum temperatures pertaining to each crop development stage were extracted from the registered data in the local meteorological offices. Then, all data were used for regression analysis together with the local wheat yield pertaining to each critical development stage (RaschRob and Pilz, 2019). For statistical analysis, SPSS-21 was used. The highest value of R^2 was considered for creating a regression equation and curves. The relationships between grain yield and maximum temperature and rainfall for each development stage and for the entire season were analysed and evaluated.

RESULTS AND DISCUSSION

Effects of maximum temperature on yield

Considering the average maximum temperatures for crop initial stage (stage I), the average maximum temperatures varied from 21.7 to 26.1°C for the study areas and no significant relationships were found between the yield and maximum temperatures in all study regions in stage I. These results showed that the phenological stages of wheat differ in sensitivity to temperature because the phenological stage from sowing to the first spikelet is less sensitive to temperature. However, increasing the maximum temperature generally caused a decreasing yield for the entire study area except for Cizre. Critical max. threshold temperatures could not be estimated in this stage because there were no relationships between max. temperatures and yield in a quadratic (polynomial) equation (Table 3).

Table 3. Critical max. temperature (°C) for yield loss at different growing stages and locations and yield loss at +1°C increase over all locations and whole seasonal GDD

Study sites	Growing stages			
	Stage I	Stage II[†]	Stage III[†]	Stage IV[†]
Siverek	ne	19.1	25.8	36.1
Kilis	ne	21.9	27.5	34.1
Cizre	ne	25.2	29.7	37.3
Gaziantep	ne	18.9	24.2	34.0

Yield loss estimated at +1°C change of mean daily temperature (54,5 kg ha^{-1} and 2,5%[‡], respectively).
ne: not estimated, [†]Without changing other factors, each degree-Celsius increase in growing season mean temperature would reduce general mean grain yield of locations.

In crop development stage (stage II), the average maximum temperatures ranged from 21.4 to 25.6°C depending on the study areas. A distinctive and negative effect of the maximum temperatures on the yield was found. As the max. temperatures increased, the wheat yield decreased. In addition, a statistically significant quadratic relationship $y=26.3x^2+1002.1x-6435.5$, $R^2=0.42$, at P=0.05 for Siverek and $y=-25.7x^2+1294.7x-13556$, $R^2=0.86$ p=0.01 for Cizre, where y refers to grain yield (kg ha^{-1}), x indicates max. temperature (°C) was found between the max. temperatures and the yield according to the regression analysis results. This stage covers a cooler season in the study sites. Thus, winter wheat requires a period of low temperatures (vernalization) at the beginning of crop development stage (Table 1 and 2). This requirement could make winter wheat more vulnerable to a higher temperature via insufficient vernalization. This is because winter wheat requires a variable low-temperature requirement (vernalization) for a proper flowering time in case the wheat experiences successful grain reproduction. Max. temperatures in Cizre are higher compared with other study areas; thus, the grain yield is lower in Cizre compared with the other study areas. The main reason of this could be attributed the lower altitude of Cizre compared to the others (Table 2). The critical max. temperatures at which the yield started to decline were found to be 19.1, 21.9, 25.2 and 18.9°C for Siverek, Kilis, Cizre and Gaziantep, respectively (Table 3).

In mid-season (stage III), we found considerably negative effects of increasing maximum temperatures on the yield in Cizre. Although the regression analysis was statistically significant ($y=30.4x^2+1804.9x-23922$, $R^2=0.84$, at P=0.01) in Cizre, there were no significant relationship between maximum temperature and grain yield in other study sites. This stage includes heading, anthesis and grain filling stages (Table 1). Heat stress during the reproductive phase is, thus, more harmful than a vegetative stage due to its direct effect on grain number and dry weight. This stage cover grain filling and heat stress at grain filling stage is one of the key factors. The critical max. temperatures at which the yield started to decline were found to be 25.8, 27.5, 29.7 and 24.2°C for Siverek, Kilis, Cizre and Gaziantep, respectively.

In the last stage of crop (stage IV), increasing maximum temperatures showed negative effects on the yield, and statistically significant ($y=-244.6x^2+18229x-33667$, $R^2=0.52$, at P=0.05) relationships were found between the yield and maximum temperatures in Cizre as occurred similarly in the stage III. The most important reason for the negative effects of the max. temperatures on the grain yield in Cizre was that the measured temperatures were higher than the tolerable levels for wheat. As connected with mid-season stage of wheat, previous stage, high temperatures (>30°C) before flowering could cause a decrease in the seed number, and those after flowering can reduce the duration of the grain fill, thus leading to a wheat yield loss. A high temperature can also affect the assimilate supply and grain quality. The critical max. temperatures at which the yield started to decline were found to be 36.1, 34.1, 37.3 and 34.0°C for Siverek, Kilis, Cizre and Gaziantep, respectively (Table 3).

The grain yield begins to decrease with a certain threshold max. temperature increase. Critical threshold max. temperatures on decreasing of yield are given in Table 3. The results varied depending on study regions, altitudes and longitudes, and crop development stages. The results in this study showed, thus, that the higher temperature negatively affected the all development stages of durum wheat, which explains why in Cizre and Kilis occurred earlier crop development stages compared with the other locations. Thus, temperature has a significant impact on the rate of development of wheat. In general, warmer temperatures, within a certain limit, tend to accelerate the rate of development, whereas cooler temperatures tend to delay development. Similarly, Uprety and Reddy (2016) showed that 1°C warming would reduce crop duration by 21 days and reproductive period by about 8 days. The other growth periods are also shortened by increasing temperatures. In a cool environment it would normally take longer to develop and reach maturity compared with growing the same crop in a warmer environment. Calendar time has been found to be a non-reliable indicator for comparing when a crop will mature or reach a certain stage of development in various growing environments. In addition, temperatures can vary greatly with locations, growing seasons, the time of day and the time of year. Thus, it is difficult to predict crop growth stages based on calendar time (Payero, 2017).

As the growing stages progressed, the increasing max. temperature affected negatively the yield (Lobell et al., 2005; Luo, 2011; Çetin and Akinci, 2014). The ranking of the smallest to the largest of the max. temperatures is as follows: Gaziantep < Siverek < Kilis < Cizre stages I and II. In the Siverek location, the critical maximum temperature value increased due to the overheating of the weather during the last growing stage. As a result, a temperature over the max. temperatures based on the critical maximum temperatures computed and provided in Table 3 will cause a decreasing grain yield.

In the previous studies, it has been reported that an increase of 2°C in the seasonal average temperature could reduce the yield up to 50% (Asseng et al., 2011). In another study, it was reported that an increase of 1°C in seasonal temperature might decrease 4.1-10.0% of grain yield (Hatfield et al., 2011; Lobell et al., 2011). Concerning global warming and/or increasing temperature, a rise of 1°C in temperature was predicted to reduce the grain yield of wheat by approximately 3-66% (Ozturk et al., 2017; Zhao et al., 2017). A possible reason for the yield decline is the increase in the temperature rate and the accelerated growth stages of wheat (Valizadeh et al., 2014). The extreme temperatures (more than 30°C) caused a decreasing seed number and a reduced duration of the grain fill leading to a wheat yield loss (Ferris et al., 1998). Li et al. (2012) showed that there was a quadratic regression between the yield and GDD before winter season for winter wheat.

A rise of 1°C was also predicted to reduce the dry matter yield by approximately 3-5% in a study (Ozturk et al., 2017). Thus, increasing the air temperatures increased the GDD. This result clarified why the grain yield was lower depending on increasing the temperature and the GDD. In this study, the critical mean temperature - the threshold mean temperature - used to decrease the grain yield was computed as 12.4°C for all of the study regions. Therefore, the grain yield declined 2.5% for each 1°C increase above the mean daily temperature derived from the mean GGD in all locations (Figure 2). GDD could be, thus, used to determine temperature effects and define the timing of some biological and agronomical processes (McMaster and Wilhelm, 1997).

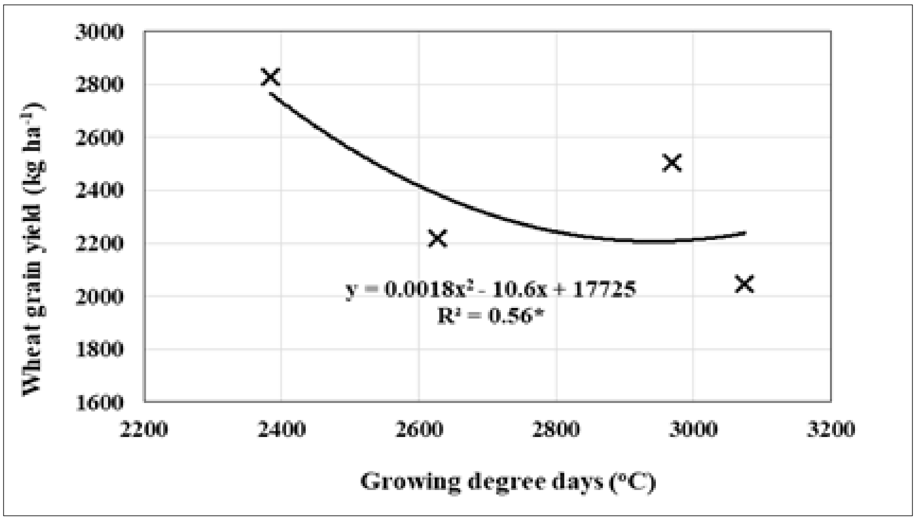

Figure 2. Relationships between wheat grain yield and growing degree days

The average GDD according to the crop development stages and the growing season for the study years are given in Table 4. The GDD was considerably distinctive from one study location to another because latitudes, longitudes and altitudes pertaining to the study locations were different. There was a high positive correlation between average of max. temperatures and GDD for the growing stages and whole season (Table 3 and 4). The GDD of the crop development stages and the entire season in Cizre and Kilis were, thus, higher compared with Siverek and Gaziantep. Similarly, the GDDs were higher in the same study regions (Cizre and Kilis) considering all development stages of the crop except for the first stage. A regression analysis showed a quadratic relationship between the yield and GDD for the entire season (Figure 2). This means that increasing the GDD caused a decreasing yield. Grigorieva et al. (2010) showed that GDD increased as long as mean monthly temperature increased for the growing season and this resulted decreasing yield trend for the wheat.

Table 4. Growing degree days (GDD, °C) belong to the crop development stages and entire growing season

Study sites	Crop development stages					Growing season (days)
	I	II	III	IV	Total	
Cizre (11 years) (2005-2017)	439.5	1077.2	716.9	735.2	2968.9	211
Siverek (12 years) (2006-2017)	476.3	715.0	552.2	640.7	2384.2	226
Gaziantep (11 years) (2007-2017)	465.0	955.0	572.0	634.5	2626.5	226
Kilis (8 years) (2010-2017)	542.4	1186.7	661.6	684.1	3074.8	226

On the other hand, the temperature in the early spring is usually the limiting factor for plants' development, and the GDD gives a direct measure of the "driving" factor. As the temperature increases, the development periods are shortened. Thus, GDD works to predict the development of a crop: the warmer it is, the faster the plant collects heat units for development. However, plants need to develop specific amounts of heat from one point in their lifecycles to another, such as from the seeding date to the four-leaf stage. The ability to estimate a specific crop stage, relative to weed cycles and insects, provides better crop production management (Miller et al., 2018).

Effects of rainfall

The amount of rainfall in the crop stage I ranged from 51.1 to 74.4 mm according to the study sites. Considering regression analysis, there weren't any significantly relationships between yield and rainfall occurred in stage I for all sites.

The amount of rainfall in crop stage II varied from 297.8 to 328.7 mm considering the study sites. The most of rainfall in the growing season occurred in this stage because this stage was the longest stage and covers winter season (Table 2) and in general, most of rainfall for the whole years occurs during this season, as a characteristic of Mediterranean climatic zone. In general, increasing rainfall in this stage for all sites increased yield. However, there was only significantly relationship [$y=0.019x^2-4.47x+2313.6$, $R^2=0.57$, $p=0.05$ where y refers to grain yield (kg ha^{-1}), x indicates to rainfall (mm)] between rainfall and yield in Siverek. Although it seems considerably positive effects the amount of rainfall on yield in Gaziantep, this relationship was not statistically significant.

In stage III, there were highly relationships between amount of rainfall and crop yield for all study sites except Cizre ($y=902.9x^{0.26}$, $R^2=0.44$, $p=0.05$ for Siverek; $y=30.3x+524.8$, $R^2=0.71$, $p=0.01$ for Kilis; and $y=-0.14x^2+$

33.6x+840.8, R^2=0.72, p=0.01 for Gaziantep). According to the regression analysis, amount of rainfall in this stage significantly increased crop yield for all sites except Cizre site. However, the rainfall caused considerable increase in crop yield in Cizre site although there was no statistically significant effect on yield. Although there is less and/or insignificant effect of rainfall on yield, the effects of rainfall on yield are different according to the study area in Stage IV.

Considering total amount of rainfall during the whole growing season, the effects of rainfall on yield were significantly found for Siverek and Gaziantep, and there were significantly linear (R^2=0.63, p=0.05) and quadratic (R^2=0.78, p=0.01) relationships between yield and rainfall for Siverek and Gaziantep, respectively (Figure 3). Although there were considerably positive effects of rainfall on yield in the other study areas, regression coefficients lower and this relationship was not statistically significant. The most important issue on relationship between rainfall and yield, the most of rainfall occurs during the winter season, that is, crop development stage (II). This stage needs less water because plant root system and canopy did not develop properly.

Concerning the effects of rainfall on grain yield, the main reason of that there was no any significant effects of rainfall on grain yield in the stage I could be probably attributed to crop initial stage which was just planting and germination stage. The reason for this is that both the plant has only about 10% surface area and minimum water consumption compared to other developmental periods. In addition, the soil moisture content before sowing might be also effective. Because the farmers adjust the planting time according to the rainfall, the water required by the plant is usually present in the soil. The fact that high amount of rainfall was not significantly related to yield could be associated with the extension of the vegetative period due to cool season. In addition, the plants still were younger and there was no need much more water because of climatic conditions as well.

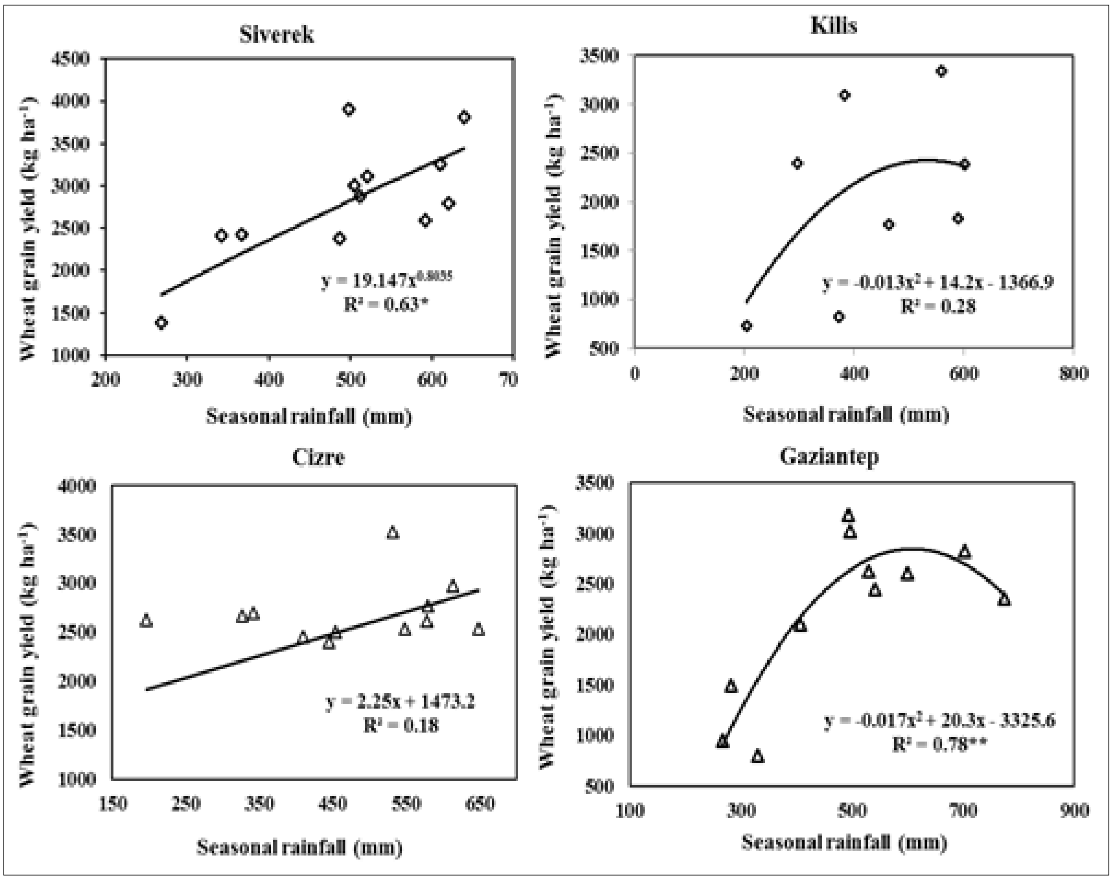

Figure 3. Relationships between seasonal rainfall and wheat grain yield

On the other hand, the reasons of highly relationships between amount of rainfall and crop yield in the stage III could be attributed to the lower amount of rainfall and higher temperatures. Higher temperature than 30°C at the stage III could cause lower yield. At the same time, the long rainy period at this stage will cause a delay in the heading time. This will shorten the already short grain filling time and result in handicaps for grain yields. However, in the third period, the increase in rainfall up to a certain level positively affects the grain yield in Siverek location. One of the most important reasons for this situation might be the formation of the flower primordia and the increase in the number of grains by affecting the flowering positively. In addition, the most positive effects of rainfall on yield in stage III was that it covers the effective full cover to the starting of maturity and dough formation. That is, the canopy cover was maximum, and it covers also flowering and pollination stages. Thus, this stage needs much more amount of water and sensitive to water deficit (Çetin and Akinci, 2014). Accordingly, the flowering and dough stages than during tillering (stage II) can be interpreted as a physiological response of the plants to produce more assimilates for the grain filling and ripening stages (stage IV). At the same time, this explains the significance of a higher leaf area at stage III (Tataw et al., 2014). The stage III was, thus, the most sensitive period of plants to drought or limited water. For this reason, plants require more water during this period (Cetin and Akinci, 2014). Likewise, reduced rainfall or water triggers the removal of pre-flowering metabolites from wheat germ and ultimately results in reduced yield (Ahmadi et al., 2009). Indeed, many studies have showed that decreasing rainfall reduced wheat yield (Dodig et al., 2010; Cetin and Akinci, 2014, Tataw et al., 2014). Considering the shortage rainfall and higher evapotranspiration since climatological conditions, rainfall was of higher importance than temperature, because the third period was the anthesis-grain filling phenological phase. In this period the plant develops its generative organs. With lower amount of rainfall the plant may produces infertile florets or the florets may not develop as required, so the winter wheat production becomes smaller.

The rainfall required to obtain the highest grain yield varied depending on the location and growing stages. According to the regression curve, the critical max. rainfall required for the highest yield in Siverek and Gaziantep was estimated in Stage I, while the critical min. rainfall was determined for Gaziantep and Kilis. The highest rainfall value shows both the point where the yield starts to decrease and the amount of irrigation water to be given depending on the rainfall. In the Stage I, the estimated rainfall for Kilis and Cizre shows the lowest yield level. The amount of rainfall required to obtain the highest yield varies according to locations and development periods, indicating that the amount of irrigation water to be applied should not exceed the critical value. The higher rainfall (535.7 mm) requirement at the last stage of development in Cizre location indicates severe terminal drought and max. temperature indicating that high yield may be related to high rainfall or irrigation water during this period. Grain yields predicted by seasonal rainfall show that yields in Gaziantep and Kilis were limited by total rainfall, while Siverek and Cizre will increase linearly in relation to rainfall. In this case, it could be concluded that Siverek and Cizre have high yield potential in terms of wheat production in conditions where water is not limited.

As a result, as rainfall in vegetative and reproductive stages exerted different effects on wheat yield, its variation will have significant implication for wheat production. Decreases in rainfall in the vegetative stage and increases in reproductive stage reduce wheat production. On the other hand, maximum temperature, minimum temperature, and solar radiation were closely correlated with rainfall. These variables had measurable influences on wheat yields. However, rainfall is considered to be the most important driving force (Yu et al., 2014).

CONCLUSIONS

The obtained regression equations were used to predict the values of the critical threshold max. temperature and rainfall causing yield in wheat. There were no appropriate polynomial relationships in the model used to estimate a threshold max. temperature for stage I (initial stage). An estimation on a threshold max. temperature could not be performed for the beginning of crop development stage (stage I) because there was no an appropriate polynomial relationships in the model used.

The critical max. temperatures (threshold values declining yield) were from 18 to 34°C in Gaziantep, 19 to 36°C in Siverek, 21 to 34°C in Kilis, and 25 to 37°C in Cizre; each interval covering crop development, stages II to IV. In addition, it was estimated that a 1°C increase in the daily average temperature might cause up to 2.5% decrease in the grain yield. Raising temperature should be considered jointly with soil moisture, rainfall, relative humidity, wind speed and advection depending on altitudes and latitudes.

Climate change, values and distribution patterns may considerably impact the yield, cultivar development, fertilization management (especially nitrogen), other management strategies and decisions, economic potential and crop-pest interactions for wheat. In the end, climate change is expected to distinctively influence crop production in different regions.

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