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Crop production in Türkiye: trends and driving variables

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Abstract

Climate change and a rapidly increasing population boost the pressure on Türkiye's cropping systems to increase crop production in order to meet rising food demand. It is unknown whether and in which direction trends and variability in harvested area and yield separately affect crop production in Türkiye. The objective of this study was to (1) quantify the long-term (2004–2020) trends of planting/harvested areas, yield and crop production for the 16 vital annual crops in Türkiye, (2) quantify the separate contribution of harvested area and yield on crop-specific production variability and (3) the potential of water and temperature-based remote sensing variables on capturing the variability of harvested areas and yield. The harvested area of the most grown crops (10 out of 16) such as wheat and barley showed a declining trend. However, the yield trend was increased for all of the study crops, which in some cases overcompensated for the decline in the harvested area on crop production. The harvested area showed a more robust explanatory power for production variability than yield except for the crops with higher breeding investments and subsidized by authorities such as wheat and sugar beet. The water-related remote sensing variables and combination of water and temperature variables largely explained the variability of the harvested area in Türkiye. In order to stabilize crop production in Türkiye, better and more efficient water management plans are crucial.

1. Introduction

Türkiye is the fourth largest country (0.78 M km^2) in the Middle East, with the region's most extensive agricultural lands (48% of the country area) (MoAF 2021). The mean temperature range of the country is between <5 °C and >18 °C with the east to the west spatial patterns (figure 1(a)). The highest temperature variability (>1.2 °C) is recorded in the central parts of the country (figure 1(b)). There is a significant variation in annual precipitation sum between central Anatolia and northern Türkiye with less than 260 mm year^{-1} and over 860 mm year^{-1}, respectively (figure 1(c)). The variability in annual precipitation sum is also significantly slighter in dry regions compared to others (figure 1(d)). Türkiye is located in a climate transition zone, so it experiences spatially diverse climatic conditions (Turkes 2020). The population increased from 27 M to 85 M during the last 60 years. The population is projected to increase to 96 M by 2050 (World Population Review 2022).

The primary crop production (based on FAO definition) in Türkiye increased from 31 M tons in 1961 to 126 M tons in 2020 (FAO 2022). The crop production remarkably increased during the last few decades in Türkiye; nevertheless, the net trade of the cereals sharply declined from +0.61 (1990–2000) to −1.71 (2010–2020) billion US dollars (FAO 2022) means the increment in production did not meet food demand for the growing population. The reduction in crop total factor productivity has been reported from the mid-1990s to the mid-2000s (Armagan *et al* 2010). As of 2020, there are only 0.57 million active farmers, down from 1.1 million in 2010 (MoAF 2021). The combination of shrinking in cropping areas (FAO 2022), long-lasting drought spells (Turkes 2020, Katipoğlu *et al* 2022, Rolbiecki *et al* 2022) and climate change (Chandio *et al* 2020)

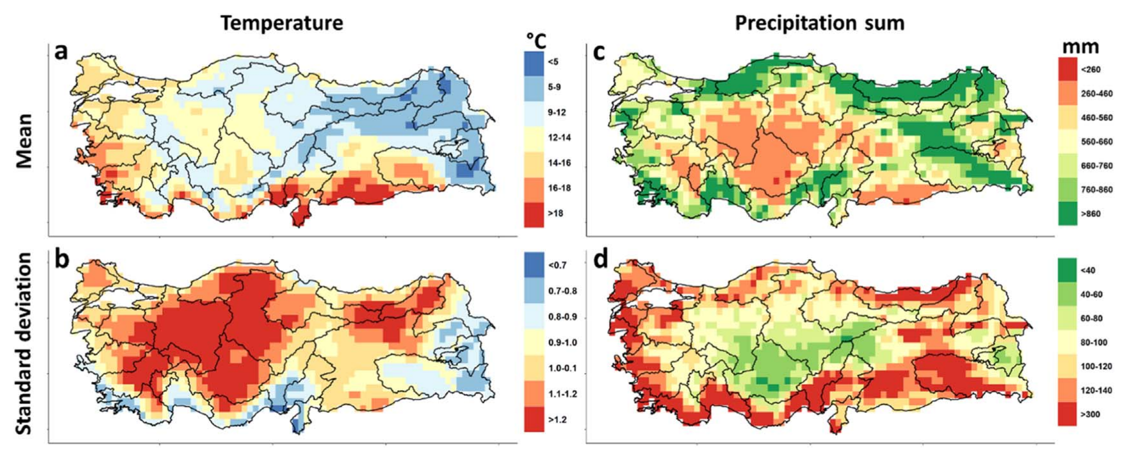

Figure 1. Spatial pattern of the mean and standard deviation of temperature (a)–(b) and annual precipitation sum (c)–(d) in the period 2004–2020 at 0.25° × 0.25° spatial resolution in Türkiye. The background polygons units indicate the water basin units.

are the main challenges threatening food security in Türkiye. The drought intensity is projected to increase by the reduction in precipitation (up to 40%) across western, southern and central regions of Türkiye under climate change (Sen *et al* 2012). The climate change projections showed +1.2 °C to +3.9 °C increase in mean temperature by 2100, depending on emission scenarios (Gorguner *et al* 2019). A significant increase in crop water demand is projected for south, west and southeastern areas of Türkiye under climate change (Nistor *et al* 2019). The climate change would result in a 16% to 43% decline in Türkiye's wheat yield without effective adaptation strategies (Vanli *et al* 2019, Kaya 2021).

To deliver sustainable food production, crop yields need to increase significantly to counteract the remarkable decline in cropping areas during recent years (Gürsoy 2020). However, the investment in modern agricultural technologies and infrastructure in Türkiye is challenging due to recent economic crises (Öniş and Kutlay 2021), field sizes (Kiropoulos *et al* 2021), and the lack of funding programs for farmers. The farm size in Türkiye is around 6 hectares which are relatively small (Gürsoy 2020). Importing more agricultural products and restoration of arable lands would be other possible options. However, those options are deeply limited by ever-growing food prices on the global scale, primarily driven by drought impacting pivotal crop producers (Santini *et al* 2022) and a drastic upsurge in inputs prices (Ben Hassen and El Bilali 2022). The increment in current irrigation intensity (45%) would also be challenging. Since it would lead to depletion of water resources (low irrigation water use efficiency (43%)) (Arslan *et al* 2020) and soil salinity (Akça *et al* 2020) in Türkiye.

These challenges increase the pressure on food security in Türkiye, which has already been under pressure in the recent decade (Gürsoy 2020). Thus, it is prime to understand what controls crop production (trend and variability) to formulate effective adaptation strategies and improve food security. Harvested area and yield are the main pillars of crop production. Most studies that explored the production response to environmental variables focused on yield but not harvested areas (Iizumi and Ramankutty 2015, Lesk *et al* 2016, Yu *et al* 2018). However, performing large-scale assessments using point base observations is challenging. Remote sensing can provide a comprehensive overview for capturing the signal of such drivers on harvested area and yield at regional scale (Kern *et al* 2018, Joglekar *et al* 2019, Wolanin *et al* 2020, Abbasi *et al* 2021). It is unknown whether contribution of harvested area and yield fluctuations in crop production variability is crop specific and whether remote sensing is effective in monitoring these fluctuations in Türkiye. The study therefore aimed to (1) Analyze the long-term trend and the contribution of harvest area and yield variability to the production of Türkiye's 16 most cultivated crops and (2) evaluating the explanatory power of water and temperature-driven remotely sensed variables in capturing the variability of the crop harvested area and yield in Türkiye.

2. Materials and methods

2.1. Data preparation and processing

The 16 most grown annual crops, as measured by planting area, harvested area, yield, and production including, wheat (*Triticum aestivum* L.), Sunflower (*Helianthus annuus* L.), sugar beet (*Beta vulgaris* L.), Soybean (*Glycine max* L.), Rice (*Oryza sativa* L.), Potato (*Solanum tuberosum* L.), Peas (*Pisum sativum* L.), Peanut (*Arachis hypogaea* L.), silage maize (*Zea mays* L.), lentil (*Lens culinars* Medic.), faba bean (*Vicia faba* L.), cotton (*Gossypium hirsutum* L.), chickpea (*Cicer arietinum* L.), canola (*Brassica napus* L.), bean (*Phaseolus vulgaris* L.), barley (*Hordeum vulgare* L.) were extracted from agricultural statistics portal of Türkiye (MoAF 2021). Data from 2004

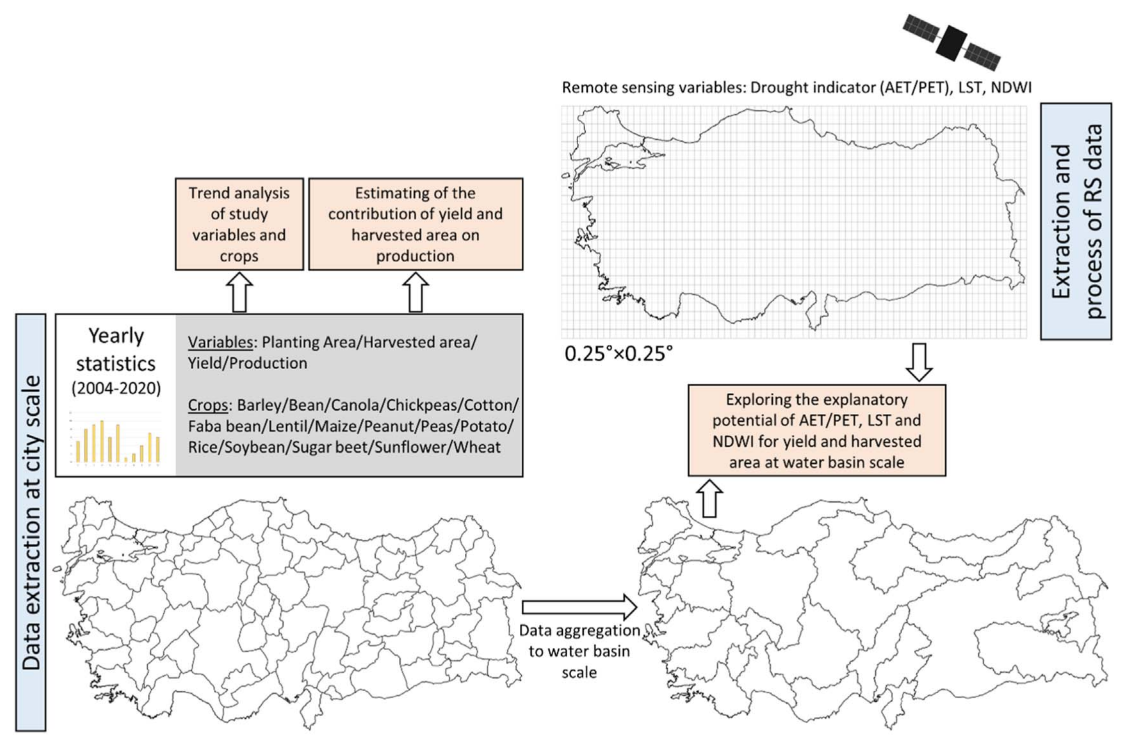

Figure 2. The schematic overview of workflow regarding data extraction, processing the remote sensing data, and data analysis to address the objectives in Türkiye. AET: actual evapotranspiration, PET: potential evapotranspiration, LST: land surface temperature, NDWI: normalized difference water index.

to 2020 was available at the city level (81 cities). To better represent (noise removal) relationships among variability of the yield/harvested areas and precipitation sum/remote sensing variables, the city scale data were aggregated into 26 water basin units. The rainfed and irrigated data were only available separately for the last 9 years of the study period. Therefore, the rainfed and irrigated systems were not discretely analyzed (figure 2).

Using 2004 as a starting point, the planting area, harvested area, yield, and production trend were computed for all crops. Each study variable in a specific year was multiplied by 100 and divided by the reported values in the year 2004. Comparing diverse crops with a wide range of yield, harvested areas, and production was possible through this calculation. The yearly harvested area of each crop was calculated relative to the total harvested area to determine the change in the growing area of each crop during the study period. The 'Rattle' package in R was used to describe the linear relationship between harvested area and crop yield (as independent variables) and specific crop production (as dependent variable) (Williams 2011). The Lindeman, Merenda and Gold (lmg) metric (R^2 divided by averaging over orders) implemented in the R package 'relaimpo' was used to quantify the percentage of response variance of independent variables on crop production (Grömping 2006). The statistical method is widely used to quantify the importance of correlated predictors in the multiple linear regression models (Carvalhais *et al* 2014, Musavi *et al* 2017, Yao *et al* 2018) as (Grömping 2006):

$$LMG(x_k) = \frac{1}{p}\sum_{i=0}^{p-1}\left(\sum_{\substack{S\subseteq\{x_1,\ldots,x_p\}\setminus\{x_k\}\\ n(S)=j}} \frac{seqR^2(\{x_k\}|S)}{\binom{p-1}{i}}\right) \tag{1}$$

where LMG (x_k) is the average contribution to R^2 while adding regressor x_k to a model of size i without x_k, $seqR^2(\{x_k\}|S)$ is the additional R^2 while adding x_k to a model with the regressors in S (Siddiqui *et al* 2020) The bootstrap resampling function provided in 'relaimpo' package was employed to examine the significance of a difference between the study variables (Grömping 2006).

Standard and de-trended data were used for the statistical test. Using linear de-trending, the datasets were de-trended for each crop (Rezaei *et al* 2015). Using de-trended data can indicate whether non-biophysical variables (e.g. change in cultivars, agro-techniques and etc.), may affect the importance of study variables. The climate data was attained from the ERA5 atmospheric re-analysis (0.25° × 0.25°) in the period 2004–2020 (Hersbach *et al* 2020).

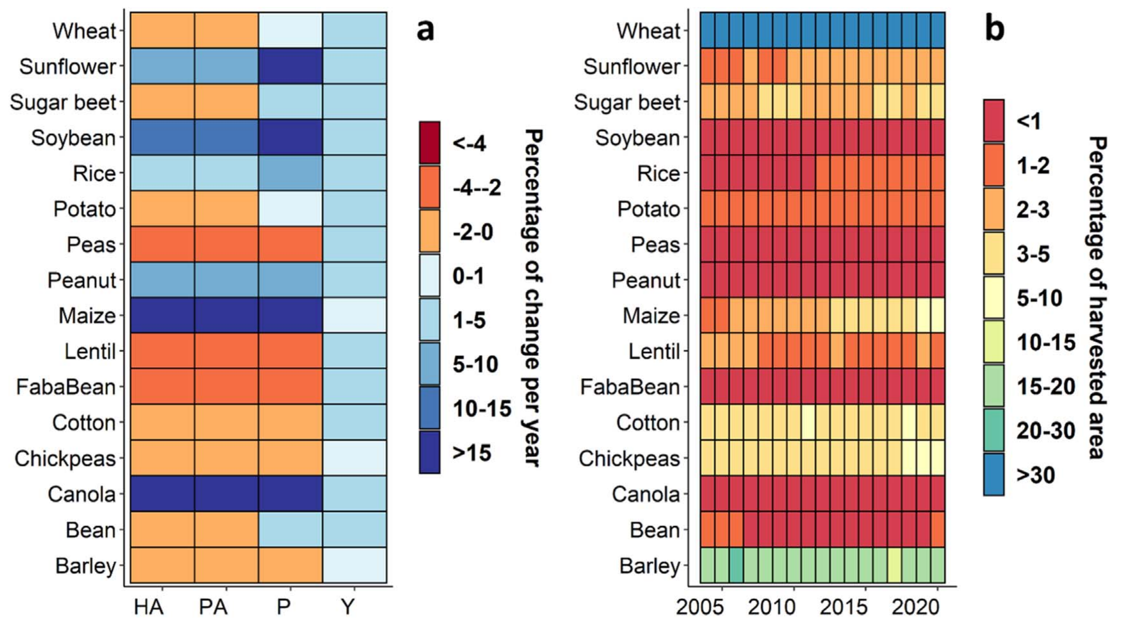

Figure 3. Linear trends of planting/harvested areas, yield and production of 16 annual crops during 2004–2020 in Türkiye (a). The values indicate the change in percentage per year, with the year 2004 assumed as a reference year. The percentage of harvested area for specific crops during the study period (b). HA: harvesting area, PA: planting area, P: production and Y: yield.

2.2. Processing of remote sensing data

Several remote sensing variables were derived to assess the variability of crop production. For this Moderate Resolution Imaging Spectroradiometer (MODIS) based land surface temperature (LST) (8 day, 1 km) (Wan *et al* 2015), ratio between actual and potential evapotranspiration (8 day, 500 m) (Running *et al* 2017) and Normalized Difference Water Index (NDWI) (Gao, 1996) were extracted for the study area over the period of 2004–2020. The latter was derived using the Near-Infrared and Short Wave Infrared bands of MODIS MOD09A1 product (8 day, 500 m) (Vermote 2015) which makes it sensitive to water content variability of plants (Gao *et al* 2015).

The data was accessed and processed using Google Earth Engine (Gorelick *et al* 2017). For each of the variables, the corresponding quality masks were used to exclude the pixles with reduced quality. Afterwards the time series were aggregated to monthly time-step using the sum for AET and PET, and mean for NDWI and LST. Finally, the data were aggregated to $0.25° \times 0.25°$ degree to correspond with the resolution of ERA5 data.

2.3. Drivers of variability in yield and harvested area

The remote sensing variables, precipitation sum (from grid-scale data), yield, and harvested areas (from city scale data) were aggregated to the water basin scale assessing the explanatory power of precipitation and remote sensing for yield and harvested area variability (figure 2). The aggregation procedure to water basin scale was performed as the city level units are not representative for distinct agro-climatic zones of the country. The variability of the harvested area was computed as the relative deviation between the trend line and the sum of all harvested areas for all study crops in specific years and water basin units. The parallel procedure was employed for the calculation of yield variability. The yield variability for all crops was calculated based on harvested area-weighted mean to add more weight to the crops with higher growing area each year and water basin units. The coefficient of determination for linear regression was computed to quantify the explanatory power of precipitation sum, AET/PET, LST, and NDWI in estimating the harvested area and yield variability during the study period on water basin scale. Multiple linear regression was also used for testing the improvement of the explanatory power of combined remote sensing variables on study variables. The relationships among precipitation sum and difference between planting areas and harvested areas were calculated for wheat and barley as the most grown areas in Türkiye, indicating the effects of drought on farmers' avoiding harvest.

3. Results

The trend analysis results indicated that planting and harvested area decreased between -1% and $<-4\%$ per year for 10 out of 16 crops since 2004 (figure 3(a)). Canola, maize, soybean, rice, peanut, and Sunflower showed an increasing trend (1% to $>15\%$ per year) for planting and harvested area during the study period (figure 3(a)).

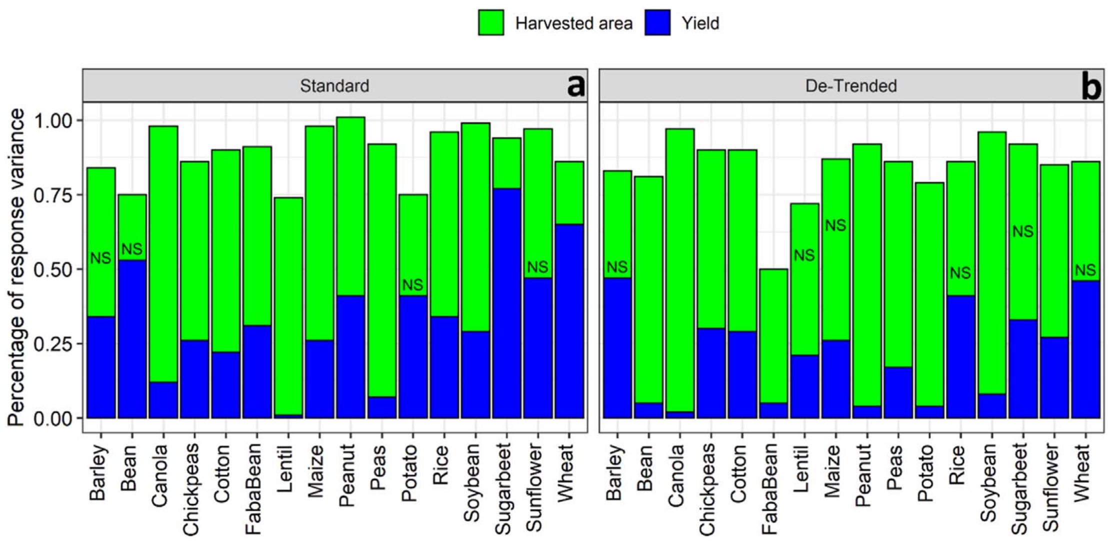

Figure 4. The relative contribution harvested area and yield on crop production for 16 vital annual crops using standard (a) and de-trended (b) data in the period 2004–2020 in Türkiye. The higher the value, the greater the impact on crop production. The significance means either harvested area or yield has a significant impact on crop production. NS = non-significant. The level of significance for all non-significant crops was at 5% probability level.

However, the harvested areas of those crops ranged between <1% and 8% of total growing areas (figure 3(b)). The yield trend was positive (up to 5% per year) for all crops during the study period (figure 3(a)). Production and harvested areas were similar in trend signs (positive or negative) for 12 out of 16 crops. Despite this, only 10 of the 16 crops showed a similar trend between production and yield (figure 3(a)).

Using standard and de-trended data, the impact of harvested area on crop production and production variability was substantially greater than yield for 12 and 14 crops out of 16 study crops, respectively (figure 4). However, the yield effect on production variability was more robust compared to the harvested area for wheat and barley as most grown crops in Türkiye. The difference between harvested area and yield on production variability was insignificant for barley, potato, bean, and Sunflower (figure 4(a)). The contribution of the harvested area to production variability was highest for canola, soybean, maize, and peas (0.62–0.95) (figure 4). On the other hand, yield importance on production variability was topmost for sugar beet, wheat, and barley among standard and de-trended datasets (0.33–0.77) (figure 4). De-trending data showed a relatively similar pattern as standard data in the importance of harvested area and yield variability on production variability for most (12 out of 16 crops) of the study crops (figure 4(b)). The variable importance was switched by de-trending of standard data from yield to harvested areas for bean, potato, and sugar beet. However, the driving factor of production variability was switched to yield for barley by de-trending data (figure 4).

The explanatory power of precipitation sum, agricultural drought (AET/PET ratio), land surface temperature (LST), Normalized difference water index (NDWI), and a combination of them showed a remarkably different performance in capturing the harvested area and yield variability during the study period. In general, the harvested area ($\bar{R}^2 = 0.14$–0.50) variability was better explained than yield ($\bar{R}^2 = 0.10$–0.41) using precipitation and remote sensing indexes (figure 5). NDWI and precipitation sum indicated the best ($\bar{R}^2 = 0.16$–0.30) and worst ($\bar{R}^2 = 0.13$–0.14) explanatory power among the single variables for both harvested area and yield variation (figure 5). The combination of RS variables showed a substantial improvement compared to single variables. Multiple regression of AET/PET, LST and NDWI explained half of the variation ($\bar{R}^2 = 0.50$) in harvested areas over the study period (figure 5). The harvested areas in marginal water basin units were better ($R^2 = >0.60$) explained by RS compared to central parts of Türkiye (figure 5). Those units showed a high precipitation variability compared to central parts (figure 1).

There was a negative relationship between precipitation sum and area difference (planting - harvested areas) for wheat and barley which are the most grown crops in Türkiye (figure 6). However, the relationship was only significant for wheat. The wheat harvest failure reached almost 0.5 M ha in an extremely dry growing season in 2007–2008 (figure 6). Such a negative relation also confirms that the lack of water availability particularly during anthesis and grain filling phases (terminal drought) would result in harvest failure at large scales (Nelson *et al* 2022).

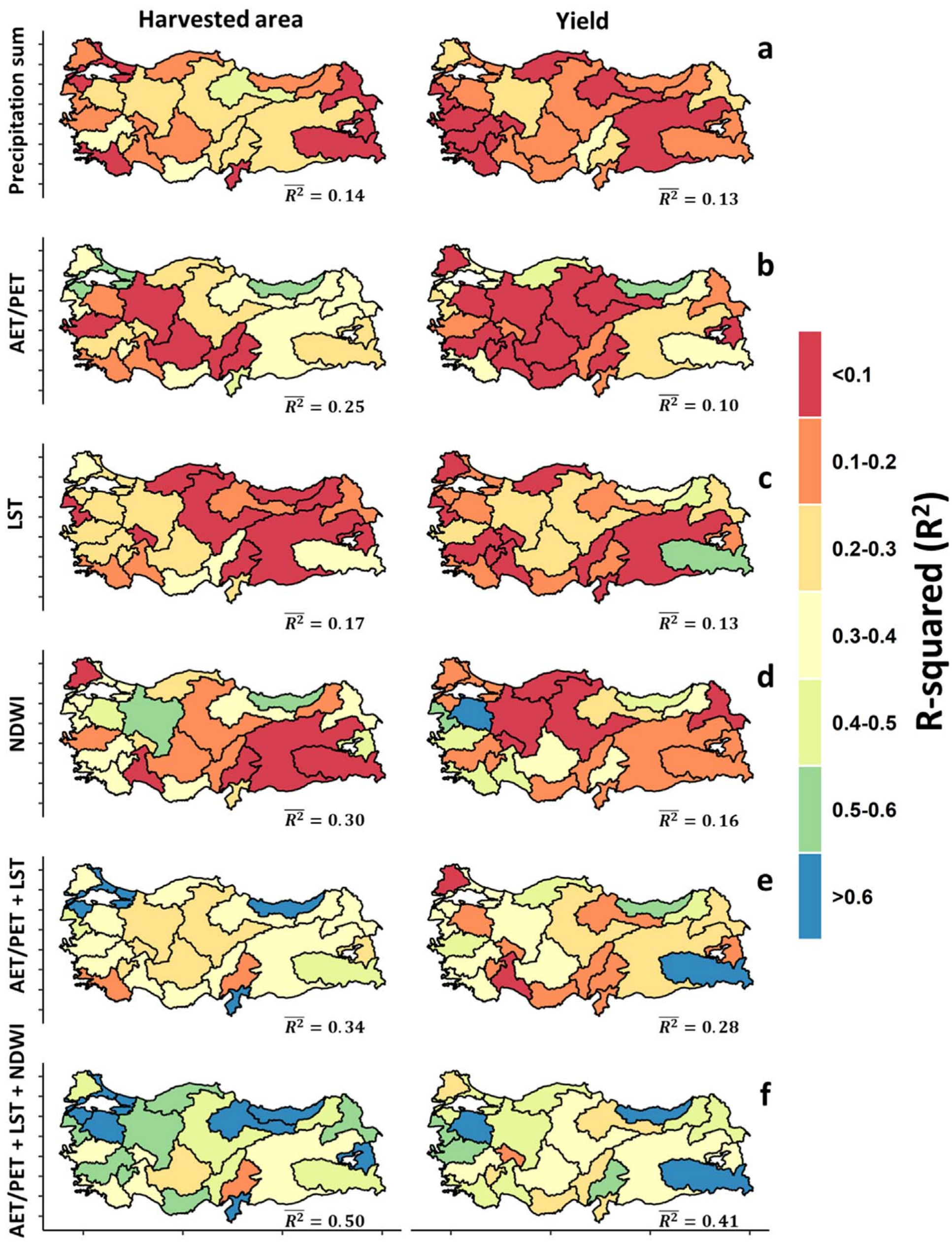

Figure 5. Coefficient of determination (R^2) between variability of harvested areas/yield and precipitation sum (a), AET/PET (b), LST (c), NDWI (d), AET/PET + LST (e) and AET/PET + LST + NDWI (f) was obtained from single (a)–(d) and multiple (e)–(f) linear regressions across Türkiye. AET: actual evapotranspiration, PET: potential evapotranspiration, LST: land surface temperature, NDWI: normalized difference water index.

4. Discussion

Based on the findings of the current study, the overall increasing trend in yield on crop production in Türkiye is crop-specific. For instance, in wheat, yield increments outweighed harvested area reductions, so production increased. However, the reduction in the harvested area dominated the effects of yield increment on production in barley. A similar discrepancy in various crop's production responses to changes in yield and harvested area trend had been captured for Iran, which is also located in the Middle East as a neighboring country (Rezaei *et al* 2021). Over the period 1985–2005, global crop production increased by 28%, of which 8% were the result of expanded harvesting areas and 20% from improved yields (Foley *et al* 2011). However, the yield of major cereals showed stagnation recently (Wiesmeier *et al* 2015, Xiong *et al* 2022) for different environments may affect the balance of yield and harvested area on crop production.

It was shown in the present study that harvested area in Türkiye had a substantial impact on most of the study crops' production variability compared to yield. De-trending of data has not changed the importance of harvested area on production variability, indicating the impact of technological changes on yield increment did

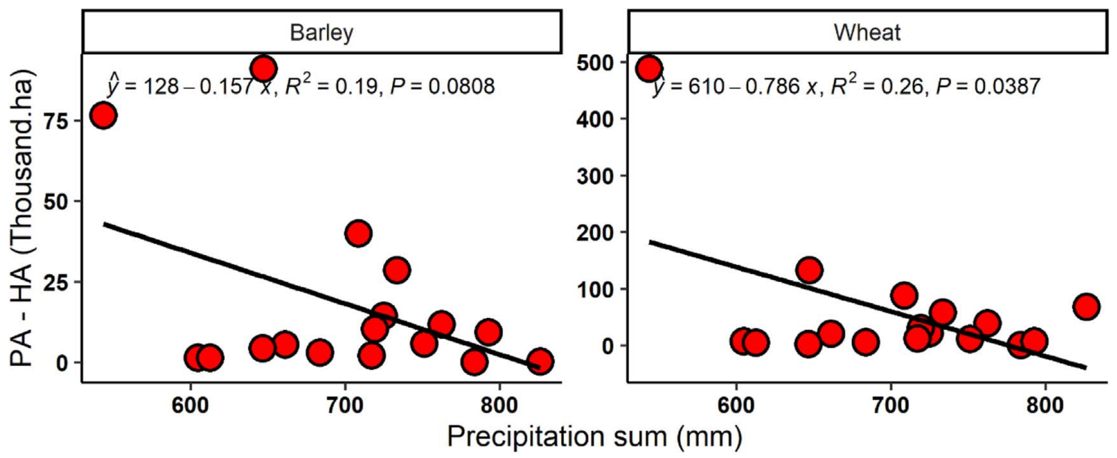

Figure 6. The relationships among annual precipitation sum and difference between planting (PA) and harvested (HA) areas for barley and wheat as most grown crops during 2004–2020 in Türkiye.

not influence the dependency of production variability on harvested area fluctuations. Closing the yield gap is a research focus for meeting food demand and stabilizing food security under climate extremes (van Ittersum *et al* 2013, Wei *et al* 2015, Liu *et al* 2022) since there is little room to extend cropland areas because of adverse environmental consequences such as soil erosion, biodiversity loss, and soil salinization (Eitelberg *et al* 2015). However, in order to have a comprehensive overview of crop production, it is necessary to conduct regional assessments of harvested area gaps (Yu *et al* 2017).

A few studies have investigated the influences of harvesting areas on crop production, which revealed that the harvested area had a surprisingly considerable impact on crop production principally under extreme weather events (Marston and Konar 2017, Rezaei *et al* 2021). The intensity of drought stress significantly increased in the period 1925–2016 (Topçu 2022) could lead to the decline in the extent of harvested area. Drought can force farmers to concentrate the limited available water on smaller areas or abandon planting areas because of meager yield (Iizumi and Ramankutty 2016). As this study captured sharp declines in harvested areas of the most important crops in Türkiye, crop production would be more susceptible to extreme weather events such as severe droughts under climate change.

The yield effect on sugar beet and wheat production was substantially more significant than on other crops. However, the dominance of yield compared to the harvested area was eliminated after de-trending (figure 4). It indicates the extended breeding efforts for sugar beet and wheat, particularly to improve yield under drought stress (Keser *et al* 2017). Farmers are encouraged to cultivate wheat continuously through a variety of subsidiary programs in Türkiye, reducing wheat imports and decreasing wheat harvest changes (Bishaw *et al* 2021).

Current results indicated the promising potential of remote sensing variables in cropping systems of Türkiye on capturing the variability of the harvested area but relatively less capability for yield. They performed better than the precipitation sum in explaining the variability of both study variables. It would be related better to the spatial coverage of remote sensing data compared to reanalysis precipitation (Hersbach *et al* 2020) which is an interpolated product from a limited number of climate stations. Water-related variables in remote sensing products performed significantly better than a temperature-related index. It indicates the importance of water availability as the primary driver governing the fluctuation of harvested area and yield at the country scale, which is in line with the other studies in the Middle East (Rezaei *et al* 2021). On the other hand, combining water and temperature-related variables boost their explanatory power by capturing variability of harvested area and yield. As drought stress was projected to increase by up to 40% in summers under climate change, crop production's dependency on water availability will increase in Türkiye in the coming decades (Bağçaci *et al* 2021).

Drought impacts on variability in planting and harvesting areas had been reported in a few studies. For instance, severe drought led to a 12% reduction in crop-harvested areas in California (Marston and Konar 2017). Or a significant reduction in the harvested area was reported in an extremely dry year compared to normal years in India (Gumma, Yamano (2019)). However, the possible difference between planting and harvesting areas in extremely dry years (particularly under terminal drought) needs to be carefully considered when remote sensing variables are employed for detecting drought signals on crop production.

It is important to note that this study has two major limitations. Firstly, no separate data were available for irrigation and rainfed crops. The availability of such data would lead to exploring the trends of change in study variables, system specific. It also aids in better understanding the effects of drought and compensatory impacts of irrigation on harvested area and yield. However, a robust association between RS-driven indices and harvested area indicates either the size of rainfed areas is remarkably higher than irrigated areas or there is insufficient water to meet the crop demand (Feitelson and Tubi 2017, Meza *et al* 2020). The second limitation is the unavailability of detailed crop type maps. By constraining the indicators to the crop-specific growing seasons, such information may significantly increase the relationships between harvested area and remotely sensed water/temperature variables. To our knowledge for the study these types of maps are not available with a sufficient frequency (ideally yearly) and detail (Rufin *et al* 2019). Crop specific maps powered by recent satellite based time series, such as Sentinel-2 (Blickensdörfer *et al* 2022) would improve the understanding of the impacts on crops in a spatially explicit manner and can be an addition for further studies.

5. Conclusions

This study concludes the following based on its main findings: (a) growing areas of the most important crops in Türkiye were shrinking, but the yield improvement avoided the decline of production for a few of them, such as wheat and sugar beet. (b) Crop production variability was primarily affected by harvested area than yield in most of the study crops, regardless of technological advancements. (c) The water-related remote sensing variables and the particular combination of water and temperature variables better explained the variability of harvested areas and yield compared to precipitation sum. (d) Extreme dry years significantly increase the difference between planting and harvesting areas of wheat as the most grown crop in Türkiye.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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