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THE IMPACT OF SOWING DIRECTIONS ON WHEAT AND COTTON YIELDS IN RELAY STRIP INTERCROPPING

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ABSTRACT

The increase in human population, urbanization, and climate change are causing a decrease in agricultural land in our country. The relay strip intercropping method has the potential to reduce competition for cultivation areas between wheat, which is a staple crop, and cotton, which is a cash crop. Therefore, it has a great importance to use this system in the most efficient way in terms of resource utilization, especially sunlight. The research was conducted at the trial fields of the Menemen Research, Application, and Production Farm belonging to the Faculty of Agriculture at Ege University, during the 2017/18 and 2019/20 production seasons. In the study, the effects of different sowing directions (N-S: north-south and E-W: east-west) on wheat and cotton yields in the IWC (relay strip intercropping of wheat and cotton) system were evaluated. According to the results obtained from the trials, although different planting directions had a slight effect on wheat yield parameters, there was no significant impact on plant yield and grain yield. However, rainfall and increasing temperatures during the grain filling period of wheat in the second year led to a significant increase in plant (36%) and grain (39%) yields. Cotton plants were more affected by the difference in planting direction than wheat. The average fiber yield was determined as 658 kg/ha in the E-W direction, while it was about 18% less in the N-S direction (560 kg/ha). Unlike wheat, temperature rises in the second year caused significant losses in cotton yield. The average fiber yield recorded in the first year at 679 kg/ha dropped to about 21% less in the second year (539 kg/ha). Our results indicate that cotton seedlings grown for a certain period under the shade of wheat have exhibited faster development in the E-W compare to N-S direction, where they receive more sunlight, and was able to optimize yield.

Key words: Intercropping, relay strip intercropping system, sowing directions, wheat-cotton interaction

INTRODUCTION

Climate change is one of the most significant factor that affects atmospheric conditions such as temperature, humidity, and precipitation, posing challenges to agricultural fields. Stress caused by high temperatures is commonly referred to as heat stress (Majeed et al., 2021), and when temperatures remain sufficiently high for a certain period, heat stress can inflict irreversible damage to plant development and functions (Hall, 2001). Consequently, climate change, particularly temperature increases and irregularities in precipitation regimes in arid and semi-arid regions, can reduce the productivity of agricultural lands. In addition to climate change, the increase in urbanization due to the rising human population is leading to a significant reduction in agricultural areas (Tanveer et al., 2017). The global human population is estimated to reach between 9.4 to 10.2 billion by 2050 (Boretti and Rosa, 2019). To meet the demands of this increasing population, agricultural production must also exhibit a corresponding upward trend. However, while urbanization restricts agricultural lands, catching up with the population increase on an agricultural product basis is quite challenging. Therefore, preserving and maintaining the balance of existing agricultural lands holds great importance for the sustainability of agricultural production (Aziz et al., 2015).

The intercropping method to be utilized in agricultural production can vary depending on the crop to be cultivated and the environmental conditions. Choosing crops with different development periods in intercrop planting systems reduces resource competition, leading to more efficient use of per unit area (Zhang et al., 2007; Aziz et al., 2015). The relay strip intercropping (IWC) method is most suitable for cultivating crops with different growth periods, such as wheat and cotton. IWC is a multiple cropping method based on planting a second crop into an existing one before the first is harvested (Queen et al., 2009). In this method, wheat is sown in strips in the fall, and spaces are left between the wheat strips for later planting of cotton (Zhang et al., 2008c). When spring arrives, cotton is sown in the previously left spaces, and for approximately 7 weeks, wheat and cotton coexist in the field until the wheat is harvested (Zhang et al., 2007; Zhang et al., 2008b). Although there is no delay in planting times, cotton seedlings growing in the shade of the dominant wheat crop experience delayed growth and development (Zhang et al., 2008b, c). The most significant resources for which crops compete in intercrop systems are light (Egan and Ransom, 1996) and soil moisture (Humphries et al., 2004). Therefore, the most considerable cause of this delay in cotton is the shading effect of wheat and competition for soil moisture. Additionally, it is noted that the productivity of wheat increases, especially around the edge rows of wheat, due to the spaces reserved for cotton after the wheat planting, as these areas can utilize environmental resources more effectively (Li et al., 2001; Zhang and Li, 2003).

Adjustments in the planting direction primarily affect the distribution of sunlight within the crop canopy but can also indirectly influence the utilization of other resources like water and plant nutrients. Although planting in a north-south orientation, particularly during the summer months, allows for more homogeneous light distribution within the canopy, the effectiveness may vary depending on the region, cultivation methods, and the specific crop. For instance, in areas where weed control is challenging, planting in an east-west orientation can create more shading between the rows, suppressing the emergence and growth of weeds. In the IWC system, the wheat plants that are sown earlier can significantly shade the cotton seedlings, especially at sunrise and sunset (Zhang et al., 2007), and therefore, planting in an east-west direction may be preferred to reduce this shading effect of wheat.

Considering all of these, the IWC system, in which wheat and cotton are cultivated together, is unconventional for agricultural production in our country. However, considering the decrease in agricultural lands and the existing competition between wheat and cotton cultivation in the available areas, the IWC system, which utilizes per unit area more effectively, is thought to hold great potential. Therefore, it is necessary to examine the resource utilization advantages of the IWC system, particularly in terms of light and soil moisture, and to make the necessary improvements to adapt it to the conditions of our country.

In conjunction with all these factors, the present study aims to investigate the yield and yield parameters of wheat and cotton across different planting directions in the IWC system, where the shading created by wheat.

MATERIALS AND METHODS

The research was conducted at an agricultural field located at the Menemen Research, Application, and Production Farm, which is affiliated with Ege University's Faculty of Agriculture. The field is situated at an altitude of 6 meters, with coordinates 38°34'45"N and 27°1'22"E, during the 2017/18 and 2019/20 production seasons. In the trial area, precipitation amounted to 463 mm and 420 mm during the growing seasons of 2017/18 and 2019/20 (November to September), respectively. Hourly air temperatures and monthly precipitation amounts for the growth seasons of wheat and cotton presented in Figure 1.

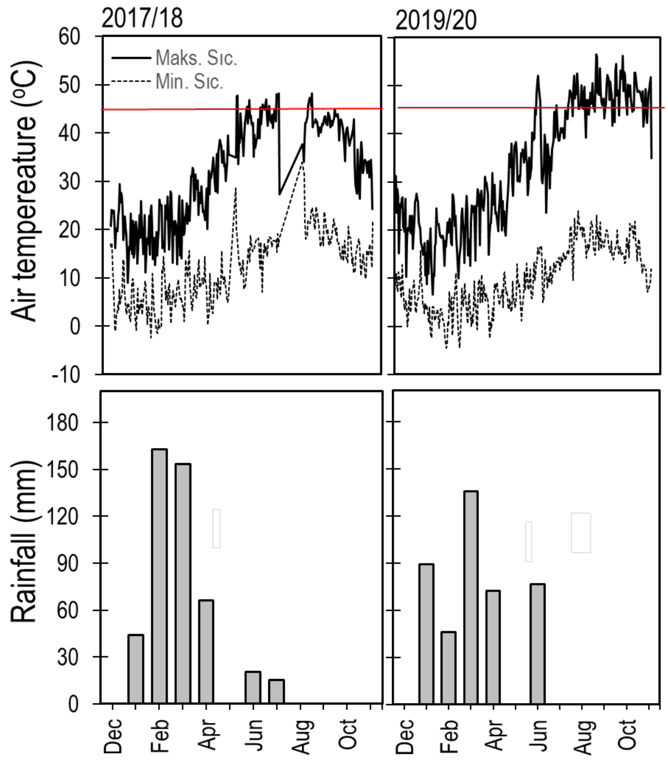

Figure 1. Daily air temperatures (°C) and total monthly precipitation amounts (mm) for the 2017/18 and 2019/20 growing seasons at the trial site. The red lines indicate the maximum air temperature of 45°C, at which cotton can perform photosynthesis (Hake and Silvertooth, 1990; Sage and Kubien, 2007).

The trial was designed as a Strip-Split-Plot system within Randomized Complete Blocks Design (RCBD) and conducted with four replications. In the study, intercropping of wheat and cotton using the relay strip intercropping method (IWC) were examined. The genotypes used for wheat and cotton, Ceyhan-99 and ST-498 respectively, are varieties commonly employed in the region. Although the row length for each replication was 5 m and the plot sizes were 10.8 m². The planting design in the IWC system was carried out according to Zhang et al. (2007). In the IWC system, the spacing between wheat rows was set at 13.5 cm, and the spacing between two rows of cotton planted between the wheat strips was set at 40.5 cm (Figure 2). The distance between the cotton strips was planted at 67.5 cm. In the IWC, the sowing design was implemented in such a way that half of the total area was covered with wheat and the other half with cotton.

Figure 2. Schematic and visuals for the relay strip intercropping of wheat and cotton (IWC).

The IWC plots were planted in two different orientations: North-South (N-S) and East-West (E-W). The wheat sowing was adjusted to a seed rate of 200 kg/ha, and was carried out with a seed drill on December 1, 2017, and November 20, 2019. Immediately after the emergence of wheat, the wheat seedlings in the strips designated for cotton planting were removed from the field, and the area was cultivated with a hoeing machine. Fertilizer was applied to the wheat areas in the form of 100 kg pure N/ha (15-15-15 fertilizer) at sowing and 100 kg ha^{-1} pure N (Ammonium sulfate fertilizer) during the tillering stage. In addition, with the 15-15-15 fertilizer applied at sowing, 100 kg P_2O_5/ha and 100 kg K_2O/ha were given to the trial area. Cotton sowing was carried out by hand on May 3, 2018, and April 22, 2020. Fertilizer was applied to the cotton plots at a total of 200 kg pure N/ha at sowing and at the beginning of flowering.

After the cotton was planted, wheat and cotton plants in the IWC plots were grown together for about 7 weeks in both years, until the wheat harvest was completed. The wheat harvest took place on June 20, 2018, in the first year and on June 14, 2020, in the second year. During the harvest, no damage was inflicted on the cotton plants in the IWC plots. Subsequently, the cotton harvests began, starting on September 20, 2018, for the first and on October 2, 2020, for the second, and the harvested cotton bolls were separated into seeds and fibers at the Ege University, Faculty of Agriculture's ginning warehouse.

Wheat measurements

Before wheat harvest, a 0.25 m^2 sample of wheat was collected from each plot. In these samples, plant height (cm), biomass (g plant^{-1}), thousand grain weight (TGW) (g), number of spikes (number/m^2), and plant yield (g plant^{-1}) parameters were measured. After the sampling process, the edge effect rows were removed, each plot was harvested by hand, and grain yields (ton/ha) were calculated.

Cotton measurements

Before the cotton harvest, 3 randomly marked cotton plants were taken as samples. In the obtained samples; plant height (cm), biomass (ton/ha), and boll number (number/plant) were determined. After the harvest, boll yield (kg/ha) was recorded, and after the ginning process (roller gin), fiber percentage (%) and fiber yield (kg/ha) were calculated.

Statistical analysis

ANOVA was performed to examine the effects of the factors using JMP v.13 (SAS Institute, 2016). The p-values calculated in order to test null hypothesis at the accepted p≤0.05 and p≤0.01 α levels. When the p-value is smaller than the accepted α levels, the null hypothesis was rejected. Treatment means were compared using the least significant difference test (LSD) at a significance level of 0.05 as described by Steel and Torrie (1980).

RESULTS AND DISCUSSION

In the study, as seen in Figure 1, particularly after April in the 2019/20 cotton growing season, there is a significant difference between the minimum and maximum temperature differences compared to the 2017/18 season. Furthermore, some researchers have indicated that cotton photosynthesis decreases to function at air temperatures of 45°C and above (Hake and Silvertooth, 1990; Sage and Kubien, 2007). Bange (2007) has suggested that while increasing temperatures at the beginning and end of the cotton growing season can have positive effects on yield, the increase in the frequency of days with high temperatures may negatively affect cotton growth and development. Similarly, Koca (2021) indicated that higher air temperatures during the summer season have a negative effect on the growth and development of maize. Additionally, some researchers have demonstrated that air temperatures above 35°C during the middle of the cotton growing season can have adverse effects on cotton boll volume and the number of boll buds (Pettigrew, 2008; Snider et al., 2009). Therefore, it is believed that particularly in the second year of the study, the daily maximum temperatures exceeding 45°C during the cotton growing season had a negative impact on the growth and development of cotton.

The study investigated the yield and yield parameters of IWC sown in different planting directions. In the statistical analyses conducted, the P-values of the Analysis of Variance Table for the measured parameters and the statistical significance levels are shown in Table 1.

Table 1. In the study, the P-values for the parameters measured in two different planting directions (North-South and East-West) and in two cultivation years (2017/18 and 2019/20) have been shown in the table.

Independent factors	Years (Y)	Directions (D)	Y x D
WHEAT			
Spike number (number/m^2)	0.51 ^{ns}	0.01*	0.99 ^{ns}
Plant height (cm)	0.03*	0.25 ^{ns}	0.40 ^{ns}
Plant yield (g/plant)	0.00**	0.66 ^{ns}	0.80 ^{ns}
Biomass (g/plant)	0.00**	0.62 ^{ns}	0.05*
Grain yield (ton/ha)	0.00**	0.66 ^{ns}	0.80 ^{ns}
Thousand grain weight (TGW) (g)	0.00**	0.41 ^{ns}	1.00 ^{ns}
COTTON			
Fiber percentage (%)	0.00**	0.47 ^{ns}	0.06 ^{ns}
Fiber yield (kg/ha)	0.01**	0.07 ^{ns}	0.33 ^{ns}
Cottonseed yield (kg/ha)	0.04**	0.06 ^{ns}	0.38 ^{ns}
Biomass (ton/ha)	0.02*	0.38 ^{ns}	0.22 ^{ns}
Plant height (cm)	0.92 ^{ns}	0.55 ^{ns}	0.05*
Boll number (number/plant)	0.78 ^{ns}	0.48 ^{ns}	0.05*

* significant at the p≤0.05 level, ** significant at the p≤0.01 level, ns: non-significant
The p-value represents the probability of observing the calculated test statistic or a more extreme value under the null hypothesis, assuming random variation, and is computed using the F-distribution

Wheat yield and yield parameters

In the study, the variation in sowing direction has caused a significant variation in spike number (See Table 1). In both years, the E-W direction negatively affected the spike number (Figure 3a), causing an average decrease of 18% compared to the N-S direction. Although radiation is less homogeneously distributed within the wheat canopy in the E-W direction, in the intercropping system, the spaces reserved for cotton have received more sunlight, leading to greater soil water loss. Therefore, there has been a significant decrease in spike number. Morgan (2003) has stated that especially between the stem elongation and flowering periods in wheat, water stress should be avoided and that water stress occurring particularly at the time of flag leaf emergence can reduce the tiller number and consequently the spike number. While there was no statistically significant difference in spike number between the trial years, a decrease of about 4% was observed in the second year. The highest spike number occurred in the first year in the N-S direction with 675 spikes/m^2, while the lowest was observed in the second year in the E-W direction with 533 spikes/m^2.

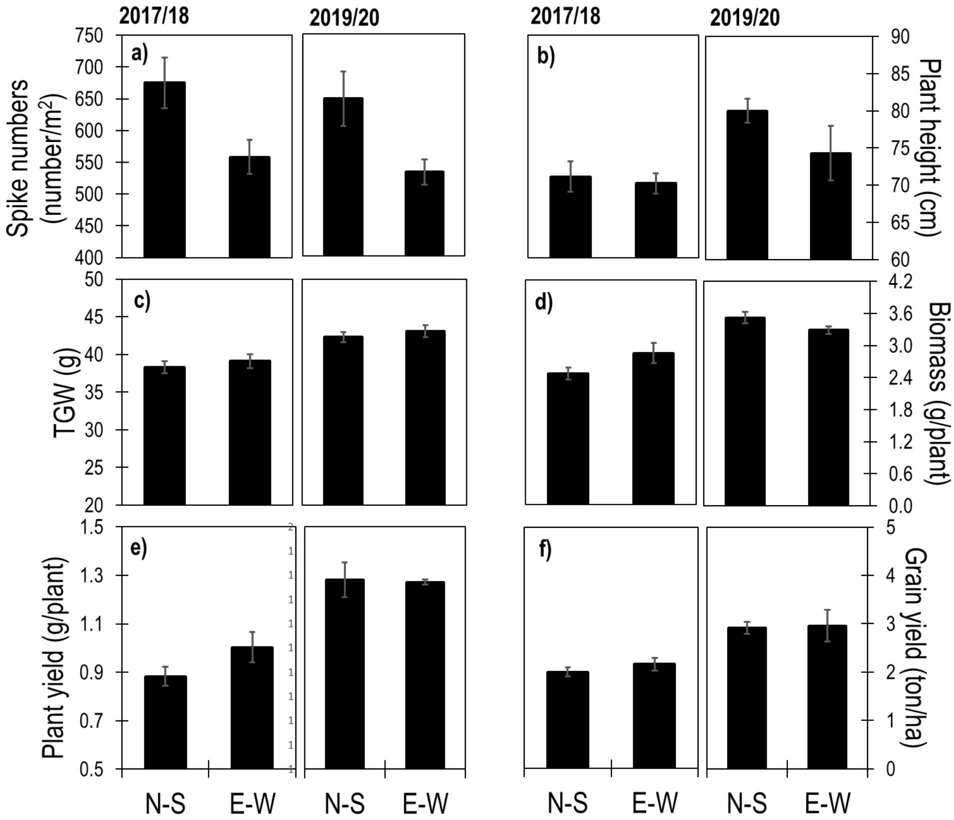

Figure 3. The effect of planting direction (North-South: N-S and East-West: E-W) on the spike numbers (a), plant height (b), thousand grain weight (TGW) (c), biomass (d), plant yield (e), and grain yield (f) in the IW, during both growing seasons (2017/18 and 2019/20).

In IW, although plant height was not significantly affected by the sowing direction statistically, when considering the average of the two years, plants in the E-W direction were recorded to be 3 cm shorter (Figure 3b). In the E-W direction, this decrease in plant height for IW is thought to be due to receiving more radiation particularly at sunrise and sunset compared to the N-S direction. Plants tend to optimize light reception for photosynthesis of their leaves under the conditions they are in, and in the case of insufficient light, a growth process called phototropism occurs, which is oriented towards the direction of light (Taiz and Zeiger, 2002). It is thought that wheat plant heights sown in the N-S direction are therefore slightly taller compared to those sown in the E-W direction. Nonetheless, there was a significant difference in plant height between the trial years, with plants being 9% taller in the second year.

According to the results obtained, the Thousand Grain Weight (TGW) was not significantly affected by the differences in sowing directions. This is thought to be because the wheat adapted to the existing conditions by the grain filling period, which significantly determines the TGW, and therefore was not affected by the direction difference. Differences in plant height based on the sowing direction support this suggestion (See Figure 3b). Additionally, it has been concluded that the directional effect on the TGW is lower because the flag leaf and the green spike, which contribute the most to grain filling (Ma et al., 2021), can directly receive light without shading. The TGW value for the IW application showed an average increase of 10% in the second year, reaching 42.7 g (Figure 3c).

It has been determined that the interaction between direction and year is significant for the biomass values of the IW application (See Table 1). In the first year of the trial, the E-W application had approximately 16% higher biomass value compared to the N-S application, while in the second year, the E-W application recorded a 7% lower value (Figure 3d). In the E-W direction, the more abundant and homogeneous radiation entering between the wheat rows compared to the N-S direction created an advantage in the first year, while it is thought to have turned into a disadvantage in the second year due to increased evaporation in the intercrop spaces caused by the temperature rise (See Figure 1). Giayetto et al. (2005) have suggested changing the sowing direction to reduce evaporation.

According to the results of the study, both plant and grain yield were not statistically significantly affected by the change in direction. However, it has been observed that the E-W application provided a slight advantage in both plant yield and grain yield in the first year (Figures 3e and 3f). While the average plant yield for the N-S application was determined to be 1.08 g/plant, the E-W application recorded a plant yield of 1.14 g/plant. In terms of average grain yield, the E-W direction (2.56 t/ha) was found to be approximately 4% higher than the N-S direction (2.46 t/ha). Pal et al. (2021) have stated that the east-west direction provides a yield advantage in wheat compared to the north-south direction. Similarly, Cook et al. (2015) have demonstrated a similar yield advantage in the east-west direction. Nonetheless, in the study, significant differences have occurred between the years in both parameters (See Table 1). There was an average increase of 36% in plant yield in the second year while grain yield similarly increased by an average of 39% in the second year. In the second year of the study, it is believed that plant yield and grain yield were significantly higher due to receiving more rainfall, especially during the wheat's grain filling period compared to the first year. Tatar et al. (2020) reported a 17% decrease in grain yield in their study examining the effects of drought occurring during the grain filling process in wheat. Similarly, Mehraban et al. (2020) have stated that the limitation of water after post-anthesis negatively affects the grain weight of wheat.

Cotton yield and yield parameters

The effect of planting direction on cotton biomass was not found to be statistically significant (See Table 1). However, the East-West direction has caused an approximate 8% increase in the average biomass of IC (Figure 4a). Additionally, significant differences in biomass values for IC were detected between the two trial years. While the average biomass value in the first year was recorded as 4.80 ton/ha, it dropped by 20% in the second year, reaching a level of 3.82 ton/ha. This decrease in biomass value is thought to be due to the stress created on the cotton plant by the high temperatures experienced in the second year. It is known that high temperatures negatively affect the growth, development, and yield of many field crops in arid and semi-arid regions (Challinor et al., 2005). Majeed et al. (2021) have stated that a 2-3°C increase in temperature in China caused about a 10% decrease in cotton biomass.

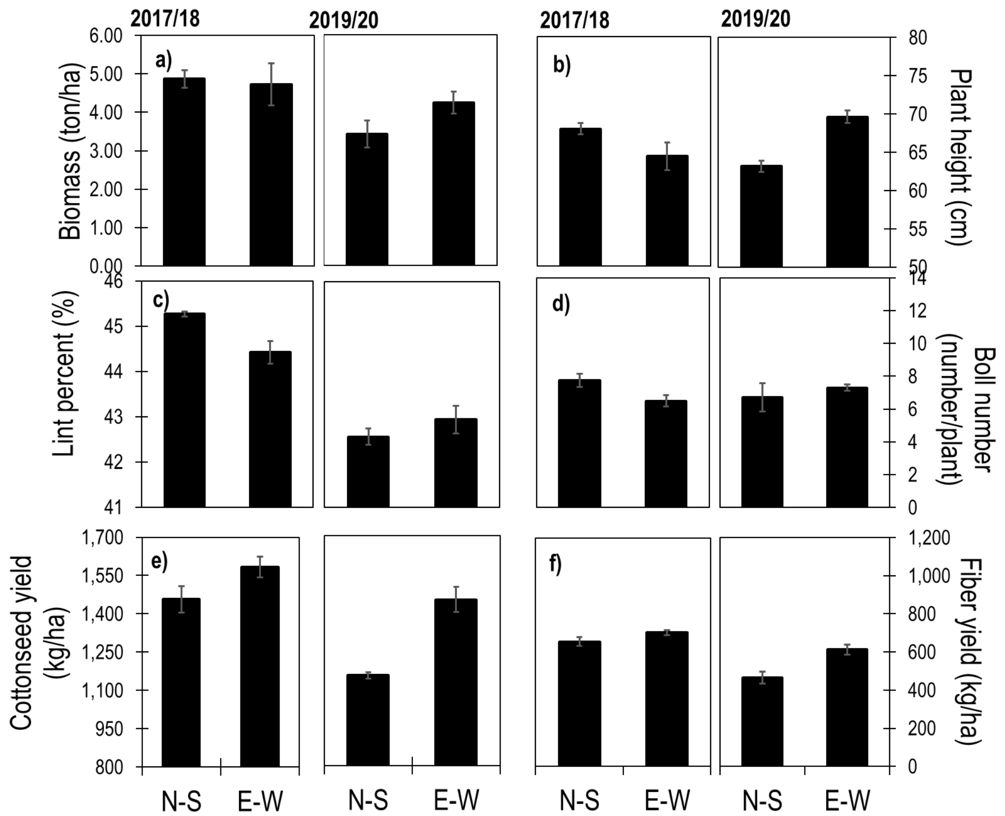

Figure 4. The effect of planting direction (North-South: N-S and East-West: E-W) on biomass (a), plant height (b), fiber yield (c), boll number (d), boll yield (e), and fiber yield (f) in IC during both growing seasons (2017/18 and 2019/20).

A significant interaction between planting direction and year was found for cotton the plant height (See Table 1). In the first trial year, plant height was found to be approximately 6% lower in the E-S compared to the N-S, but in the second year, it was found to be approximately 11% higher (Figure 4b). Reddy et al. (1992) found that increasing temperatures (up to 30°C) had a positive effect on plant height. Furthermore, in generative stage, it was determined that higher air temperatures (35°C) triggered stem elongation more than lower air temperatures (20-30°C) (Reddy et al., 1991). In the second year, the increase in plant height in the East-West direction is thought to be due to higher daytime temperatures starting from May, especially when wheat and cotton are grown together, allowing the cotton to grow faster, resulting in a slightly higher plant height.

Even though no significant interaction was found between planting direction and years in lint percentage, a slight difference between the two years has attracted attention (Figure 4c). In the first year, the lint percentage in the E-W direction decreased slightly (2%), while in the second year, on the contrary, an increase in lint percentage was observed in the E-W direction. However, in the second year of the trial, the average lint percentage value in the IC was 5% lower, and the average lint percentage value was determined as 43%.

A significant interaction between Direction x Year was found for the boll number, an important yield component in cotton plants (See Table 1). Similar to plant height and lint percent parameters, in the first year of the trial, the boll number (6.5 bolls/plant) in the E-W direction of the IC application was lower than in the N-S direction, but in the second year, the opposite was true, with a higher boll number value reached in the E-W direction (7.3 bolls/plant) (Figure 4d). Taller cotton plants tend to have more fruiting branches (Patil et al., 2017; Yan et al., 2019), which inevitably leads to a higher number of bolls. Moreover, there is said to be a quadratic relationship between boll retention speed and plant height (Zhang et al., 2020). While the boll retention speed increases up to a certain point with the increase in the plant height, it can decrease as a result of excessive elongation. Based on the findings in the study, it can be said that the relationship between the plant height and the number of bolls is linear. In other words, in the second year, it has been determined that the increase in plant height as a result of faster development in the E-W direction has led to an increase in the number of bolls.

Different planting directions and trial years have caused similar differences in cottonseed and fiber yield. The average cottonseed yield was recorded as 1503 kg/ha in the E-W application and 1275 kg/ha in the N-S application. The average fiber yield value for the E-W application was 658 kg/ha, which was 18% lower in the N-S application and had a value of 560 kg/ha. In addition, the difference between the trial years was found to be statistically significant; while the average fiber yield was 679 kg/ha in the first year, it was recorded as 539 kg/ha in the second year. The advantage of planting direction can vary depending on the climatic conditions and soil structure of the region where cultivation is carried out. For example, farmers who grow cotton in the northern regions of China generally perform planting in the North-South direction. This is stated to be due to the cooling effect created by the north winds prevailing in the summer months entering between the rows of cotton (Zhang et al., 2008c). Dhingra et al. (1991) stated in their studies that the planting of intercrop cowpea, which grows under the shade of the dominant corn plant, in the North-South direction yielded better results. However, in this study, it is observed that in the climatic and soil conditions of the region where planting is carried out, the E-W direction is more advantageous in terms of cotton yield in both years (Figures 4e and 4f). The decrease in yield in the second year of the research is thought to be due to the higher daytime maximum temperatures after June (generative stages of the cotton) compared to the first year (See Figure 1). It has been stated that both short-term and long-term increases in daytime temperature will reduce boll biomass and consequently lead to a decrease in yield (Li et al., 2020). In addition, many researchers have presented that photosynthesis is restricted at temperatures above the optimum (Bibi et al., 2008), respiration and photorespiration increase (Krieg, 1986; Ludwig et al., 1965), metabolism slows down (Burke et al., 1988), pollination and fertilization decrease (Snider et al., 2009), and plant growth rate decreases (Reddy et al., 1996).

CONCLUSION

In the study, although a slight effect of the sowing direction on yield parameters was detected, this effect was not clearly observed on the grain yield of wheat. The main reason for this is thought to be that the thousand grain weight, which is one of the main determinant of wheat yield, is not affected by the planting direction. In addition, there has been a significant increase in wheat yield in the second year. This is thought to be primarily due to the differences in rainfall during May, which coincides with the grain filling period. On the other hand, when considering cotton yield determinants such as plant height, biomass, and the number of bolls, it has been found that rapid growth especially in the early stages positively affects cotton yield. The shading effect of the dominant wheat plants have been less pronounced in the E-W direction, which has allowed the cotton seedlings to develop faster than N-S application and attain a stronger presence, ultimately leading to higher cotton yield.

In conclusion, although the wheat plant is not significantly affected by the planting directions, the planting of the IWC system in the E-W direction has been found promising for the cotton yield due to the faster development of early cotton growth, especially during the growing seasons with high temperatures.

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