Determination and Assessments the Yield Gap Between the Wheat Yield and Potential Yield in Turkey

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Abstract

Knowing the current and the potential production amount of wheat is essential to meet the growing needs. Yield is determined by many factors. The main factors that limit the potential yield are genetic characteristics, and climatic factors such as rainfall and radiation, and management. Wheat is mostly grown in non-irrigated areas in Turkey. The most significant factors that limit dry agriculture wheat production yield in the Mediterranean climatic type are rainfall and its distribution in the growing season. A steady increase in yield is observed in Turkey in recent years. Average annual wheat production is 20.6 million tons. The potential production in this work is determined as 54 million tons. The gap is about 33 million tons. The actual production is 39% of the potential production. The average yield of the Growing Season Rainfall (GSRF) <500 mm areas is 1.9 t ha⁻¹, and potential yield of 4.7 t ha⁻¹, whereas the average yield of GSRF >500 mm areas is 2.2 t ha⁻¹, and the potential yield is 8.8 t ha⁻¹. The gap between the actual yield and potential yield is quite large. The current yield between the areas (GSRF <500 and >500 mm) is very small. So it is difficult to explain the gap just because of the rainfall.

Introduction

Wheat, with its direct and indirect use, is one of the most important food sources of our country and the world. Turkey’s population, which was 80 million in 2016, is expected to exceed 93 million in 2050 according to 2013-2075 population projections. In recent years, average annual wheat consumption per person is around 213 kg (TURKSTAT, 2017). It is expected that by 2050 per capita grain consumption will be close to and above (160 kg) current values (158 kg) (Alexandratos and Bruinsma, 2012). According to today’s projections, Turkey will need additional 3 tons of wheat to feed extra 13 million people in 2050. Despite being a self-sufficient country in wheat production, this balance has changed in recent years and the sufficiency rate has dropped to 90% (2014-2015) (TURKSTAT, 2017). This gap will continue to grow up in the coming years.

The world population is expected to reach 9.4 or 10.2 billion by 2050 (United Nations, 2017). As it is today, people in 2050 will meet most of their need of daily calories (41%) from grains (Kruze, 2010). Total grain production needs to be increased from 2 million tons (2005-2007) to 3 million tons in 2050 to meet increased biodiesel need and high caloric consumption induced by the increased national income, changing desires, and increased population. Yet the rate of increase in yields of basic field crops (maize, rice, wheat) was 1.95%, 1.1%, 1.08% in the period from 1987-2007, it is estimated to be to 0.56%, 0.61% and 0.74% in 2007-2050, respectively. At this rate, the increase in wheat production will be only 38-40% in 2050 (Tilman et al., 2011; Alexandratos and Bruinsma, 2012). In other words, it seems to be a serious decrease in productivity in the future compared to the past. In order to meet the need, the increase rate should be 2.4%. In this case, it is estimated that there will be 388 million tons of wheat production gap in the world in 2050 (Ray et al., 2013).

Compared to the years 1961-63, wheat yield doubled between the years 2005-2007. This increase has resulted in the development of varieties, which are semi-dwarf, resistant to diseases, drought, warmth and cold, and widespread production and usage of organic nitrogen. In other words, this tremendous increase happened because of the ‘Green Revolution’. Although agronomic applications increase the yield in developing countries by a certain amount, it seems difficult to recapture this success in developed countries. Yield increase in developed countries will only be achieved with genetic progress in the upcoming years.

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Rainfall is at the head of the limiting factors to reach the potential yield. It has been found that in the case of 450-500 mm water presence in the soil, the yield can be 6000-7000 kg ha\(^{-1}\). Besides excess water than plant need in the soil can cause decrease in the yield (Zhang et al., 2002; Schilling et al., 2008). Studies have shown that sufficient GSRF to reach maximum yield varies from 400 to 600 mm depending on environmental factors (Patrignani et al., 2014). Passioura and Angus (2010) noted that the radiation is the main factor that limits the yield in the area (rainfall >500 mm).

All plants need a certain amount of water for vegetative and generative development. There are many factors that regulate the production yield of dry agriculture wheat production, but the most important of them is the amount of rainfall (Tiryakioğlu et al., 2017; Hay and Porter, 2006; Fuentes et al., 2003) and its distribution by month (Nielsen and Halvarson, 1991). Higher-sized wheat requires 101 mm of water for vegetative growth, and it has been reported that the yield for each 1 cm of available water is increased by 149 kg ha\(^{-1}\) (Leggett, 1959). It is reported that shorten (semi dwarf) wheat requires 59 mm of water for vegetative growth and is expected 154 kg ha\(^{-1}\) for each 1 cm of water (Schilling et al., 2008). Wheat water stress was more susceptible to stem-elongation and grain-filling than other periods (Zhang and Oweis, 1999) and 70% of this consumption happens in the flowering period (French and Schultz, 1984a). This period in our country, which features Mediterranean climate, is generally arid (Soylu and Sade, 2012).

It is important how much the production will be able to increase to meet the needs that will arise in the upcoming years and to sustain the economic income. In this study it is aimed to determine the gap between yield potential in existing wheat production conditions (dry or irrigated) and actual production amount in Turkey, and to investigate the probable causes of and solutions of it.

Materials and Methods

Winter wheat is usually grown to benefit from winter precipitation. Turkey is under the effect of the Mediterranean climate zone which is characterized with cold and rainy winters, and dry and hot summers. Although the average rainfall is 624.6 mm, it varies from 351 mm (Aksaray province) to 1458 mm (Rize province). Wheat water consumption varies between 360-730 mm according to geographical regions (Kanber, 1982; Anonymous, 2016). Precipitations is not enough for wheat production can in most cultivated areas.

In this study, average wheat cultivation area, production and yield values of the last five years (2012-2016) and monthly rainfall on the basis of cities in Turkey have been used (MGM, 2017; TURKSTAT, 2017). All assessments have been done according to winter bread wheat (*Triticum aestivum* L.) since it constitutes most of the wheat production (79%) in Turkey (TURKSTAT, 2017). The average yield was obtained by taking the average of bread wheat yield and durum wheat yield. Even though there have been little fluctuations (19000-40000 ha) in the gap between cultivated and harvested areas, calculations have been made considering cultivated areas.

Turkey wheat production areas are divided into two main groups as the cities with GSRF (October - June) below 500 mm and 500 mm above. Then these groups were separated into production regions among themselves (Figure 1) based on the classification of agro-climatological (MGM, 2017). The yield potential of these regions is evaluated at the same. Kirkkareli was assessed in the second group because of its location. There is no wheat production in Rize and Trabzon provinces. Turkey shows significant climatic changes ranging from temperate climate to terrestrial climate in short distances in terms of its climatic characteristics. The mean precipitation of the regions is shown in Figure 2.

The attainable potential yield must be known to determine the accessibility of the current production. There are different yield definitions (Figure 3) and calculation methods for this. In our study, yield parameters such as current yield (Yc), potential yield (Yp), yield gap (Yg), theoretical yield (Yt) were obtained considering previous studies (Chapagain and Good, 2015; Van Ittersum et al., 2013; Connor, 2004; Fischer et al., 2009). Current yield (Yc); is defined as yield averages of the last few years obtained by farmers producing in a certain region and climatic conditions. Yc in the study was determined by taking the average of the yield and production values of the last 5 years (2012-2016). In our study, the current yield of irrigated areas is shown as Yci and the yield of rainfed areas as Ycr.

### Figure 1 Agro-climatological regions of Turkey

![Agro-climatological regions of Turkey](image)

### Figure 2 GSRF of the regions

Potential yield is determined by field experiments, yield contests, maximum yield in farmer field and crop simulation methods (Van Ittersum et al., 2013). The methods have advantages and disadvantages compared to each other. Potential yield (same as Attainable yield) for irrigated crop (Ypi) or GSRF >500 mm regions; It is defined as the highest yield, which is well adapted to the...
region, is not lack of water and nutritional elements, and is obtained in an environment where the agronomic applications (soil processing, sowing time, sowing frequency, weed, disease and harmful struggle, etc.) are done correctly and properly. Water deficiency in these regions does not limit the yield. In this study, the highest yield value has been taken as Ypi obtained in the experiments by the research institutes and universities.

Potential yield for rainfed crop (Ypw): It is used instead of Ypi when wheat is grown without irrigating and the rainfall cannot meet the plant water need (GSRF <500 mm). The yield in these areas is limited by water deficiency (Connor et al., 2011). There is a significant relationship between GSRF and yield in these regions (French and Schultz, 1984a). Ypw is calculated by yield simulation models, transpiration efficiency, GSRF and linear models using yield values (French and Schultz, 1984b). In the study Ypw in the provinces where GSRF below 500 mm in Mediterranean Climatic characteristics has been determined using Equation 1 (Schillinger et al., 2008) obtained as a result of multiple regression analysis taking the seasonal distribution of rainfall for years to some extent.

\[
Y_{pw} = 150 \times OWR + 1745SR - 1986
\]  

1

(Ypw : Yield (kg ha\(^{-1}\))  
OWR : Over winter rainfall, cm (October - March)  
SR : Spring rainfall, cm (April-June)

The yield gap (Yg) has been determined as the difference between current yield and potential yield (Yp-Yc). In the study done, the values found in the provinces have been collected and the Yg value for the country has been calculated. Theoretical yield is determined by genetic and environmental factors and can be estimated by models such as APSIM, CERES, CropSyst or SUCROS (FAO and DWFI, 2015). Sinclair et al. (2013) reported the theoretical yield as 12.9 t ha\(^{-1}\) (Lollato et al., 2017), but this value is not taken into consideration in the study since it might be higher in value depending on genetic and agronomic developments.

**Results and Discussion**

Considering the last 30 years in Turkey, there has been a decrease in agricultural areas with a total of 2.6 million hectares, largely because of urbanization pressure and this decline has become a significant trend starting from 2000s. As in developed countries (Fischer et al., 2009), 1.7 million hectares (18%) of this decline happened in wheat production areas. Despite the decrease in cultivated areas, there is a slight increase in total wheat production. The wheat yield, which followed a fluctuating trend until mid-1990s, has entered a trend of about 2% annual increase after this date. Despite the decline in cultivation areas, the high rate of yield growth has also led to an increase in production (Figure 4). This increasing trend shows similar characteristics with the increasing trend in the Midland American Region in the years 1960-1980 (Patrignani et al., 2014). It is thought that this is related to fertilizer use and the application of information in some agronomic practices.

The rainfed area is 5.9 million hectares in 7.7 million wheat production areas in total. GSRF is below 500 mm in 3.3 million hectares of rainfed area and GSRF is above 500 mm in 2.6 million hectares of it. Cultivation area, production, yield and potential yield values for provinces are given in Tables 1 and 2. While the current yield (Ycr) of rainfed areas is 2 t ha\(^{-1}\), the current yield (Yci) of irrigated areas is 3.5 t ha\(^{-1}\) in across Turkey. While the current yield is 1.9 t ha\(^{-1}\) in rainfed areas, it is 3.4 t ha\(^{-1}\) in irrigated areas of the provinces where GSRF<500 mm (Table 1). The current yield is 2.2 t ha\(^{-1}\) in the rainfed areas and 3.7 t ha\(^{-1}\) in irrigated areas of the provinces where GSRF>500 mm (Table 2).

\[
y = 4.0477x^2 - 54.094x + 19324
\]

\[
y = -3.2635x^2 + 19.215x + 9549.5
\]

\[
y = 1.4856x^2 - 15.894x + 2040.5
\]

**Figure 3 Wheat yield definitions (FAO and DWFI, 2015)**

**Figure 4 The wheat cultivated area, production and yield in Turkey**

Yield values and average regional values of the regions comprised of provinces with GSRF<500 mm are given in Figure 5. There are significant differences between regions comprised of the provinces where GSRF<500 mm (Figure 5a). The Ycr (1.3 t ha\(^{-1}\)) in non-irrigated areas of the provinces located in the region 5 and 6 is quite low compared to the other regions. The Ycr (1.9-2.2 t ha\(^{-1}\)) of the provinces in the regions 1, 8 and 9 are partially similar. Among them, region 9 (396 mm) and region 1 (408 mm) are the areas where GSRF is the lowest. It is difficult to say that the difference in Ycr among regions is influenced by the amount of precipitation. A similar thing is valid for Yci too. In these regions, the Ypw due to GSRF varied between 4.3 t ha\(^{-1}\) and 5.4 t ha\(^{-1}\) (Figure 5a), whereas the average Ypw of the provinces where GSRF is <500 mm has been determined as 4.7 t ha\(^{-1}\) (Figure 5b).
A multiple linear regression model was constructed for the effect of winter and spring precipitation amounts on estimates of Ypw. The model was highly significant (P<0.001) and descriptive (R² = 0.998). While the model was not sufficiently affected by winter precipitation, it was observed that the spring precipitation value contributed significantly. Ypi is seen 20-25% higher the regions 6 and 8 compared to other regions. In general evaluation of the areas where GSRF<500 mm, Yp’s are more than twice than Yc’s (Figure 5b). It is expected that there is little difference between actual Ycr and Ypw in dry farming areas and this also means that this gap might close if irrigation can be done (Van Itersum et al., 2013). The fact that the average Yci is 1.3 t ha⁻¹ lower than Ypw in these provinces indicates that the difference between Yp and Yc is not only water related. The yield values and average regional values of the regions where GSRF>500 mm are given in Figure 6. Ycr value varies in a wide range from 1.6 to 3.2 t ha⁻¹ in these regions (Figure 6a). The highest Ypr value is in region 3, the lowest is in region 7. Other regions show similarities among themselves. Yci values are similar in the regions 2,
3 and 4 and they are about 33% higher in the regions 6, 7 and 8. The Yp is the lowest (5.0 t ha$^{-1}$) in the region 8, and it is followed by the regions 7, 2, 3, 6 respectively (Figure 6a). The average Yp is 4 times higher than Ycr and 2.4 times higher than Ycr in the regions comprised of provinces where GSRF > 500 mm (Figure 6b). It is remarkable that the mean Yc value is 50% higher than the Ycr value of the regions where GSRF > 500 mm.

Potential yield is defined in different forms and is calculated by different methods. However, significant differences (50%) can be found between the values calculated according to the used method (Lobell et al., 2009). The main reason for this is the fact that the soil characteristics at the local level are not known precisely and that the distribution of climate characteristics such as temperature and humidity is changing over the year. Since the Yp varies according to the methods, the Yg will change as well. Nevertheless, the information obtained knowledge about Yg will be quite valuable, no matter which method is used.

Table 2 The cultivated area, production and yields of provinces with GSRF > 500 mm

<table>
<thead>
<tr>
<th>Province</th>
<th>Rainfall (mm)</th>
<th>Rainfed</th>
<th>Irrigated</th>
<th>Potential yield Ypi</th>
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<td>Aydın</td>
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</tr>
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</table>

R: Region; T: Total; CA: Cul. Area (1000 ha); PR: Production (1000 ton); Y: Yield (kg/ha); M: Max. Yield (kg/ha); RF: References; R1: Aktas and Eren. 2014; R2: Öztürk et al., 2015; R3: Dinçer and Yuktubay. 2012; R4: Doğan and Kendal, 2012; R5: Şemret, 2011; R6: Kendal et al., 2012

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Despite the high yield increase in recent years in Turkey, the yield is still well below Yp and the world average. Yc is about 21 million tons. In our study, Yp was found 54 million tons (Figure 7). Yg is about 33 million tons, in other words, Yc is 39% of Yp. Lower yield is actually an expected result in farmers’ conditions. Because technology, financial situation, taking risks and economical factors are driving factors on productivity at farm level. This value varies from 20% to 80% in a wide range in the world. It is 79% in the UK, 67% in some parts of the US and 40% to 95% in India. The fact that wheat potential yield varies from 9 to 10 tons has been demonstrated in the studies carried out in the countries having similar climatic conditions with Turkey (Fischer et al., 2009; Lobell et al., 2009). Neumann et al. (2010) stated that Yg varies from 2 to 8 t ha⁻¹, the highest values are in the regions 4, 5 and 6, in Turkey on his global scale study. In our study, it varies between 2.3 t ha⁻¹ (GSRF <500, 1 and 9 region) and 7.7 t ha⁻¹ (GSRF> 500, 4 regions) when the regional Yg average is taken into consideration. The yield of the farmers should be close to 80% of the potential yield (Lobell et al., 2009). To reach 43 million tons of Yc can be considered as the first step target for Turkey if the development of knowledge and technology in terms of farming is realized. Yield shows little increase as it approaches to the potential yield. When present production exceeds 70% in the areas where rainfall-related production is done, yield stagnation appears (Cassman, 1999). Yield increase has decreased rapidly and has nearly ended in some regions of the US and in many parts of the world (especially in industrial countries) since 1980s (Calderini and Slafer, 1998; Fischer et al., 2009; Patrignani et al., 2014). However, a steady yield increase has been observed in Turkey since the 2000s. This shows that there has been an increase in awareness of some of the agronomic and cultural practices (selection of varieties, fertilizing, pesticide use, etc.) in recent years, but there are a lot more shortcomings.

In order to reach or approach to the attainable yield, agronomics variables must be well known and applied (Lobell et al., 2009). The yield is under the influence of biotic and abiotic factors. Abiotic factors include radiation, irrigation, irradiation, temperature, vernalization, fertilization, photoperiod, variety and agronomic applications (irrigation, fertilization, sowing time, etc.) (Licker et al., 2010; Lollato et al., 2017). Losses due to biotic factors in wheat production (Weeds, animal pests, pathogens) have a significant place. Pesticide use is directly related to the cultural level and economic conditions of the farmers. Weeds (8%), animal pests (8%), pathogens (10%) and viruses (2%) cause total 28% yield loss worldwide. This loss potentially reaches 50% (Oerke, 2006).

The most important factor restricting yield in farmer conditions is water and insufficient fertilization (Boling et al., 2010). The yield is directly related to nitrogen fertilization in wheat production (Nielsen and Halvarson, 1991; Fiez et al., 1994; Kara, 2010) and about half of the yield increase in developed countries is related to nitrogen use (Bruinsma, 2003; Heisey and Norton, 2007). Inadequate fertilization is reported to cause yield loss up to 35-63% (Boling et al., 2010). Use of nitrogen fertilizer ranges from 45 to 75 kg ha⁻¹, and as for phosphorous fertilizer, its use ranges from 22 to 32 kg ha⁻¹ in wheat production in Turkey (Kacar and Katk, 2009). According to this nitrogen amount, maximum yield per hectare is 3500 kg ha⁻¹, and this situation is compatible with Turkey’s average yield. The amount of nitrogenous fertilizer needs to be folded 2 or 3 times according to the regions to reach the potential yield. 15 kg nitrogen for 6 t ha⁻¹ and 20 kg for 8 t ha⁻¹ yield is required in the Mediterranean climate zone (Savin et al., 2006).

Most of the land is suitable for farming even if 62% of the soil is slightly alkaline, 30% are neutral, 92% are loamy or clay and loamy, and with low organic matter in Turkey (Doğan, 2012). But especially in the regions 1, 5, 6, 8 and 9, the most important limiting factor on yield is the lack of rainfall. The ongoing drought is seen in these regions starting especially from the middle of May or end of June and July (Soylu and Sade, 2012). Small sized wheat varieties can increase productivity up to a certain level in low-rainfall environments (Brancourt-Hulmel et al., 2003; Condon et al., 2004). Selecting bread wheat that is smaller sized, early and less affected by climatic fluctuations in these regions will be effective in increasing production. In regions where GSRF is above 700 mm, high rainfall may result in yield loss (Patrignani et al. 2014). There is not a region that receives more than 700 mm of rainfall during the growing season in Turkey. It is difficult to say that the surplus of precipitation is a limiting factor in the wheat production of our country since the rainfall generally takes place at the beginning of the growing season (the characteristic of Mediterranean climate) in the provinces that have high precipitation.
Wheat production (1000 ton)

Current production (Yc)  
Potential production (Yp)

Figure 7 Turkey wheat yield gap, current production and potential production

Conclusion

Seasonal climate anomaly that have been common in recent years, increases in input costs, declining agricultural land, etc. can be considered as the most important obstacles to the increase of wheat production. A meaningful yield increase trend has been observed in Turkey in recent years. This increase has to be reached to higher rates and made permanent. While the gap between Ycr and Yci is low, Yg is quite high throughout Turkey. This shows that other factors (variety, fertilization, agronomic application, etc.) are more effective on the low yield more than soil characteristics and precipitation. Turkey is engaged in wheat production in a wide topography of up to 2000 m above sea level. It is obvious that regional based planning is a necessity. The protection of agricultural lands is significant for the permanence of production. Seasonal climate irregularities, increases in input costs, declining agricultural land, etc., which are common in recent years can be considered as the most important obstacles to increase in wheat production.

References


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