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Effects of phenological stages, growth and meteorological factor on the albedo of different crop cultivars

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Abstract. Albedo is a key component of the atmospheric, climatologic and remote sensing studies by means of global warming, energy balance, evapotranspiration, climate models, hydrological cycle etc. For these reasons, the accurate determination of surface albedo has become more important. In this study, the variation of measured albedo values of winter wheat, barley and sunflower cultivars according to phenological stages was investigated for the first time in the northwestern part of Turkey. Additionally, influences of leaf area index as growth indicator and rainfall as meteorological variable on albedo were also analyzed. The average albedo values of winter wheat, barley and sunflower in both growing periods varied from 0.176 to 0.190 for winter wheat, from 0.171 to 0.189 for sunflower and from 0.187 to 0.214 for barley cultivars. According to phenological stages, the minimum and maximum average albedo values were found for winter wheat as 0.121 between sowing and germination and 0.247 between stem formation and head emergence; for sunflower as 0.150 between sowing and germination and 0.212 between leaf initiation and immature bud; for barley as 0.144 sowing and germination and 0.261 between head emergence and flowering stages. Additionally, significant relationships were found between albedo and leaf area index for winter wheat, barley and sunflower as $r^2=0.87$, $r^2=0.82$ and $r^2=0.77$, respectively.

Keywords: agrometeorology, albedo, winter wheat, barley, sunflower.

INTRODUCTION

One of the most important factors driving the climate is the absorbed energy on the surface. The energy absorption of surfaces is related to its reflection amount. Albedo, which is one of the important micrometeorological factors, indicates how much the surface reflects incoming radiation energy. Therefore, changes in albedo affect on the energy balance components of the surface (Iziomon and Mayer, 2002; Myhre and Myhre, 2003). This is because the surface albedo controls the radiative energy distribution.

Daytime net radiation is affected by the variation of albedo. Nevertheless, there is an inverse relationship between albedo and net radiation. Likewise, the decrease in net radiation causes changes in soil heat flux, sensible- and latent heat fluxes. As stated by Wie et al. (2020), shortwave radiation changes due to albedo. This affects the surface energy balance and surface temperature. The reflection amount of shortwave radiation is related to the angle of incidence of the incoming shortwave radiation during the daytime. For this reason, albedo values increase at sunrise and sunset hours. However, the low values of global solar radiation values at these times limits the effect of this increase of albedo on net radiation (Wie et al. 2020). Albedo and energy balance components such as net radiation etc. are not regularly measured meteorological variables at climatological stations by the responsible institutions in the world. There is no network to provide this kind of data for agricultural crops especially in developing countries. Therefore, collecting experimental albedo data is crucial for model development and comparing model results (Starr et al., 2020). Having actual albedo values for plants is also useful in order to validate remote sensing data too (Dexter, 2004). This is because the limited number of actual albedo measurements makes it difficult to compare remote sensing data for different crop surfaces especially where there are no ground observations. In particular, changes in vegetation affect the surface albedo, thus influence on climate patterns. Therefore, surface albedo is extremely significant in climate models. Consequently, having experimental albedo data for different plant surfaces is important for developers and users of climate models and studies of energy balance components (Myhre and Myhre, 2003).

Furthermore, cultivars with higher albedo would provide a partial mitigation of global warming and thus climate change (Henderson-Sellers and Wilson, 1983; Ridgwell et al, 2009). Doughty et al. (2011) found the effects of increases in crop albedo on the cooling of the regional climate using the model. They determined that increasing albedo values decreases the temperatures and hence the latent heat fluxes in the atmosphere, and thus cloudiness and precipitation decrease. Fuller and Ottke (2002) stated that surface albedo is an important variable for General Circulation Models (GCMs) and any changes of albedo caused a decrease in rains. Ridgwell et al. (2009) found that 0.17 °C cooling in climate models increased the surface albedo values by 0.03 - 0.09. Kala and Hirsch (2020) emphasized that the increase in plant albedo values can reduce global warming. Using the Weather Research and Forecasting (WRF) model, they simulated increases in plant albedo values

from 0.02 to 0.1 in two agricultural regions of Australia. Wood et al. (2008) investigated the effects of albedo changes on climate by using a simple planetary model (Daisyworld) to show the long-term effects of coupling between life and its environment.

Plants albedo is higher than the albedo of many other natural surfaces, especially since they cover the surface completely. Leaf Area Index (LAI) expresses the plant leaf area per unit soil surface. It indicates growth of a plant and coverage of surface by leaves. For this reason there is a relationship between albedo and LAI. Albedo is critical data not only for the reduction of global warming, but also for accurately calculating net radiation (Kumar et al. 2020). It should be noted that the net radiation value also affects other energy balance components. As written by Uysal and Şaylan (2019), the ratio between soil heat flux and net radiation can be estimated using some relationships based on LAI, albedo and Normalized Difference Vegetation Index (NDVI) etc.

Surface albedo is also an extremely important input data, especially in radiation transfer models, which predict the radiation effect by changing the use of the ground surface. This situation underlines the importance of correctly detecting surface albedo. Zhou et al. (2020) determined in a model study that the reference albedo value was generally lower than the constant value of 0.23 according to seasonal and regional variations.

Furthermore, net shortwave- and net radiation values can be calculated using albedo and global solar radiation values. These data are used to make necessary calculations in agriculture, meteorology and other engineering fields. In addition, in many applications, the albedo value is taken as a constant for a crop to represent the whole growing period, but it changes during the development period. However, as Dixon (1983) and Starr et al. (2020) pointed out, albedo changes over time and many factors affect this change. So albedo is not constant. Until today, many studies have been conducted on the albedo of plants (Dexter, 2004). Breuer et al. (2003) stated that it is difficult to determine the upper and lower limits of the albedo value, which is necessary and important for many crop growth-and climate models, and these values for various plants were published by Kondratyev (1969, 1972) and Iqbal (1983). To summarize these studies; the minimum and maximum albedo values were determined for two sunflower cultivars as 0.21-0.32 and 0.23-0.29 by Gates (1980); for barley as 0.20 and 0.26 by Fritschen (1967); as 0.23 and 0.26 by Monteith and Unsworth (1990); as 0.14 and 0.36 by Pigggin and Schwerdtfeger (1973); for winter wheat as 0.18 and 0.23 by Fritschen (1967); as 0.10 and 0.25 by Kondratyev (1969); as 0.13 and 0.21 by Kondratyev (1972);

as 0.16 and 0.23 by Sellers (1965), Kondratyev (1969), Pielke (1984); as 0.13 and 0.25 by Piggin and Schwerdtfeger (1973); as 0.22 and 0.26 by Monteith and Unsworth (1990) and as 0.20 and 0.23 by Song (1998). Additionally, Impens and Lemeur (1969) estimated the albedo of sunflower as 0.28.

Albedo of the land surface can be influenced by natural variability and anthropogenic impacts. Furthermore, albedo varies depending on cultivars, plant growing stages, sun angle and surface characteristics such as color of soil, soil moisture, soil organic matter content, surface roughness etc. (Dickson, 1983; Henderson-Sellers and Wilson, 1983; Kumar et al., 2020). Piggin and Schwerdtfeger (1973), Dexter (2004) explained the seasonal trends of albedo in terms of changes in crop development and soil moisture. Furthermore, Minnis et al. (1997) and Song (1998) stated that albedo tends to decrease as the plant height and leaf, greenness, plant water status, soil moisture increase, but it tends to increase as the LAI increases. Additionally, Oguntunde and Giesen (2004) also found a strong correlation for both between albedo and LAI and between albedo and crop height for maize. Dexter (2004) also investigated the relationships between albedo and LAI for wheat. Additionally, Serban et al. (2011) investigated the albedo values of 25 winter wheat cultivars in Romania and found that each had different values and temporal changes. They determined the average albedo value for all cultivars as 0.226. Furthermore, Zhang et al. (2013) assigned that the albedo values of plants varied during the growth period due to their different pigment, size and LAI values. The same researchers found that the albedo values tended to increase from the tillering to the grain formation stage, but began to decrease after the grain formation. Again, Zhang et al. (2013) stated that the albedo value is higher in the morning and afternoon times corresponding to 40° Sun angles. In addition, Yin (1998) emphasized that the biggest obstacle that complicates the measurement of albedo in agricultural lands is the 3-dimensional area (depth, shape and surface) covered by plants. Also, some researchers found that there is a tendency to decrease in albedo values when the height of the cultivated plants increases (Jarvis et al., 1976; Rauner, 1976; Shuttleworth, 1989). Furthermore, Linacre (1992), Minnis et al. (1997), Song (1998) determined that albedo tends to decrease when humidity increases on the surface. Additionally, Wang et al. (2010) compared the albedo values measured on the surface with the albedo values calculated by remote sensing and found little differences between them. Furthermore, surface roughness is other an important parameter affecting albedo as stated by Ogilvy (1991). Likewise, Bowers and Hanks (1965)

and Post et al. (1993) specified that the albedo was a function of the combination of soil color – pigment- and its spatial distribution, if the soil surface was partially smooth. Dexter et al. (2004) determined that the annual trend of wheat's albedo changed according to atmospheric and surface conditions.

64% of northwestern part of Turkey (Thrace part) is agricultural land and rainfed agriculture is dominant in that part. Wheat, barley and sunflower are generally grown in this region. However, the actual albedo values of these crops and their cultivars grown in the Thrace region of Turkey are not known. Therefore, the objectives of our study are (i) to determine for the first time the actual albedo values of different cultivars of wheat, barley and sunflower crops widely grown in Thrace part of Turkey; (ii) to examine the effect of phenological stages on these albedo values; (iii) to estimate the relationship between leaf area index as growth indicator and their albedo values; (iv) to determine the effect of rainy/dry days on crop surface albedo.

MATERIALS AND METHODS

Research Site

The experimental studies were carried out at the fields (41°41'56"N, 27°12'39" E, 171 m asl) of Atatürk Soil, Water and Agricultural Meteorology Research Institute (ASWAM) located at the Kırklareli city in Thrace part of Turkey (Fig. 1). The measurements were made during two growing periods of winter wheat and barley (WB1: 2014/15 growing period, WB2:2016/17 growing period) and sunflower (SF1: 2016 growing period, SF2: 2018 growing period) on the experiment fields. The six experimental plots were established on the fields of the ASWAM. Fig. 2 shows the location of trial plots and measurements. Furthermore, some physical and chemical properties of the soils at the research area are given in Tab. 1.

Albedo measurements were made in the six plots. The dimensions of each plot were 35x35 m. (1225 m²). There was a distance of 1 m between the plots.

Wheat (*Triticum aestivum*) cultivars, Gelibolu (WW_g), Selimiye (WW_s), Bereket (WW_b), Pehlivan (WW_p), Kate1A (WW_k); barley (*Hordeum vulgare*) cultivar, Bolayır (BR_b), and sunflower (*Helianthus annuus*) cultivars, Sanay (SF_s), Pioneer (SF_p), Tunca (SF_t) widely grown in Thrace part of Turkey were used for albedo measurements. Wheat-sunflower rotation applied in the trial plots.

Sunflower fertilization was performed with 100 kg ha⁻¹ diammoniumphosphate (18-46-0) as base fertilizer



Fig. 1. Location of experiment field (The map is rearranged from the Google Earth).

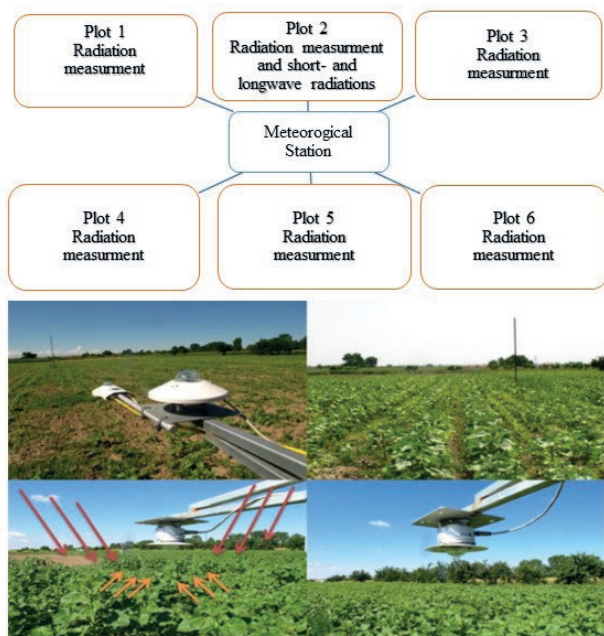


Fig. 2. Trial plots and radiation measurements.

and 100 kg ha^{-1} urea in hoeing. 150 kg ha^{-1} diammoniumphosphate (18-46-0) as base fertilizer, 150 kg ha^{-1} urea in tillering period and 100 kg ha^{-1} urea fertilizers were applied for wheat and barley during the growing period.

Observations and measurements

The experimental studies were carried out at six plots. In only one of these plots, incoming radiation

was measured by using the upward-facing pyranometer (Kipp&Zonen, CMP6). At the same plot, incoming and outgoing short- and longwave radiations were measured using the four components radiation sensor (Kipp&Zonen, CNR4). In the other plots, the reflected radiations from the surfaces were measured using inverted (downward) pyranometers (Kipp&Zonen, CMP6). Surface albedo is calculated as the ratio of outgoing and incoming radiations. Data from all sensors were recorded by a datalogger at the agrometeorological station in a tower placed between the plots. The measurement system consisted of the temperature and relative humidity meter (Hygromer MP100A, Rotronic Instr. Corp., at 2 m), the rain gauge (TE525 Tipping Bucket Rain Gauge, Campbell Sci., at 1 m), the four component radiation sensor (Incoming-Outgoing Short and Longwave Radiation; CNR4, Kipp&Zonen), seven pyranometers (Kipp&Zonen, CMP6), the anemometer (#NRG40C, at 2 m) and wind vane sensor (#NRG200P, NRG Systems, at 2 m), the soil water content sensor (TDR, Campbell Sci. at 30 cm depth), the soil temperature sensors (at 5, 10, 20 cm depths), the data logger (CR1000, Campbell Sci.), the multiplexer (Campbell Sci.). Albedo measurements were installed at 1.75 m above soil surface for winter wheat, barley and 2.25 m for sunflower. Additionally, LAI was measured using the radiation-based Plant Canopy Analyzer (LI-COR, 2200C) in an interval of two weeks. Phenological stages (BBCH scale) of crops were observed and recorded during the growing periods. Furthermore, all meteorological data were measured in an interval of 1 s and recorded every 30 min.

Table 1. Physical and chemical properties of the soil in the experiment field.

| Soil Depth (cm.) | Saturation (%) | pH | Total Salt (%) | Lime (CaCO ₃) (%) | Organic Matter (%) | P ₂ O ₅ (kg ha ⁻¹) | K ₂ O (kg ha ⁻¹) | Soil Structure | | | Soil Type | Field Capacity (%) | Wilting Point (%) |
|------------------|----------------|------|----------------|-------------------------------|--------------------|--|---|----------------|----------|----------|-----------------|--------------------|-------------------|
| | | | | | | | | Clay (%) | Silt (%) | Sand (%) | | | |
| 0-30 | 40 | 7.20 | 0.03 | 6.0 | 0.77 | 186.9 | 670.3 | 22.92 | 35.42 | 41.67 | Loam | 25.31 | 15.31 |
| 30-60 | 49 | 7.50 | 0.03 | 6.0 | 0.54 | 207.7 | 350.4 | 20.83 | 22.92 | 56.25 | Sandy-Clay-Loam | 22.31 | 14.27 |
| 60-90 | 44 | 7.49 | 0.03 | 5.0 | 0.45 | 282.7 | 227.6 | 12.50 | 20.83 | 66.67 | Sandy-Loam | 17.91 | 10.78 |

RESULTS AND DISCUSSION

Meteorological variables

In this study, the changes in the actual albedo values of different winter wheat, barley and sunflower cultivars grown in the Thrace region of Turkey under the conditions (climate, soil, crop) during the development period were determined by field measurements for the first time. In addition to the albedo measurements, the LAI values of the crops were also measured. After that, first, the albedo differences between crop cultivars; then, the change of albedo values according to phenological stages and finally the relationships between albedo and other factors such as LAI, precipitation were determined.

Development of crops

Information on the phenological stages observed in the development period of the crops are given below in the Tab. 2. Additionally, SF₁ cultivar could not provide homogeneous and sufficient emergence during the germination period at the beginning of the SF₁ period. Therefore, SF₁ was planted again and late in this period. In this context, the phenological stages and growth of SF₁ in the SF₁ period were different from the other cultivars.

The temporal variations of meteorological variables measured on the field during WB1 period for winter wheat and barley cultivars are given in Fig. 3. In WB1 (between 14 November 2014 and 17 June 2015), the average, maximum and minimum temperatures were 9.9, 25.2 and -6.8 °C, respectively. The total precipitation amount during that period was 460.4 mm with a daily maximum of 61.2 mm. Furthermore, the average volumetric soil water content between 0 and 30 cm depths was 19 % with a maximum of 24.7 % and with a minimum of 11.4 %. Additionally, net radiation in WB1 ranged from -62.2 to 195.4 W m⁻² with an average value of 65.8 W m⁻². The average global solar radiation was 142.2 W m⁻² and changed between 9.6 and 355.2 W m⁻² throughout WB1. The average relative humidity in WB1 was 76.2%.

The amount of precipitation (366.3 mm) during WB2 was 20.44% less than the total precipitation amount of WB1 (Fig. 4). Therefore, WB2 period was drier than WB1 period. The average daily precipitation amount was 1.5 mm throughout the WB2 period and the daily maximum precipitation was measured as 51.0 mm. Due to the scarcity of rainfall in the WB2 period,

Table 2. Phenological stages of crops.

| Plants Stage | Phenological Stages (Date) | | | | | | | | |
|--|----------------------------|---------|---------|---------|---------|---------|---------|---------|---------|
| | S | G | TL | T | SF | HE | F | M | H |
| WB1 | 14 Nov. | 24 Nov | 08 Dec. | 10 Feb. | 27 Mar. | 08 May | 18 May | 04 June | 17 June |
| WB2 | 26 Oct. | 11 Nov. | 02 Dec. | 23 Feb. | 23 Mar. | 03 May | 20 May | 05 June | 29 June |
| | S | G | L | I | F | M | H | | |
| SF1 (SF ₁ , SF ₂) | 08 Apr. | 14 Apr. | 16 May | 17 Jun. | 24 Jun. | 14 Jul. | 05 Sep | | |
| SF1 (SF ₁) | 31 May | 10 Jun. | 24 Jun | 14 Jul. | 05 Aug. | 18 Aug. | 24 Sep. | | |
| SF2 | 25 Apr. | 04 May | 18 May | 19 Jun. | 28 Jun. | 23 Jul. | 04 Sep. | | |

S: Sowing; G: Germination; TL: Third leaf; T: Tillering; SF: Stem formation; HE: Head Emergence; F: Flowering; M: Maturity; H: Harvest, L: Leaf initiation; I: Immature bud; F: Flowering; M: Maturity; H: Harvest.

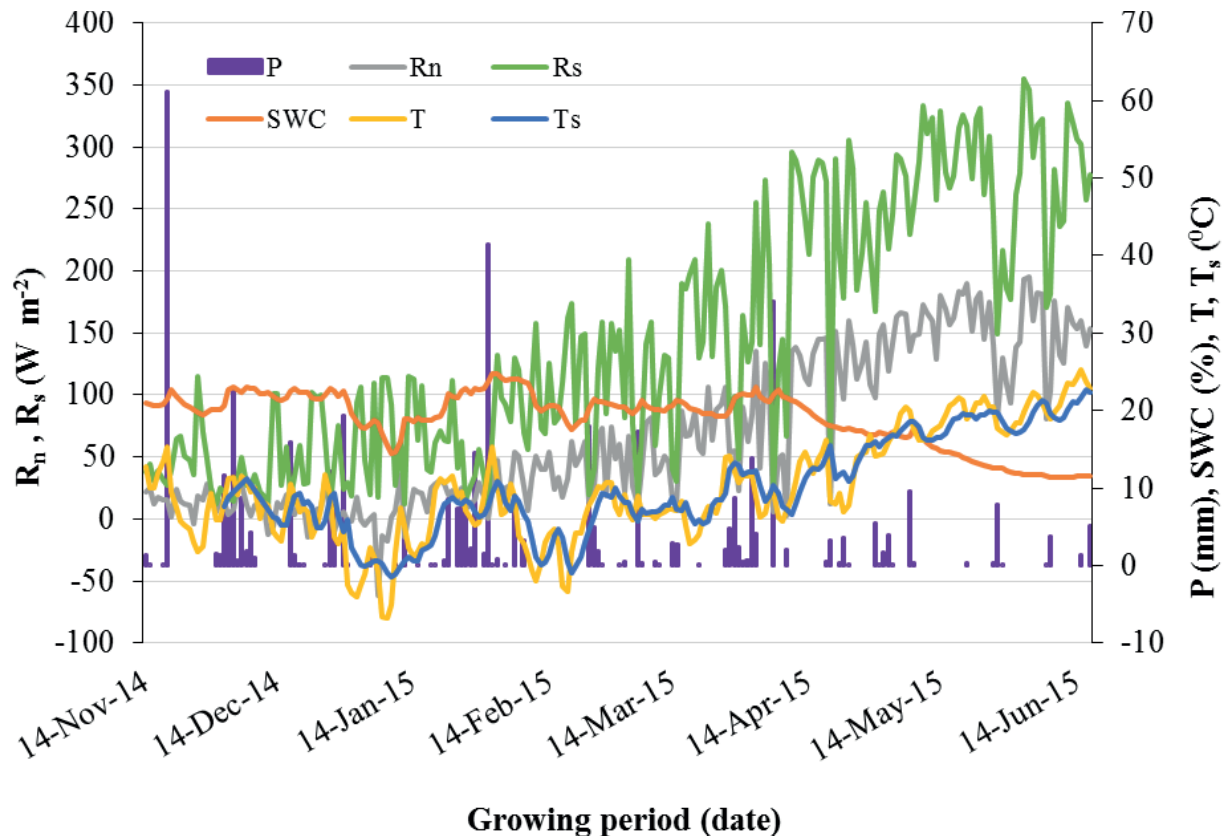


Fig. 3. Time series of meteorological variables during WB1 growing period.

the soil water content was also lower than in the WB1 period. Average soil water content was 17% in WB2. Soil water content varied between 13.5% and 21.2% during this period. Less precipitation led to a decrease in cloudiness and more net radiation in the WB2 period. Therefore, the average net radiation in the WB2 period was determined as 71.9 W m^{-2} . Daily average net radiation varied between -24.3 and 211.3 W m^{-2} during this period. In WB2, the daily average temperature was 9.8 , and the maximum and minimum temperatures were 29.7 and -8.4 °C, respectively. The daily average soil temperature was determined to be slightly higher than the air temperature (10.3 °C). During the WB2, the minimum and maximum soil temperatures varied between -17.3 and 36.3 °C. Furthermore, global solar radiation was also higher in WB2 period than WB1. Average global solar radiation in WB2 was measured as 155.4 W m^{-2} varied between 11.1 and 348.1 W m^{-2} . The time series of the measured daily average relative humidity in the WB2 period were 75.9% , respectively. As can be seen in the Fig. 3 and 4, the average air temperature of wheat and barley in the first growing period (WB1) was slightly higher than in the second period (WB2). Furthermore,

total rainfall in the WB1 was 25.7% more than WB2 measured rainfall. Additionally, the average soil water content in the WB1 was 2% more than WB2. In contrast, average global solar radiation in the WB1 was about 9.3% less than WB2.

The first growing period of sunflower (SF1) was in 2016 and the second (SF2) was in 2018. During the SF1 period, the total amount of precipitation was 146.7 mm. The temporal distributions of meteorological variables are shown in Fig. 5. In SF1, the average and maximum of the daily total precipitation amounts were 0.9 and 30.2 mm, respectively. The average soil water content was 11.3% in the SF1 period changed between 7 and 24.5% . This situation shows that the crop was under water stress in different phenological stages. The average of daily net radiation was 120.4 W m^{-2} during this period and varied from 15.4 to 183.3 W m^{-2} . During the SF1 period, the average air- and soil temperatures were 21.3 and 20.9 °C, respectively. Additionally, the average of the global solar radiation in SF1 was 248.3 W m^{-2} and varied between 62.1 and 344.4 W m^{-2} .

The total amount of precipitation was 210 mm during the SF2 and this period was more humid compared

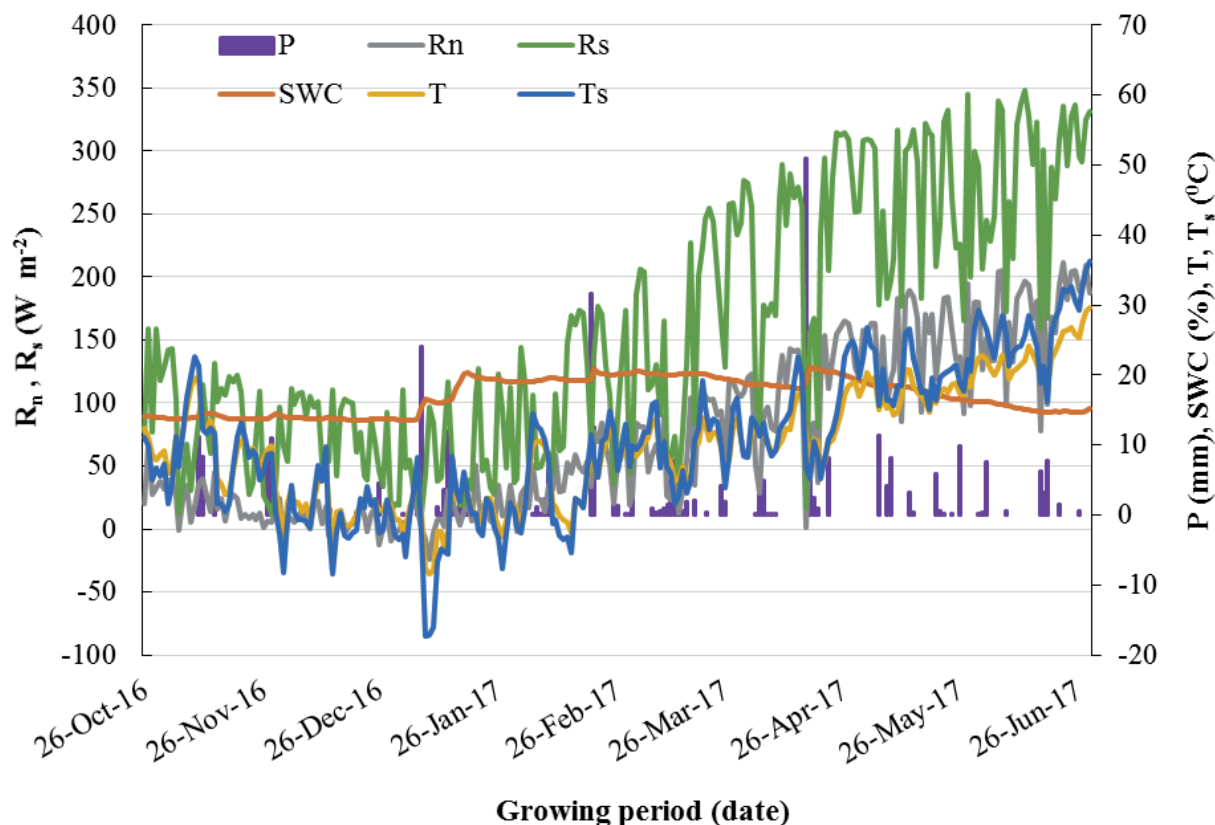


Fig. 4. Time series of meteorological variables during WB2 growing period.

to SF1. In the SF2 period, the average of daily total precipitation was 1.6 mm and it was 0.7 mm day⁻¹ more than SF1. During this period, the maximum total precipitation per day was recorded as 23.5 mm. The temporal distributions of meteorological variables are given in Fig. 6. The average soil water content (18.5%) in this period was considerably higher than in the SF1 period. Additionally, average net radiation during SF2 period was about 28% more than SF1. The lowest daily average net radiation was measured as 35.8 and the maximum value was 230.0 W m⁻². Average air- and soil temperatures in SF2 period were higher than in SF1 period. Therefore, SF2 period was a warmer period than SF1. In addition to these, the average, minimum and maximum values of the global solar radiation value during the SF2 period were determined as 266.1, 75.4 and 356.4 W m⁻², respectively.

Albedo of winter wheat and barley

It was necessary to determine how albedo values change in our country by making measurements for dif-

ferent cultivars. In both development periods (WB1 and WB2), one barley and five wheat cultivars were grown in the trial plots. The distribution of the measured albedo values during the day in both growing periods was examined. Although the same cultivars of wheat and barley were grown in both growing periods, hourly averages of albedo values were not the same. Hence, it was determined that the barley had higher albedo values than the wheat cultivars in both periods.

In both periods, albedo had higher values at sunrise and sunset hours compared to midday. This was related to the angle of incidence of the sun. Similar relationships to the temporal change of the albedo found in this study during the day were also emphasized by Impens and Lemeur (1969).

The average albedo values of cereal crops for the WB1 were determined as 0.190 for WW_g, 0.203 for WW_s, 0.183 for WW_b, 0.171 for WW_p, 0.181 for WW_k and 0.214 for BR_b cultivars. In the Tab. 3, the albedo values in WB1 are given according to their phenological stages during the growing period from sowing to harvest. Low albedo values were observed on the bare soil surface during the planting of the crops. Additionally, it was

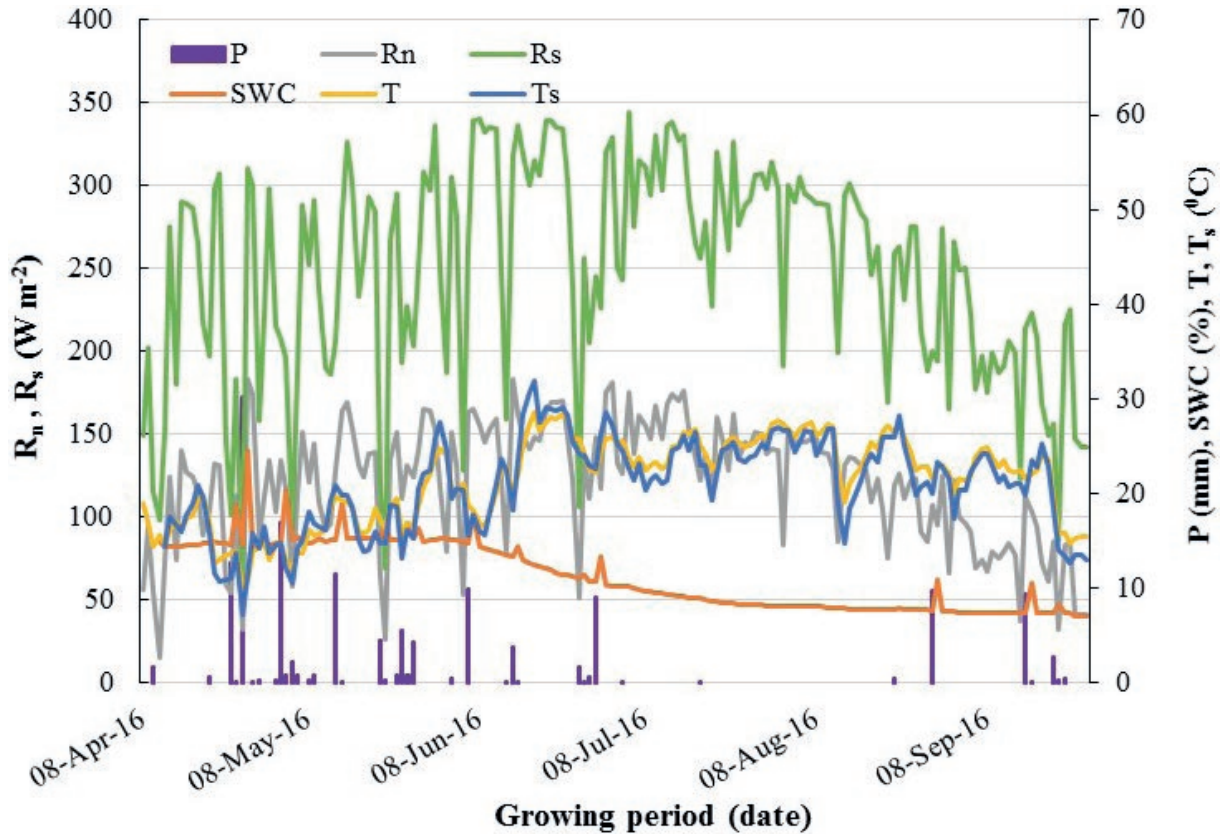


Fig. 5. Time series of meteorological variables during SF1 growing period.

determined that the albedo values increasing with the emergence of the crops have different values according to their phenological stages.

Additionally, it was determined that the average albedo values of wheat cultivars ranged from 0.171 to 0.203 throughout WB1 (Fig. 7). Furthermore, the average albedo for five cultivars of wheat was 0.185 for all days (rainy and non-rainy (dry) days). Similarly, average barley's albedo changed between 0.144 and 0.261. As can be seen from the values, the average albedo values differ between wheat and barley cultivars during the growing stages.

Fig. 7. Time series of daily average albedo and daily total precipitation during WB1.

In order to understand the effect of rainy and dry days on the albedo of crop cultivars, the albedo values on rainy ($\geq 1 \text{ mm d}^{-1}$) and dry days ($< 1 \text{ mm d}^{-1}$) were determined. On the rainy days, average albedo values for five cultivars of winter wheat was 8.4 % less than the average albedo in the dry days in WB1. On the rainy days, albedo values of wheat were a little bit decreased

and average albedo of all wheat cultivars changed from 0.165 to 0.190. The average barley's albedo was 0.199 on rainy days in WB1. On dry days, average albedo varied from 0.171 to 0.205 for all wheat cultivars and it was 0.221 for barley in WB1. The average albedo value of barley for all data was determined to be about 13.1 % higher than the average of wheat cultivars.

The effect of bare soil on albedo decreased as the plant's surface coverage increased in WB1. During sowing (S) and germination (G) stage in WB1, the surface albedo changed between 0.121 and 0.152 for all wheat cultivars for all data when it varied from 0.087 to 0.112 with the effect of soil water content on the rainy days. This value was 0.106 in barley variety on rainy days during S-G stage. With the emergency of the wheat to the surface, albedo of winter wheat and barley increased. Between S and G stages in the WB1 period, the maximum albedo value was determined as 0.152 for WW_s and the minimum albedo was 0.121 for WW_p . In all wheat cultivars except WW_k and WW_g , the maximum albedo value occurred between stem formation (SF) and heat emergence (HE) phenological stage. In this period, the maximum average albedo in the period of SF-HE

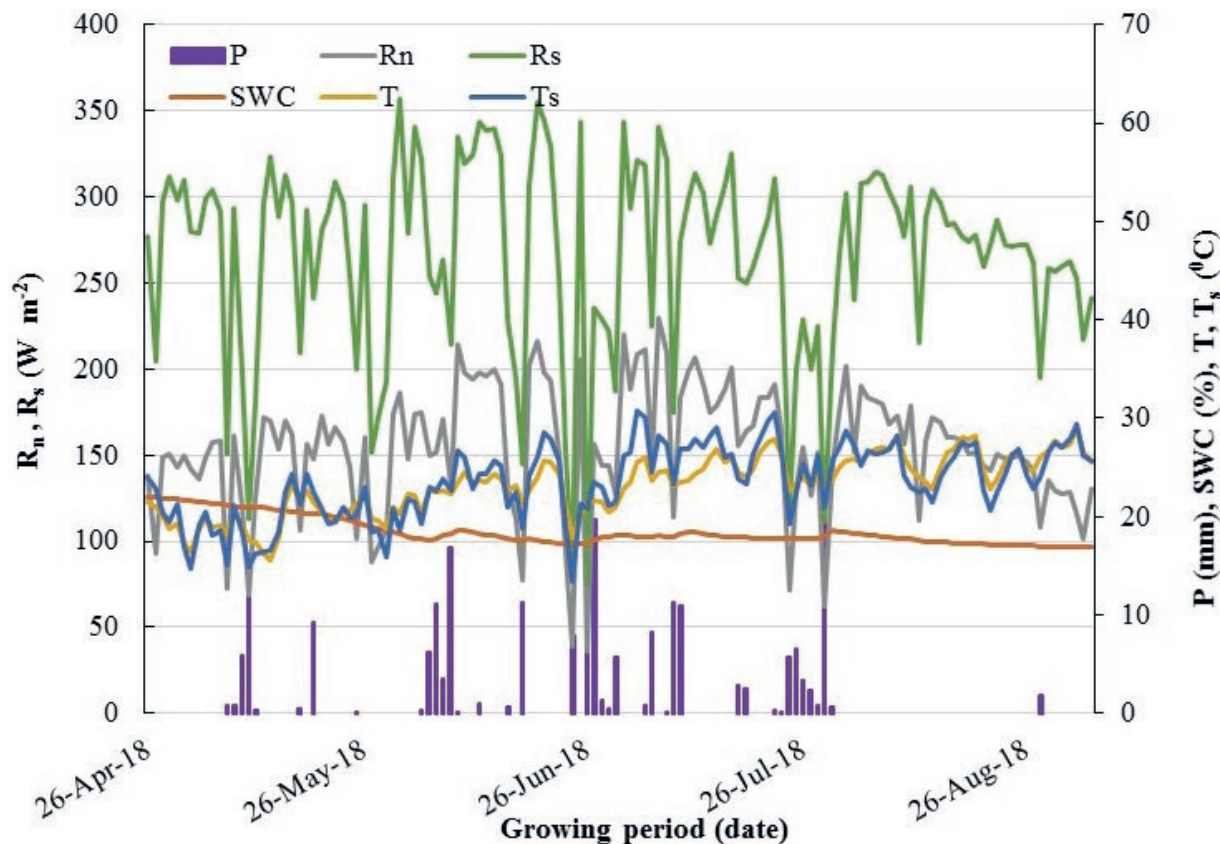


Fig. 6. Time series of meteorological variables during SF2 growing period.

Table 3. Albedo values of winter wheat and barley cultivars in WB1 according to phenological stages.

| | S-G | G-TL | TL-T | T-SF | SF-HE | HE-F | F-M | M-H | Average |
|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|---------|
| WW _g | 0.136 | 0.164 | 0.176 | 0.184 | 0.219 | 0.223 | 0.216 | 0.199 | 0.190 |
| WW _s | 0.152 | 0.181 | 0.194 | 0.206 | 0.247 | 0.236 | 0.207 | 0.204 | 0.203 |
| WW _b | 0.134 | 0.162 | 0.180 | 0.198 | 0.227 | 0.217 | 0.181 | 0.164 | 0.183 |
| WW _p | 0.121 | 0.144 | 0.160 | 0.170 | 0.200 | 0.196 | 0.194 | 0.181 | 0.171 |
| WW _k | 0.125 | 0.144 | 0.157 | 0.182 | 0.210 | 0.212 | 0.218 | 0.198 | 0.181 |
| BR _b | 0.144 | 0.183 | 0.203 | 0.220 | 0.258 | 0.261 | 0.225 | 0.214 | 0.214 |

was determined as 0.247 for WW_s. For WW_k, the maximum average albedo value was determined as 0.218 in the period from flowering (F) to maturity (M). Furthermore, for Barley (BR_b) in WB1 period, the maximum average albedo value was measured as 0.261 between HE and F phenological stages. The maximum albedo of barley was higher than the wheat cultivars. Additionally, albedo values measured on dry days were determined to be higher than those on rainy days. On dry days in WB1, the highest albedo value was determined as 0.252

between SF-HE stage for WW_s, while the lowest albedo value was determined as 0.127 for the WW_p. Furthermore, increasing soil water content with the effect of rainfall and wetting of the crop surface caused the albedo value to decrease as expected.

The average albedo values for WB2 were calculated as 0.180 for WW_g, WW_b, 0.176 for WW_s, 0.181 for WW_p, WW_k and 0.187 for BR_b (Tab. 4). The average albedo (0.180) of the wheat cultivars in WB2 was less than the average albedo (0.185) in WB1. During the WB2, the average wheat albedo varied from 0.176 to 0.187 (Fig. 8). Most of the wheat cultivars reached their maximum in the WB2 period between HE and F stage except WW_p. However, this time the maximum wheat albedo was determined as 0.227 for WW_p. The same maximum value for BR_b was measured between SF and HE phenological phase.

In the WB2 period, the average albedo on rainy days (for all wheat cultivars) was determined as 7.87% less than the average albedo on dry days. This is because the albedo of the water is less than the albedo of the plants. In addition, the fact that the amount of rainfall in the WB2 period is less than in the WB1 period

Table 4. Albedo values of winter wheat and barley cultivars in WB2 according to phenological stages.

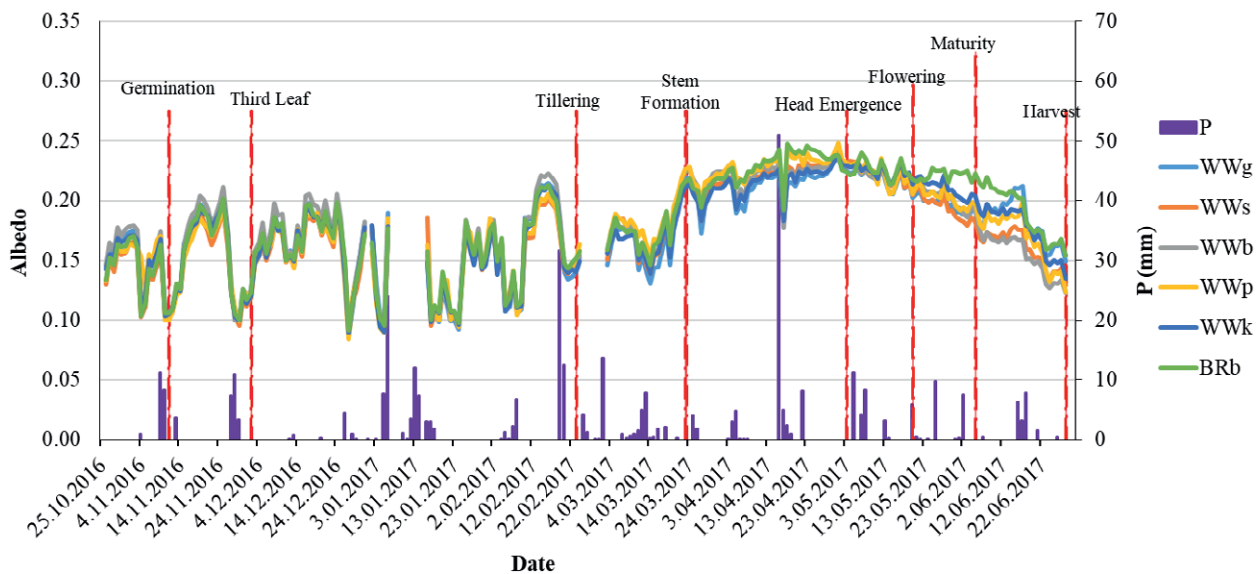
| | S-G | G-TL | TL-T | T-SF | SF-HE | HE-F | F-M | M-H | Average |
|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|---------|
| WW _g | 0.151 | 0.156 | 0.156 | 0.166 | 0.214 | 0.218 | 0.197 | 0.181 | 0.180 |
| WW _s | 0.140 | 0.148 | 0.152 | 0.172 | 0.219 | 0.221 | 0.194 | 0.158 | 0.176 |
| WW _b | 0.154 | 0.159 | 0.160 | 0.173 | 0.221 | 0.221 | 0.202 | 0.153 | 0.180 |
| WW _p | 0.148 | 0.150 | 0.153 | 0.181 | 0.227 | 0.222 | 0.203 | 0.166 | 0.181 |
| WW _k | 0.148 | 0.154 | 0.154 | 0.168 | 0.216 | 0.224 | 0.210 | 0.174 | 0.181 |
| BR _b | 0.144 | 0.154 | 0.157 | 0.178 | 0.227 | 0.226 | 0.222 | 0.188 | 0.187 |

might be one of the reasons why the albedo values in dry days were high in WB2. This was because increasing soil moisture, cloudiness can lead to decrease the albedo of surface. Approximately 24% of the WB1 and 20% of the WB2 consisted of rainy days. In WB2, the average albedo values of all wheat cultivars with growth stages were calculated as 0.148 for S-G; 0.153 for G and third leaf (TL); 0.155 for TL-tillering (T); 0.172 for T-SF; 0.219 for SF-HE; 0.221 for HE-F; 0.201 for F-M and 0.166 for M-Harvest (H) phenological stages.

As a result, it has been determined that the albedo values of five wheat cultivars were different in the phenological stages of WB1 and WB2. The reason for the low albedo that occurs during periods of rainfall can be explained by the increase in the water content of the soil with the rainfall and the fact that the soil reflects less radiation and its color turns dark. It was observed that the albedo of wheat and barley suddenly decrease on the days when there was precipitation in both grow-

ing periods. For this reason, deviations of albedo values from the mean were high in phenological stages when the number of rainy days was high. Barley and wheat cultivars attained the highest reflectance values in both periods during SF and F. The reason for this was the increase in canopy development, LAI and soil coverage in this period. In addition, as well as color changes of plant organs especially leaves caused an increase in albedo values. In general, there was a trend towards a decrease in albedo values after HE stage. Likewise, the albedo value has an increasing trend from G to HE phases.

Although Oguntunde and Van de Giesen (2004) found different albedo values for six different cereal cultivars according to phenological periods, they could not detect a significant difference between the albedo coefficients. However, unlike Oguntunde and Van de Giesen (2004), in this study, albedo differences were determined between wheat and barley cultivars. The differences between determined albedo values in WB1 and WB2 periods (WB1-WB2) for wheat and barley are given in the following Fig. 9. When we analyzed the differences in the measured albedo values of winter wheat in different phenological stages in both development periods (WB1-WB2), it was determined that the greatest albedo difference for WW_p and WW_k cultivars was in the S-G period. For WW_g, WW_s and BR_b, the highest differences were detected in TL-T stage. As can be seen in Fig. 9, the albedo values measured in the WB1 period are generally higher than the albedo in WB2 except between the S and G phenological stage.

**Fig. 8.** Time series of daily average albedo and daily total precipitation during WB2.

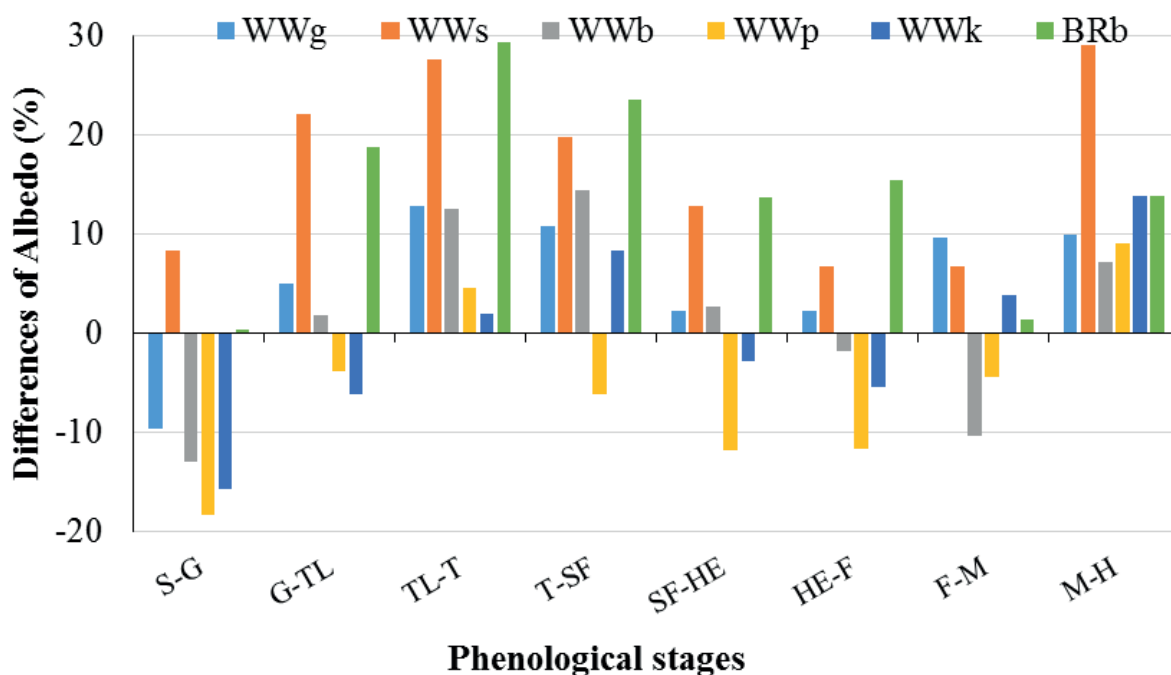


Fig. 9. Differences (WB1-WB2) in albedo values of winter wheat and barley cultivars.

Albedo of sunflower

The albedo values during the SF1 and SF2 growing periods changed asymmetrically during the daytime. The reason for the increase in the albedo at sunrise and sunset hours is the angle of incidence of the sun. The albedo values of sunflower cultivars with growth stages from the sowing to the harvest of SF1 and SF2 are shown in Tab. 5 and 6. Low albedo values were observed on the bare soil surface during the planting of the crops. It was determined that the albedo values increasing with the emergence of the crops. Considering the phenological development periods, although three cultivars of sunflower had different albedo values, they had a similar trend. The average albedo values of sunflower for the SF1 period were measured as 0.186 for SF_s, 0.189 for SF_t and 0.187 for SF_p (Tab. 5). The average albedo values of sunflower cultivars in SF2 period were determined as 0.172 for SF_s, 0.178 for SF_p and 0.164 for SF_t (Tab. 6). There was no significant difference between albedo values except SF_t. Furthermore, albedo values in SF2 were determined to be slightly lower than SF1 period albedo. This might be due to the fact that the SF2 development period was more rainy (210 mm) compared to the SF1 period (147.6 mm) and consequently the soil water content was higher.

Albedo values were determined according to the phenological stages of the sunflower, too. It has been

Table 5. Average albedo values in different phenological stage in SF1.

| | S - G | G - L | L - I | I - F | F - M | M - H | Average |
|-----------------|-------|-------|--------------|-------|-------|-------|---------|
| SF _s | 0.159 | 0.181 | 0.212 | 0.200 | 0.185 | 0.180 | 0.186 |
| SF _p | 0.164 | 0.184 | 0.210 | 0.200 | 0.186 | 0.176 | 0.187 |
| SF _t | 0.164 | 0.197 | 0.199 | 0.197 | 0.196 | 0.178 | 0.189 |

Table 6. Average albedo values in different phenological stage in SF2.

| | S - G | G - L | L - I | I - F | F - M | M - H | Average |
|-----------------|-------|-------|--------------|--------------|-------|-------|---------|
| SF _s | 0.157 | 0.160 | 0.186 | 0.189 | 0.177 | 0.156 | 0.171 |
| SF _p | 0.168 | 0.170 | 0.196 | 0.191 | 0.187 | 0.157 | 0.178 |
| SF _t | 0.150 | 0.157 | 0.179 | 0.181 | 0.171 | 0.146 | 0.164 |

determined that the sunflower had different albedo values in different phenological stages. Time series of daily average values of albedo measurements in SF1 and SF2 are shown in Fig. 10 and 11. The reason for the low albedo occurring during the rainy periods in SF2 can be explained by the increase in the water content of the soil as a result of the rainfall and the less reflection of the incoming energy.

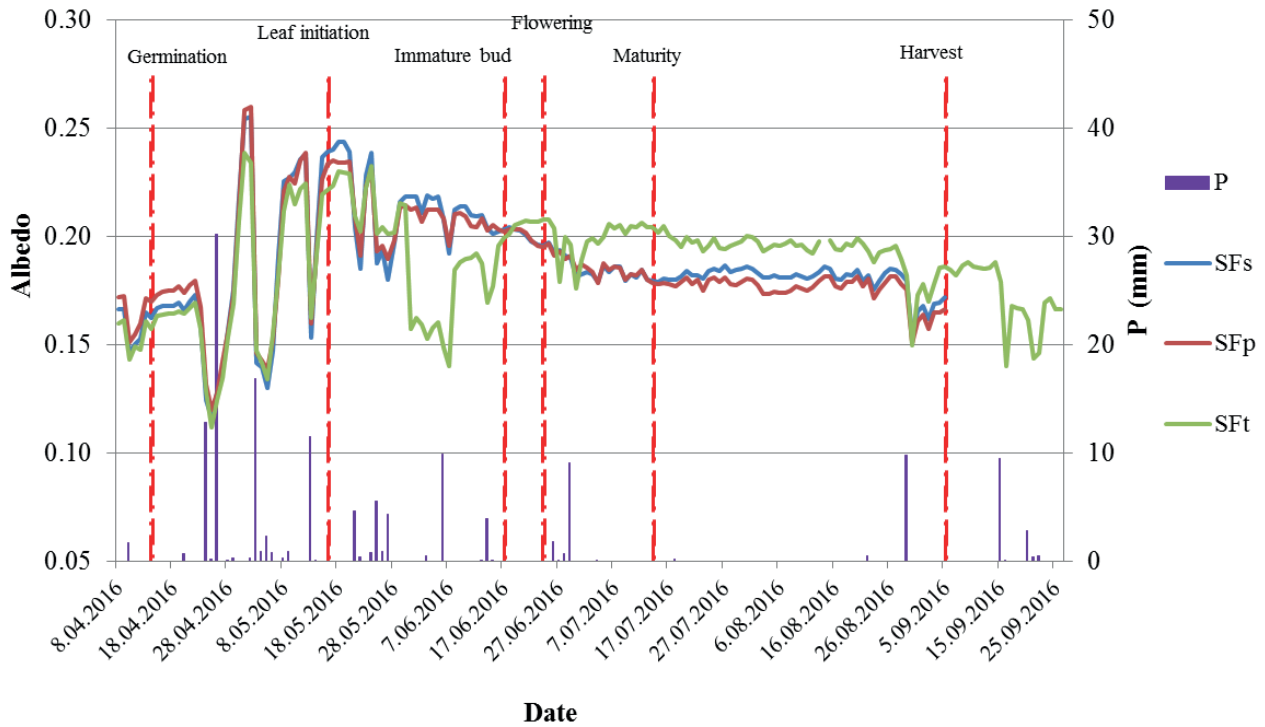


Fig. 10. Time series of daily average albedo and daily total precipitation during SF1.

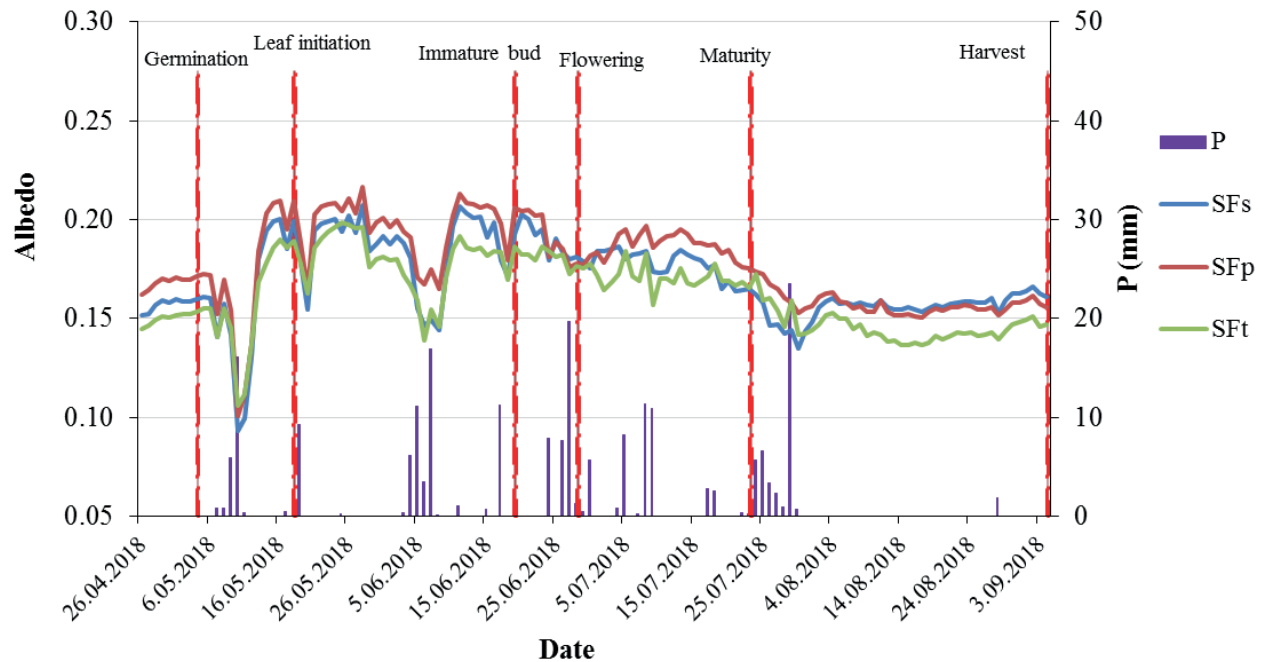


Fig. 11. Time series of daily average albedo and daily total precipitation during SF2.

In SF1, the albedo varied from 0.159 to 0.212 for SF_s; from 0.164 to 0.210 for SF_p and from 0.164 to 0.199 for SF_t. Maximum albedo value in SF1 was determined

between leaf initiation (L) and immature bud (I) phenological stage for all three sunflower cultivars. Although the highest albedo was determined for SF_s, there were

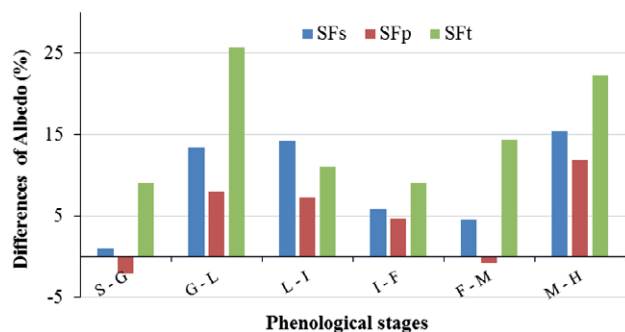


Fig. 12. Differences (SF1-SF2) in albedo values of sunflower cultivars.

minor differences between the maximum values of the cultivars. They changed between 0.199 and 0.212 for sunflower cultivars. The average albedo of sunflower on rainy days in the SF1 period was about 7.5% lower than the albedo for all the data (rainy and dry days). When the albedo values in SF1 on dry days were analyzed, albedo values increased in all cultivars and the average albedo value was calculated as 0.189.

In SF2, the albedo varied from 0.157 to 0.189 for SF_s; between 0.168 and 0.196 for SF_p and between 0.150 and 0.181 for SF_t. The average albedo of all three cultivars in the SF2 period was 0.171 for all data, 0.173 for dry days (low soil moisture) and 0.162 for rainy days (high soil moisture). The maximum albedo of sunflower determined between immature bud (I) and flowering (F) stage except for SF_p (L-I). In SF2 period, similar to SF1; albedo values on rainy days were about 5.3% lower. On dry days, the average albedo value risen up to 0.173. As seen in Tab. 6, during the SF2, maximum albedo values varied between 0.181 and 0.196 for all cultivars. It was determined the highest albedo for SF_p variety in SF2.

Comparing the albedo values obtained in two growing periods for all sunflower cultivars in different phenological stage, the biggest difference in the albedo occurred in the G-L phase. The difference between the albedo values of SF_s and SF_t cultivars determined in both periods was minimum on S-G stage. The difference between the albedo values of both growing periods was calculated as the smallest (4.83%) for the SF_p and the highest (15.25%) for the SF_t (Fig. 12).

The average albedo was 0.179 for SF_s, 0.183 for SF_p and 0.177 for SF_t, when the average values of both periods for all three cultivars were analyzed. Additionally, considering the average albedo values in both periods, they ranged from 0.157 to 0.212 for SF_s; from 0.164 to 0.210 for SF_p and from 0.150 to 0.199 for SF_t. For all the albedo values of cultivars measured in both periods; average albedo was calculated as 0.160 in S-G; 0.175 in

G-L; 0.198 in L-I; 0.193 in I-F, 0.184 in F-M and 0.166 in M-H stages.

Although the average albedo values determined for all growing periods of different cultivars did not change much, differences were determined in albedo values according to phenological periods.

Average albedo values of all growing periods of winter wheat, barley and sunflower cultivars were found as 0.185 for WW_g, 0.189 for WW_s, 0.182 for WW_b, 0.176 for WW_p, 0.181 for WW_k, 0.200 for BR_b, 0.179 for SF_s, 0.176 for SF_t and 0.182 for SF_p, respectively. The variation of average, maximum and minimum albedo values of all periods for all crops are given in Fig. 13-15.

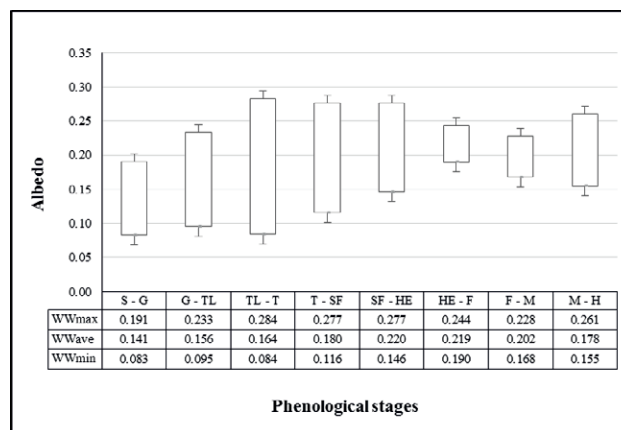


Fig. 13. Variation of average (WW_{ave}), maximum (WW_{max}) and minimum (WW_{min}) albedo values of all wheat cultivars for WB1 and WB2 periods.

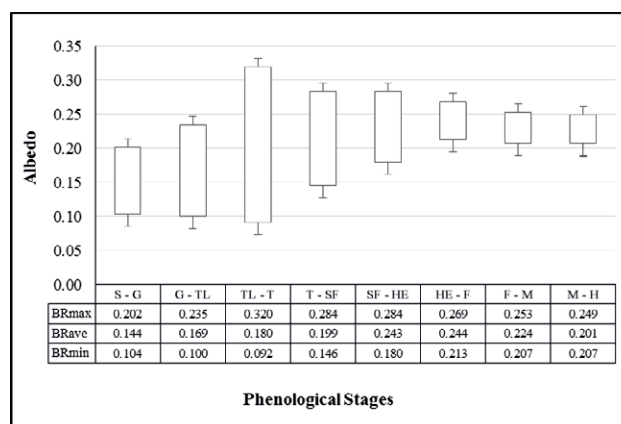


Fig. 14. Variation of average (WW_{ave}), maximum (WW_{max}) and minimum (WW_{min}) albedo values of barley for WB1 and WB2 period.

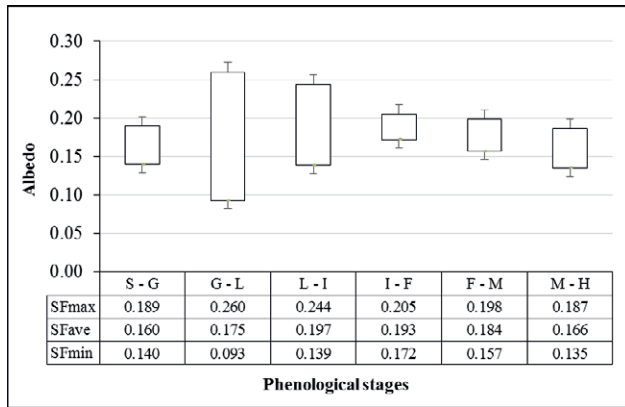


Fig. 15. Variation of average (SF_{ave}), maximum (SF_{max}) and minimum (SF_{min}) albedo values of all sunflower cultivars for SF1 and SF2 period.

Relationship between albedo and LAI

Relationship between albedo and LAI for Winter Wheat and Barley

LAI values of winter wheat and barley cultivars were measured periodically during both growing periods. Although there were differences between the LAI values of the crops, they had a similar time series (Fig. 16 and 17).

The highest LAI was determined in WB1 for BR_b with a value of approximately 4.91 between HE and F phase. In other wheat cultivars, LAI reached its maximum in the same phenological stage, too. The average LAI values in WB1 were 2.11 for WW_g, 2.01 for WW_s, 2.20 for WW_b, 2.17 for WW_p, 2.14 for WW_k and 2.06 for BR_b. Additionally, maximum LAI for WW_g, WW_s, WW_b, WW_p, WW_k and BR_b cultivars were measured as 4.57, 4.48, 4.77, 4.78, 4.44 and 4.91, respectively. Although there were very small differences between LAI of cultivars in the WB2 period, the general LAI pattern

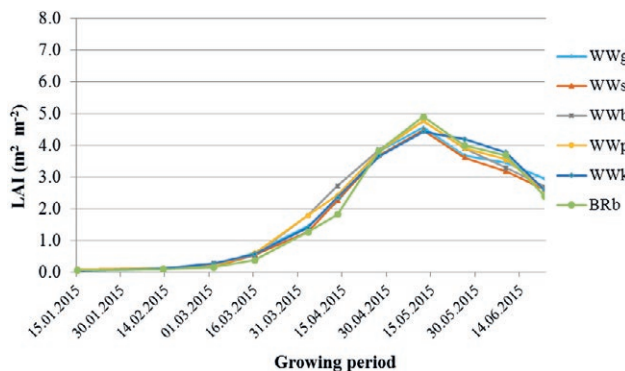


Fig. 16. LAI values of winter wheat and barley cultivars in WB1.

showed similar characteristics for all cultivars (Fig. 17). LAI values in this period increased to a maximum of 7.1. All wheat and barley cultivars had similar tendencies and values. In WB2 period, the highest values were detected between HE and F phenological stage, too. Fig. 18 shows the relationships between measured albedo values of wheat, barley cultivars and LAI values for both growing periods.

Statistically significant and strong relationships, which were $r^2=0.85$ and $r^2=0.83$, respectively, were found between LAI and albedo for wheat and barley in WB1. Similarly, determination coefficients for both crops in WB2 were calculated as 0.89 and 0.81, respectively. This showed us that even if only LAI value was used as input, the albedo values of these crops can be determined to a great extent.

Relationship between albedo and LAI for Sunflower

LAI values were measured periodically throughout the growing period of SF1, too. However, LAI can not be measured in SF2 because of technical problems. Although there were differences between the LAI of the sunflower cultivars, they had similar characteristics except SF_t. The albedo value of the sunflower, which was approximately 0.15 in the planting stage, increased by maximum 2.7% with the emergence. The highest albedo values varied from 0.21 to 0.232 within three cultivars during the leaf initiation stage (Fig. 19). When the LAI values of sunflower cultivars were examined, it reached the maximum LAI value (up to 3) for the SF_s cultivar and the lowest LAI value was approximately 1.1 in the late planted SF_t cultivar.

Fig. 20 shows the relationship between albedo and LAI of sunflower cultivars grown in SF1. As can be seen in Fig. 20, the determination coefficients between LAI and albedo for SF_p and SF_s cultivars were the same

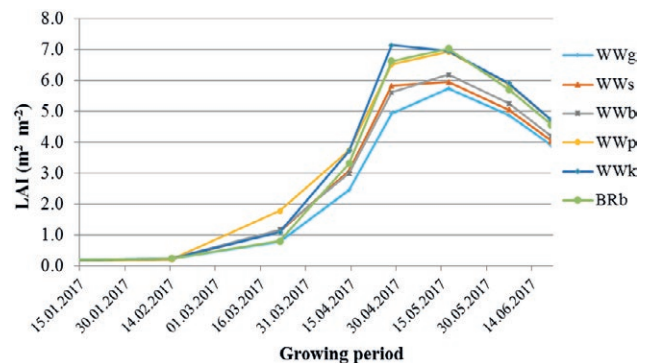


Fig. 17. LAI values of winter wheat and barley cultivars in WB2.

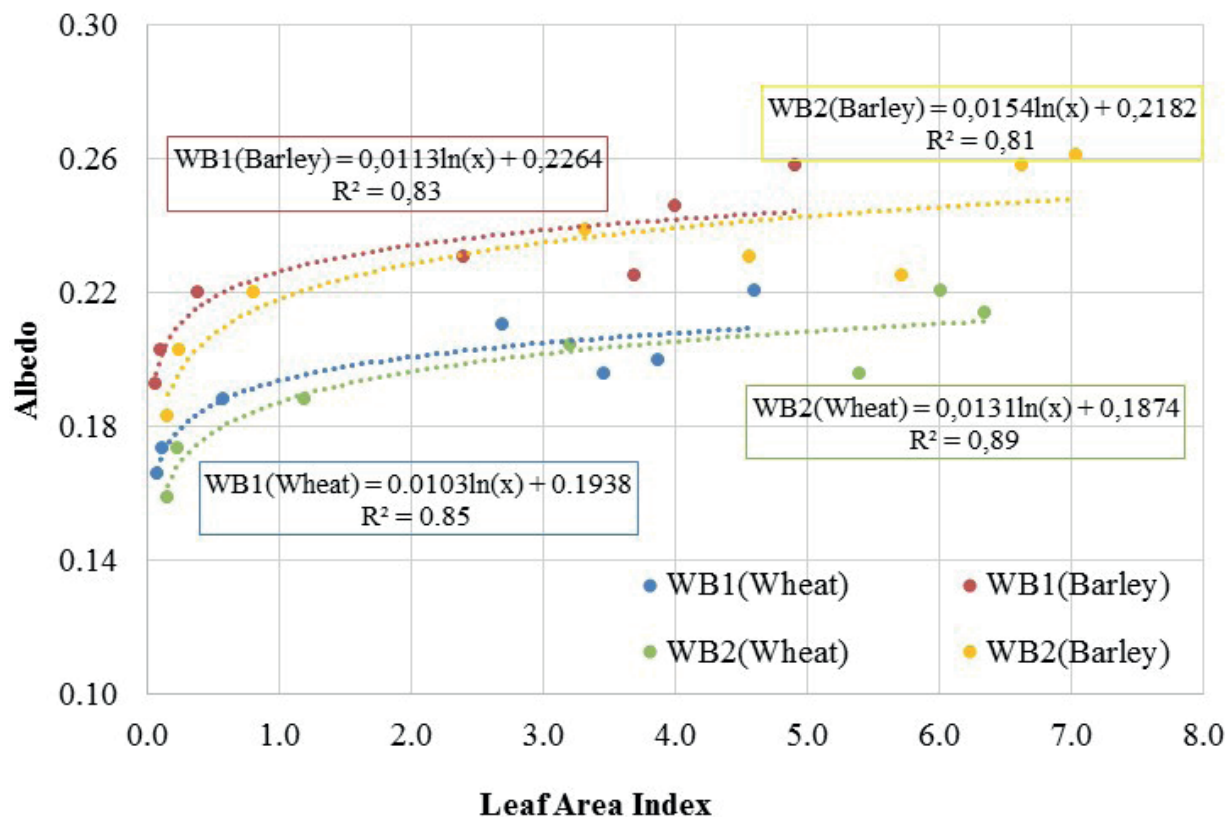


Fig. 18. Relationships between albedo and LAI values for winter wheat and barley cultivars in WB1 and WB2.

as 0.77. However, the weak relationship was estimated between the albedo and LAI for SF_t .

CONCLUSION

In this study, the variation of albedo with growth stages and its relationships with LAI and precipitation (rainy and dry days) were investigated by measuring albedo for winter wheat, sunflower and barley cultivars in Thrace part of Turkey. Other aim of this study was to fill the lack on about the ground albedo observations for widely grown crop cultivars in Thrace part.

Consequently, significant relationships were found between albedo and LAI for wheat and barley cultivars (wheat $r^2=0.87$, barley $r^2=0.82$) for whole growing periods. In general, the decrease in the incoming radiation and the high soil water content values caused a decrease in the albedo values on rainy days. Our average albedo values for the growing periods of the five-winter wheat cultivars considered in this study varied from 0.176 to 0.190. These values are similar to Sellers (1965), Konratyev (1969, 1972), Fritshen (1967), and Pielke (1984);

however, it is less than the values specified by Song (1998), Monteith and Unsworth (1990) and Şerban et al. (2011). The reason for these differences might be the diversity in crop cultivars, climatic and soil conditions etc. Similarly, our average albedo value determined for the two growth periods of barley is within the values determined by Frithschen (1967), but it is smaller than the values determined by Monteith and Unsworth (1990). The values determined for sunflower in this study are less than those determined by Gates (1980) and Impens and Lemeur (1969).

As known, many factors influence on the surface albedo. For this reason, determination of the variations of surface albedo with growth stage of crops are important in crop growth, eco-hydrological and climate models. However, it should be noted that all approaches developed for the determination of albedo in models should be based on ground-based observation. For this reason, ground based albedo observation is also necessary for the development of models, too. Furthermore, validation of the albedo values determined by remote sensing with the ground-based observations is extremely important for the comparison of the models of albedo.

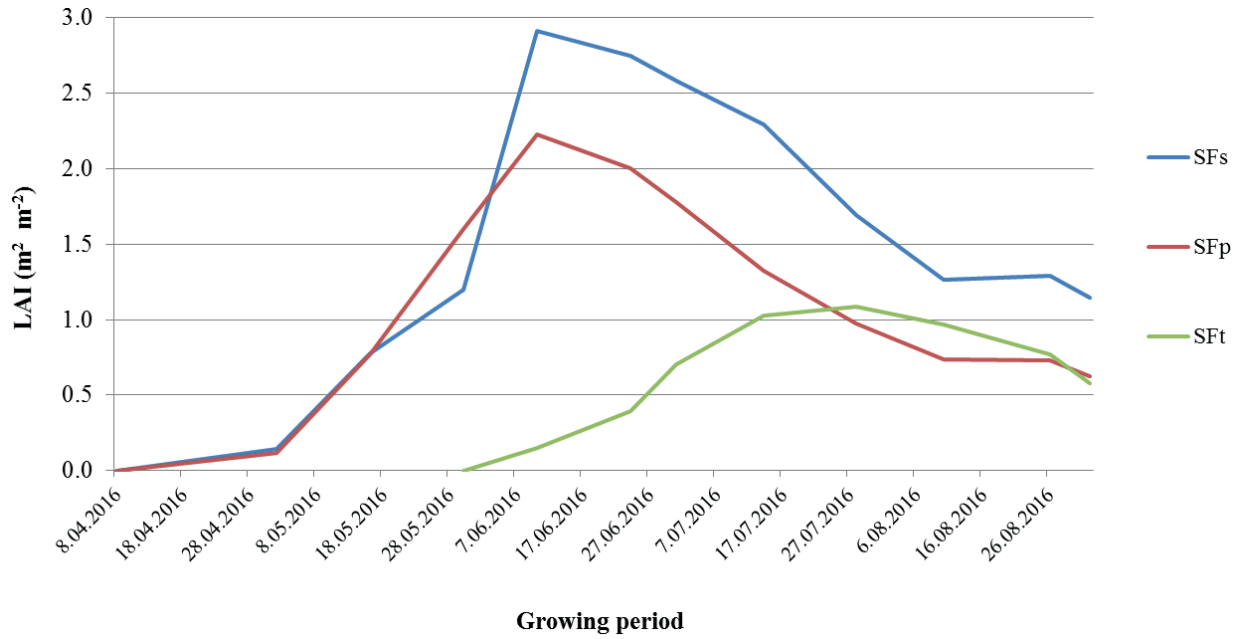


Fig. 19. Time series of the Leaf Area Index during SF1.

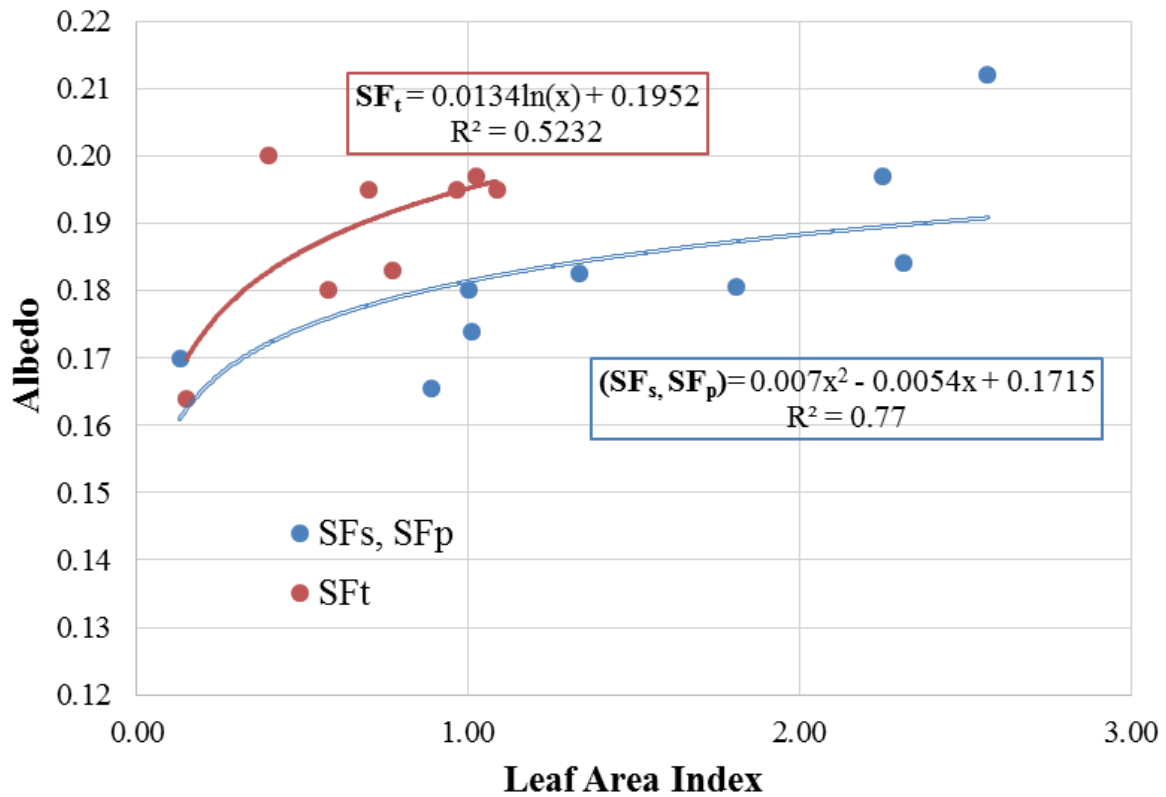


Fig. 20. Relationship between albedo and LAI of sunflower cultivars grown in SF1.

Therefore, ground based albedo observation is very helpful for model studies to enhance the temporal resolution of surface albedo.

As stated before, albedo is a micrometeorological data that is effective in energy balance of the surface, climate change, climate models, remote sensing and many sectors (agriculture, etc). For this reason, this study is going to be useful for researchers and engineers who need albedo data. In addition, it was revealed that the albedo data, which is one of the hypotheses of this study, was not a constant during the whole growing period, but changed with phenological- and growth stages and weather conditions.

We hope that the results of this study will be a reference to experts working in this field and needing this data, both in our country and around the world. In this study, only precipitation and LAI are considered as meteorological and plant growth factors in terms of their effect on albedo. In future studies, it would be useful to consider other factors and/or energy balance components and include remote sensing and climate models.

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